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(ARTICLES BASED ON DISSERTATION DONE AT AIISH)
VOLUME VII: 2008-2009

PART - A
AUDIOLOGY

Compiled by

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Manasagangothri, Mysore – 570 006
Foreword

AIISH presents with great satisfaction, the seventh volume of full length articles based on the dissertation work done by our post graduate students in part fulfillment of their PG degrees in Audiology, Speech Language Pathologist and Special Education (HI) for your reading.

This volume includes articles based on dissertations done by the post graduate students during the year 2008-09. There are 44 articles in total. Part A comprises of 20 papers related to Audiology. Several students have shown interest in the areas of developing diagnostic/screening tests, issues related to understanding, evaluating and comparing the benefits of hearing aids/FM system. The interest in the hot topics of Cochlear dead region, Auditory dys-synchrony, Vestibular Evoked Myogenic Potential (VEMP), Post Auricular Muscle Response (PAMR) has continued. Multifrequency, Multicomponent Tympanometry is a ‘fresh’ topic in the list. Evoked potential testing continues to attract our students. Part B comprises of 20 papers in the area of Speech-Language Pathology. Our faculty have generated interest in the areas of swallowing disorders, sign language, dementia and relevance of Yoga in Speech Language Pathology which is encouraging. Topics in the area of voice assessment, analysis, issues related to language development and bilingualism, dyslexia and aphasia continue to interest our students. Part C contains 4 papers of students of M.S Ed (HI). These papers cover the area of teaching methods, curricular adaptation and attitudes of teachers. The M.S.Ed (HI) program is not attracting more students. However, those who have enrolled are trained and groomed well as master trainers. Even though there are only four papers in this section, it is published as a separate section as the readership for each section may be different. To the best of our knowledge, this is the first effort to publish articles based on M.S. Ed (HI) dissertations. Since AIISH library is digitized, these articles will be available for review to all the researchers, in India and abroad, in the area of Special education.

The titles of the articles are the titles of the dissertations. The first authors are the II M.Sc (Aud), M.Sc (SLP) & M.S.Ed (HI) students of 2008-09 and the second authors are their respective guides who have supervised and guided the research work. The AIISH faculty members who have guided the dissertations have modified and edited the papers to bring it to the present shape to the best of their abilities in spite of their busy academic schedules. Dr. G.Malar, Reader, Special Education has put in great efforts to procure and compile the edited articles and has herself corrected english in many of the articles. This is the highly appreciated. The neat formatting by Ms. N. Parimala in a very short time is acknowledged. The unattended mistakes in print and references, if any, in spite of best efforts put in is regretted.

You may please e-mail your valuable feedback about this volume to aiish_dir@yahoo.com with the subject “Student research, Volume VII A/B/C, 2008-09”.

Dr. Vijayalakshmi Basavaraj
Director
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Dichotic Word Test (DWT) in Indian English Speaking Children

Arunraj K & N. Devi*

Abstract

The study was aimed in developing dichotic word test for children speaking English in India and also to investigate the effect of list, gender, age and ear. The developed test consists of two lists of monosyllables with each list having 25 word pairs. These word pairs have equal duration and aligned in such a way that both words were presented dichotically at the same time. The developed test material was administered on five groups of normal hearing children (20 in each group) with the age range of 7 to 12 years. The results revealed significant difference between age and ear. As the age increases, the performance of the children also increased showing greater right ear score followed by left ear score and double correct score which indicates the presence of right ear advantage. However, there was no significant difference between list and gender. Reliability measure showed good test retest reliability for both the list. Thus the present data findings can be used as reference for children with central deficits especially cortical lesions.

Key words: Dichotic word test, Central auditory processing disorder

Introduction

Auditory processing disorders (APDs) refer to problems in the perceptual processing of auditory information by the central nervous system as demonstrated by difficulties in one or more of the following skills: Sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance in competing acoustic signal, and auditory performance in degraded acoustic signals (ASHA, 2005). Normal auditory processing involves a number of distinct processes or skills. A breakdown or deficit in any one of the skills leads to central auditory processing disorder (CAPD).

Numerous tests have been developed over the period of time to assess central auditory function as the CAPD represents a heterogeneous group of auditory deficits. One among the test is dichotic listening tests which is the most powerful behavioral test battery for assessment of hemispheric function, inter-hemispheric transfer of information, and development and maturation of auditory nervous system in children and adolescents, as well as identification of lesions of the central auditory nervous system (Keith & Anderson, 2007). A number of studies have identified the presence of binaural integration deficits in children with learning and reading disorders (Moncrieff & Musiek, 2002).

Dichotic tasks utilizes syllables, digits, words, spondees and sentences to measure the dichotic listening. Of the variety of speech stimuli available to measure dichotic listening,

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digits are the most utilized due to limited contextual cues and quite easier. But digits are closed-set task that may tend to overestimate dichotic speech recognition ability and highly familiar that is relatively easy to recognize for both normal hearing and hearing-impaired listeners (Strouse & Wilson, 1999a, 1999b). As an alternative, monosyllabic words are meaningful components of speech that limit the use of syntactical cues; recorded monosyllabic word lists offer a standardized test of word recognition that are commercially available and in widespread use; presence of large normative database for these monaural word-recognition materials from listeners with normal hearing and listeners with hearing loss across age groups in both quiet and competing message listening environments; and also words are an open set stimulus that may result in recognition performance in the middle of the difficulty continuum i.e. neither too easy nor too difficult, yet sensitive to performance differences between ears and groups (Roup, Wiley, & Wilson, 2006).

Damasio, Damasio, Castro-Caldus, and Ferro (1976) compared a digit test with multisyllabic word test and concluded that the “coding and decoding of words that stands for digits is, in many instances, not as lateralized a process as coding and decoding of words not representing digits”. Developing Dichotic Word Test (DWT) is most crucial because the auditory system is undergoing maturation, thus age-specific data are required to help in making decisions about whether a child’s auditory system is developing normally or otherwise (Keith, 2000) and also to incorporate as part of the central auditory nervous system evaluation battery, since dichotic measures have demonstrated good sensitivity in identifying and differentiating cerebral level lesion (Roup, Wiley, & Wilson, 2006).

Normative data from a representative population is required to ensure if it is a valid and reliable measure of auditory processing ability (Musiek, Gollegly, & Ross, 1985) and also it is ideal to have speech tests in all languages as the individual perception of speech is influenced by their first language or mother tongue (Singh & Black, 1966). Currently, available data documenting dichotic monosyllabic-word recognition performance, other than dichotic digits, is limited for both young and older adults (Prior, Cumming, & Hendy, 1984) especially on Indian population for assessing the auditory processing. Hence the current study is aimed in developing and standardizing the dichotic word test on Indian English speaking children of Kannada origin and also to investigate the effects of different stimulus list, gender, age and ear difference.

Method

The current study was carried out in two phases that include the development of stimuli (Phase I) and to establishing the preliminary data for dichotic word test (Phase II).
Phase I: Development of the English Dichotic Word Stimuli

The test stimulus was prepared using monosyllable words developed by Sivaprasad and Yathiraj (2006) as a reference. These words were phonetically balanced using frequencies of occurrences of English speech sounds in India by Ramakrishna et al. (1962) and were familiarized for the children within the range of 7 years to 7 years 11 months. These familiarized words were spoken by a female speaker who had a clear articulation using standard spoken Indian English of the Mysore region in an accent widely used in formal speech and were recorded using the Praat version 5.0.32 software with a sampling rate of 24,000 Hz. The digitized word signals were then edited and equalized for overall intensity to achieve equal average levels using Adobe Audition version 2.0 software. A goodness test of recorded material was done to ensure the good quality of the stimuli by presenting the recorded material to ten Indian-English speaking normal hearing adults of the Mysore region. The word pairs with more than 90% acceptance by these individuals were selected as stimuli.

Using these familiar words, two lists of twenty-five pairs of words were constructed in such a way that the onset and offset of the stimulus coincides with a deviation in duration not exceeding 0.2 ms as per the guidelines given by Lamm, Share, Shatil, and Epstein (1999) and the paired words were of either voiced or voiceless at the initial position. The word pairs with same phoneme in the same word positions were avoided as per the guidelines of Roup, Wiley, and Wilson (2006). Inter-stimulus interval of about ten seconds was added between word pairs to function as the response time. Two different sets of single word pairs consisting of five practice word pairs followed by twenty test word pairs were formed. A 30-second, 1000 Hz calibration tone was recorded at the beginning of the compact disc at a level equal to the average intensity of the words.

Phase II – Establishing preliminary data for dichotic word test

Participants

Data were collected from 100 English speaking children of the Mysore region between 7 to 12 years whose mother tongue was Kannada and their instruction was English for at least two year. These participants were divided into five age groups (7-7.11; 8-8.11; 9-9.11; 10-10.11; 11-11.11 years) with equal males and females in each group (N=20).

Participants included for the collection of preliminary data had bilateral normal-hearing thresholds (0-15 dB HL) at frequencies 250 Hz to 8000 Hz for air conduction thresholds and 250 Hz to 4000 Hz for bone conduction thresholds; Bilateral type-A tympanogram with presence of acoustic reflexes (ipsi & contra) in both ears; Speech recognition threshold of ±12 dB (re: PTA of 0.5, 1 & 2 kHz); Speech identification score of > 90% at 40 dBSL (re: SRT) in both ears; Passed the Screening Checklist for Auditory Processing (SCAP) developed by Yathiraj & Mascarenhas (2003), ruling out any auditory processing deficit; no otologic and/or neurologic problems; no illness on the day of testing; no behavioral problems and; good academic performance. Parental consent was obtained before the children participated in the study.
Testing environment

The testing were carried in a sound treated double room situation and noise levels maintained within permissible limits as per ANSI S 3.1- 1991.

Instrumentation

A Calibrated two channel diagnostic audiometer Grasen-Standler Model GSI 61 coupled with acoustically matched TDH 39 headphones housed in MX - 41/AR and Radio ear B-71 bone vibrator used to estimate the Pure tone threshold, Speech Recognition Thresholds (SRT), Speech Identification Scores (SIS), and Uncomfortable level for speech (UCL), Calibrated middle ear analyzer GSI- Tympstar version 2 for Tympanometry and reflexometry and Pentium IV computer with Adobe Audition 2.0 version software for presenting the developed test material.

Procedure: The test was carried out in two stages.

Stage I – Procedure for participants selection

Screening checklist for Auditory Processing (SCAP) developed by Yathiraj and Mascarenhas (2003) was given to the class teacher and were asked to score on a two point rating scale (Yes/No). Children who scored less than 50% (<6/12) were considered for the study (passed SCAP). Pure tone thresholds were obtained at octave intervals between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction (Mastoid placement) using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959). Speech recognition threshold was obtained using the spondee word list for children in English developed by Swarnalatha and Rathna (1972) which were presented at 20 dBSL (re: PTA). Speech identification score was carried out at 40dBSL (re: SRT) using the monosyllabic words in English developed by Rout and Yathiraj (1996). Tympanometry (226 Hz) and Reflexometry (500, 1000, 2000, & 4000 Hz both ipsi and contra) were carried out to rule out any middle ear pathology.

Stage II – Administration of Dichotic Word Test

The dichotic word test material was played through Pentium IV computer connected to the calibrated GSI 61 audiometer. Equipment testing was done at the beginning of each test session to ensure appropriate routing of signals, and channel balancing. Intensity setting was set to a most comfortable level (40dB SL re SRT). Each subject was asked to listen to the instructions for dichotic tasks that were recorded before each set of dichotic words on the compact disc. The children were instructed as ‘You will be hearing two words, one to each ear at the same time. You should repeat both the words that you heard’. Task understanding was ensured using five practice items in each list before proceeding to the real test.
Calculation of Scores for Dichotic Word Tests

The subject’s responses were recorded in-terms of correct responses for each ear. The right-ear score (RES), left-ear score (LES) and double correct score (DCS) were calculated for both the lists. A score of one was given to each correct pair and each correct word. The possible total correct response for each test paradigm was 20 for each ear.

Test Retest Reliability

The test retest reliability of dichotic word test was examined by repeating the tests on two randomly selected subjects from each age group, two to four weeks after the administration of the first test.

Analysis

The data for the dichotic word test was calculated by computing the means and standard deviations for right ear score, left ear score, and double correct score using SPSS 17.0 software.

Results and Discussion

The statistical analyses were carried out to investigate the effect of list, gender, age and ear and also to obtain the preliminary data. Along with descriptive statistics, Mixed analysis of variance (overall list, gender, & age effects), Multivariate analysis of variance (age effect within each list), Paired t test (ear effect & list effect within subjects) and Cronbach's Alpha test (test reliability) were carried out. Whenever necessary, Duncan’s post Hoc analysis was used.

List Effect

The mean, standard deviation and range for single correct scores and double correct scores were obtained for the two lists across five age groups and are represented in Table 1.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Right Correct Score</th>
<th>Left Correct Score</th>
<th>Double Correct Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>List I</td>
<td>List II</td>
<td>List I</td>
</tr>
<tr>
<td>7 – 7.11 years</td>
<td>Mean 5.85</td>
<td>6.00</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>SD 1.59</td>
<td>1.29</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Range 2 - 8</td>
<td>4 - 8</td>
<td>2 - 6</td>
</tr>
</tbody>
</table>
From the Table 1, it can be seen that the mean values between the two lists for the single correct scores and double correct scores are almost similar. Mixed ANOVA was carried out to examine the overall list effect. Mixed ANOVA results showed no significant difference on lists for single correct scores \(F(1, 90) = 0.002, p > 0.05\) and double correct score \(F(1, 90) = 0.01, p > 0.05\) but there was an interaction seen in single correct score for the list, ear, and gender \(F(1, 90) = 4.24, p < 0.05\) and list, ear, gender, and group \(F(4, 90) = 3.83, p < 0.05\). Hence, to explore these interactions, paired ‘t’ test was done to evaluate the difference in scores between two lists across age groups. Results for the paired t test are shown in Table 2.

### Table 2. ‘t’ value, Degrees of freedom and its significance between the two lists across age groups.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Dependent variable</th>
<th>t - value</th>
<th>df</th>
<th>Sig. (2 tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 – 7.11 years</td>
<td>RCSI - RCSII</td>
<td>0.39</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>LCSI - LCSII</td>
<td>0.59</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>DCSI - DCSII</td>
<td>0.20</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td>8 – 8.11 years</td>
<td>RCSI - RCSII</td>
<td>1.94</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>LCSI - LCSII</td>
<td>0.19</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>DCSI - DCSII</td>
<td>1.39</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td>9 – 9.11 years</td>
<td>RCSI - RCSII</td>
<td>0.36</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>LCSI - LCSII</td>
<td>0.40</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>DCSI - DCSII</td>
<td>0.25</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td>10 – 10.11 years</td>
<td>RCSI - RCSII</td>
<td>0.28</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>LCSI - LCSII</td>
<td>0.49</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>DCSI - DCSII</td>
<td>0.21</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
<tr>
<td></td>
<td>RCSI - RCSII</td>
<td>0.58</td>
<td>19</td>
<td>( p &gt; 0.05 )</td>
</tr>
</tbody>
</table>
It can be seen from the Table 2, that the paired ‘t’ test did not reveal significant difference between two lists for both single and double correct scores. This trend is seen in all the age groups which indicate that aligning the two words in two different channels at 0 ms lag time does not alter the performance of the subjects between the lists. Both the lists have equal difficulty and hence either of the lists can be used in clinical practice.

**Gender Effect**

The mean and standard deviation for males and females across the two lists for all the five age groups are calculated and are listed in Table 3.

Table 3. Mean and Standard Deviation (SD) for males and females across lists and age group

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Gender</th>
<th>RCS List I</th>
<th>RCS List II</th>
<th>LCS List I</th>
<th>LCS List II</th>
<th>DCS List I</th>
<th>DCS List II</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-7.11</td>
<td>M</td>
<td>6.50 1.35</td>
<td>5.80 1.47</td>
<td>4.80 1.03</td>
<td>6.20 1.13</td>
<td>2.70 1.49</td>
<td>3.80 1.31</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>5.20 1.61</td>
<td>5.00 1.77</td>
<td>3.70 1.25</td>
<td>6.20 1.13</td>
<td>1.90 1.52</td>
<td>3.80 1.31</td>
</tr>
<tr>
<td>8-8.11</td>
<td>M</td>
<td>8.30 1.56</td>
<td>8.60 1.77</td>
<td>6.90 1.10</td>
<td>6.60 1.34</td>
<td>4.50 0.84</td>
<td>4.40 0.51</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>8.00 1.33</td>
<td>9.00 1.56</td>
<td>6.20 1.13</td>
<td>6.40 1.34</td>
<td>4.40 0.51</td>
<td>4.70 1.88</td>
</tr>
<tr>
<td>9-9.11</td>
<td>M</td>
<td>10.30 1.70</td>
<td>10.70 2.00</td>
<td>8.50 1.95</td>
<td>8.10 1.59</td>
<td>6.90 1.28</td>
<td>7.50 2.22</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>10.60 3.02</td>
<td>10.70 2.31</td>
<td>9.10 2.72</td>
<td>9.00 1.33</td>
<td>10.70 2.31</td>
<td>7.50 2.22</td>
</tr>
<tr>
<td>10-10.11</td>
<td>M</td>
<td>12.90 2.28</td>
<td>12.50 1.71</td>
<td>11.50 2.12</td>
<td>11.00 1.63</td>
<td>9.60 1.64</td>
<td>11.00 1.63</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>12.80 1.98</td>
<td>12.90 2.13</td>
<td>10.60 1.34</td>
<td>11.20 3.48</td>
<td>8.50 1.90</td>
<td>11.00 1.63</td>
</tr>
<tr>
<td>11-11.11</td>
<td>M</td>
<td>14.00 3.65</td>
<td>14.00 2.62</td>
<td>10.70 3.23</td>
<td>14.80 1.81</td>
<td>8.60 2.75</td>
<td>13.60 1.50</td>
</tr>
</tbody>
</table>

**Note.** RCS - Right Correct Score; LCS - Left Correct Score; DCS - Double Correct Score; M - Male; F – Female.
From Table 3, it can be seen that mean scores for males and females are almost similar for single and double correct scores for both the lists. Mixed ANOVA was done to find out the overall effect on gender. Results of mixed ANOVA revealed no significant difference in gender for single correct scores [F (1, 90) = 0.243, \( p > 0.01 \)] as well as for the double correct scores [F (1, 90) = 1.04, \( p > 0.05 \)].

Existing literature has also shown that girls have more verbal ability than boys though it is not obvious until about the age of 11 years (Maccoby, & Jacklin, 1974). Young girls, aged 1 to 5 years are more proficient in language skills, talk at an earlier age, produce longer utterances, and have larger vocabularies than boys (Ruble, & Martin, 1998; cited in Plotnik, 1999) and these advantages for verbal and written language persist even through the school years (Lynn, 1992). Although there appear to be a gender difference favoring for females, this difference is relatively small and thus has little practical significance (Hyde, 1994; cited in Plotnik, 1999). Bellis and Wilber (2001) also advocated that the gender effects on the auditory evaluation of inter-hemispheric transfer are small and clinically insignificant.

The present study is in congruence with the previous studies done by Roberts et al. (1994) and Meyers, Roberts, Bayless, Volkert, and Evitts (2002) on dichotic word test indicating that, there exist no significant difference between the performance of the males and females across age and lists. Hence it can be concluded that boys and girls in the age range of 7 to 12 years develop in a similar manner in the way they develop binaural integration.

**Age Effect**

Since there was no difference in the mean scores of males and females, the data of both the gender were combined to see the age effect. The means and standard deviation (SD) across the age groups for both the list were obtained and are represented in Table 4.

**Table 4.** Mean and Standard Deviation (SD) across age groups for both the lists

<table>
<thead>
<tr>
<th>Age Group</th>
<th>List I</th>
<th>List II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCS</td>
<td>LCS</td>
</tr>
<tr>
<td>7 – 7.11 years</td>
<td>Mean</td>
<td>5.85</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.59</td>
</tr>
<tr>
<td>8 – 8.11 years</td>
<td>Mean</td>
<td>8.15</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.42</td>
</tr>
<tr>
<td>9 – 9.11 years</td>
<td>Mean</td>
<td>10.45</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.39</td>
</tr>
<tr>
<td>10 – 10.11 years</td>
<td>Mean</td>
<td>12.85</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.08</td>
</tr>
<tr>
<td>11 – 11.11 years</td>
<td>Mean</td>
<td>14.60</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.84</td>
</tr>
</tbody>
</table>

*Note.* RCS – Right Correct Score; LCS – Left Correct Score; DCS – Double Correct Score
It can be seen from the Table 4, that the mean scores for right correct scores, left correct scores and double correct scores increased as the age increased. On comparison between the ears, the right ear scores have higher scores compared to left ear scores indicating right ear advantage for both the list. Also, we can find that the mean double correct scores are lesser for all the age groups as compared to single correct scores.

It can also be inferred from Figure 1 and 2 that, the mean right correct score increased as the age increases from 7 to 12 years for both the lists. Similar trend is also seen for the mean left correct score and mean double correct score across the age groups. But the mean value is much lesser for double correct score compared to right ear correct score and left ear correct score.

Mixed ANOVA was done to investigate overall significant difference between the groups. Results of Mixed ANOVA revealed significant effect on age \[F (4, 90) = 108.48, p < 0.001\] for the single correct scores. There was also a significant interaction for ear, gender, and group \[F (4, 90) = 3.376, p < 0.05\], and for the list, ear, gender, and group \[F (4, 90) = 3.83, p < 0.05\]. But there was no interaction seen for the list, and group \[F (4, 90) = 0.24, p > 0.05\], list, gender, and group \[F (4, 90) = 0.13, p > 0.05\], ear, and group \[F (4, 90) = 0.18, p > 0.05\], and list, ear, and group \[F (4, 90) = 0.89, p > 0.05\]. Similarly for double correct scores, there was a significant difference seen for the group \[F (4, 90) = 87.83, p > 0.01\]. However, there was no significant interaction seen for list, and group \[F (4, 90) = 0.45, p > 0.05\],

Figure 1 & 2. Mean Right Correct Scores, Left Correct Scores and Double Correct Scores across age groups for list I and II.
gender, and group \[F (4, 90) = 1.98, p > 0.05\], and list, gender, and group \[F (4, 90) = 1.36, p > 0.05\] for the double correct score.

MANOVA was done to further investigate for the significant differences in different age groups within each list. Results of MANOVA revealed significant difference across the age groups for right correct scores \[F(4,95) = 41.95, p < 0.01\], left correct scores \[F(4,95) = 47.77, p < 0.01\] and double correct scores \[F(4,95) = 61.89, p < 0.01\] for the list I, and right correct scores \[F(4,95) = 71.05, p < 0.01\], left correct scores \[F(4,95) = 54.97, p < 0.01\] and double correct scores \[F(4,95) = 62.31, p < 0.01\] for list II. To understand which group is specifically different, Duncan Post-Hoc analysis was carried out. Means of the groups were presented in homogeneous subsets depending on the results of Post-Hoc analysis. Duncan’s post-Hoc analysis also shows significant difference across all the age groups at 95% of the confidence level for right ear correct scores, left ear correct scores and double correct scores. Mean scores for different age groups fall into different subsets indicating a significant difference between all the age groups.

The improvement in the dichotic word scores with the advancement of age could be due to the differential myelination of the sub-cortical and the cortical structures. The corpus callosum and certain auditory association areas may not have completed myelinogenesis until 10 to 12 years or older (Salamy, Mendelson, Tooley, & Chapline, 1980; Hayakawa et al., 1989) and hence the dichotic listening performances (Yakovlev, & Lecouis, 1967; cited in Chermak & Musiek, 1997). Somatosensory evoked potentials used to measure inter-hemispheric transfer time also indicates that the maturity of the corpus callosum ranges from 10 to 20 years of age (Salamy et al., 1980) and are one among to show significant age related changes (Pujal, Vendrell, Junque, Marti-Vilalta, & Capdevila, 1993). Due to the delay in myelination of higher cortical structures, there is not much information transmitted to the higher level and hence scores may be reduced in the lower age group. As age increases, the myelination of the cortical structures especially the corpus callosum might get completed and the scores of the dichotic listening increases.

The present study is in consonance with that of Berlin, Hughes, Lowe-Bell, and Berlin (1973) as well as Willeford and Burleigh (1994), where the right and left ear score increased significantly with age, which suggests an increase in the brain’s ability to process two channel stimuli as function of age. However, ear advantage varies with the type of the stimuli used. More the linguistically load on the stimuli presented, more pronounced are the maturational effects (Bellis, 1996). The dichotic CV had higher right ear advantage (Berlin et al., 1973) where as dichotic sentences had right ear advantage which reduces as the age increases (Willeford & Burleigh, 1994). Since the dichotic word are an open stimulus set, it results in recognition performance in the middle of the difficulty continuum i.e., neither too easy nor too difficult, yet sensitive to performance differences between ears and groups (Roup, Wiley, & Wilson, 2006).
The mean scores for left ear are reduced as compared to right ear scores due to the inability of the corpus callosum to transfer complex stimuli from the right hemisphere to the left hemisphere. As the child becomes older and myelination of the corpus callosum is completed, the inter-hemispheric transfer of information improves and left ear scores approach to those obtained in adults (Musiek, Gollegly, & Baran, 1984).

The double correct scores are less compared to single correct scores in all the age groups may be due to the inability to process both channel at the same time at the younger age and also suggested that the single correct scores should be used to calculate the norms rather than double correct scores. Dermody, Mackie, and Katach (1983) also found that the double correct scores do not provide information about the differential ear effects compared to ear correct scores.

**Ear Effect**

The means and standard deviation (SD) for right and left ear across the age groups for both the lists are tabulated in Table 1. From Table 1, it can be inferred that mean score of right ear was greater than that of left ear in both the lists irrespective of the age groups. This indicates the presence of right ear advantage for all the age groups. Mixed ANOVA was done to investigate the difference in scores across two ears in both the lists. Results of mixed ANOVA revealed significant difference in scores between right and left ear \[F (1, 90) = 113.37, p < 0.01\] for both the lists. There is an interaction seen for the ear, gender, and group \[F (4, 90) = 3.37, p < 0.05\], list, ear, and gender \[F (1, 90) = 4.24, p < 0.05\] and list, ear, gender, and group \[F (4, 90) = 3.83, p < 0.05\]. Hence, paired ‘t’ test was administered to further evaluate difference in the scores between the two ears across age groups for both the lists. Results of paired ‘t’ test across the age groups are shown in Table 5. Results of paired ‘t’ test revealed a significant difference between the right ear scores and the left ear scores for all the age groups except for the list I in 11 to 11.11 year group, where it reached a significance level and yet, did not show a significant difference.

**Table 5. Paired ‘t’ Test showing t value and its significant difference across two ears**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Pairs</th>
<th>t-value</th>
<th>df</th>
<th>Sig. (2 tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 – 7.11  years</td>
<td>RCSI – LCSI</td>
<td>6.02</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>RCSII – LCSII</td>
<td>4.72</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td>8 – 8.11  years</td>
<td>RCSI – LCSI</td>
<td>5.44</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>RCSII – LCSII</td>
<td>8.15</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td>9 – 9.11  years</td>
<td>RCSI – LCSI</td>
<td>5.47</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>RCSII – LCSII</td>
<td>6.27</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td>10 – 10.11 years</td>
<td>RCSI – LCSI</td>
<td>6.28</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td></td>
<td>RCSII – LCSII</td>
<td>7.95</td>
<td>19</td>
<td>(p &lt; 0.01)</td>
</tr>
<tr>
<td>11 – 11.11 years</td>
<td>RCSI – LCSI</td>
<td>2.04</td>
<td>19</td>
<td>(p = 0.05)</td>
</tr>
<tr>
<td></td>
<td>RCSII – LCSII</td>
<td>2.90</td>
<td>19</td>
<td>(p &lt; 0.05)</td>
</tr>
</tbody>
</table>

*Note. RCSI – Right Correct Score for List I; RCSII - Right Correct Score for List II LCSI – Left Correct Score for List I; LCSII - Left Correct Score for List II*
The presence of a right ear advantage as obtained in the present study is in accordance with the literature reported earlier (Kimura, 1961a, 1961b; Katz, 1962; Berlin et al., 1973; Wexler & Halwes 1983; Musiek et al., 1989). Converging evidence in the field of dichotic listening strongly suggests that the right ear advantage arises through mechanisms postulated by Kimura’s structural model (Kimura, 1967). According to this model, the ear difference is attributed to the bilateral asymmetry in brain function as a function of stimulus type and the right ear advantage has been interpreted as resulting from rigid bottom up neural connections (Hugdahl, 2005), that is the contralateral projections of the ascending auditory system consist of more fibers and consequently produce more cortical activity than the ipsilateral projections and the fact that the left hemisphere is dominant for speech in most cases (Rasmussen, & Milner, 1977; Kandel, Schwartz, & Jessell, 1991). In addition, stronger activity in the contralateral system inhibits the processing on the ipsilateral side (Yasin, 2007) thus resulting in a better performance for the right ear than the left ear.

Right ear advantage in dichotic listening has also been attributed to the close proximity of the left temporal lobe which is closer to the left primary speech areas than the right anterior temporal lobe (Berlin et al., 1973). Hence, it is postulated that there is less transmission loss to the left posterior temporal parietal lobe on the basis of proximities within the areas of the brain. Due to this proximity there is more efficient interaction between shorter pathways (Berlin et al., 1973). Similar findings have been reported by Studdert-Kennedy and Shankweiler (1970).

In the present study, 11 to 11.11 year age group did not show significant difference between right ear and left ear scores in list I but the mean scores of right ear scores are higher compared to left ear scores and the significance level for this group was $p = 0.05$. Thus we expect that the right ear advantage was present for this age group also.

**Reliability Measure**

The reliability measure for 10% of the total subjects participated were analyzed using Cronbach's Alpha test in SPSS 17.0 software. The subjects were retested after a gap of two to four weeks. The results of the reliability measure are shown in Table 6.

<table>
<thead>
<tr>
<th>Lists</th>
<th>Dependent variable</th>
<th>Alpha values</th>
</tr>
</thead>
<tbody>
<tr>
<td>List I</td>
<td>Right Correct Score</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>Left Correct Score</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Double Correct Score</td>
<td>0.81</td>
</tr>
<tr>
<td>List II</td>
<td>Right Correct Score</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>Left Correct Score</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Double Correct Score</td>
<td>0.78</td>
</tr>
</tbody>
</table>
Table 6 reveals that all the scores obtained on dichotic word test at two different times are having an alpha value of greater than 0.7 which indicates good reliability of the test.

In conclusion, analysis of the results obtained from the present study revealed significant difference in Ear and Age but did not show significance for list and Gender. Also good reliability of the test was seen across the lists and ears.

**Summary and Conclusions**

The purpose of the present study was to develop a dichotic word test in English for Indian children and to establish the preliminary data. The test consist of two lists of 25 monosyllables each, with five being the practice words and were familiar for seven years old children. The duration of the monosyllabic pairs was equal and they were either voiced or voiceless. These paired words were aligned and imposed on a stereo track in such a way that monosyllable pairs were played simultaneously in both ears.

To establish the preliminary data for developed dichotic word test, five groups of children with the age range from 7 to 12 years were taken and each group consisted of twenty children with equal number of males and females. All the children had English as the medium of instruction for at least one year, belonged to the region of Mysore, were right handed and none of them had a history of any otological or neurological disturbances. These children were initially tested with routine audiometric testing (PTA, SRT, SIS & Immittance) and Screening Checklist for Auditory Processing Disorder (SCAP) to ensure normal auditory functioning prior to the administration of the dichotic test stimuli.

Responses were scored in terms of single correct scores (right & left ear) and double correct scores. The raw data was subjected to statistical analysis. The mean and the standard deviation were also calculated for both the list across the age groups. Results revealed no significant difference in list and gender for all the age groups whereas ear and age showed significant difference. Right ear scores were greater compared to left ear scores whereas mean double correct score values were less compared to single correct scores (Right & Left correct scores). All the correct scores (single & double correct scores) increased as the age increased for all the age groups irrespective of gender and list. Test retest reliability measures showed good reliability indicating the usefulness of the developed test in clinical population.

**References**


Ramakrishna, B. S., Nair, K.K., Chiplunkar, V. N., Atal, B. S., Ramachandran, V., & Subramanian, R. (1962). Relative efficiencies of Indian languages. Some aspects of the relative efficiencies in Indian languages (pp. 34). Indian Institute of Science, Bangalore.


Comparison of Acceptable Noise Level and Signal to Noise Ratio Using Directional Microphone and FM System

Bhavya M. & N. M. Mamatha*

Abstract

The present study was taken up with the aim to evaluate the benefit of directional microphone and frequency modulation system (FM) on Acceptable Noise Level (ANL) and Signal to Noise Ratio (SNR) using two different background competing stimuli (cafeteria noise & speech babble). The study also aimed at comparing ANL and SNR across different aided conditions (hearing aid with directional microphone turned off, hearing aid with directional microphone turned on and FM system) for two different competing background stimuli. 28 individuals with moderate to moderately severe sensorineural hearing loss in the age range of 20-60 years participated in the study. ANL and SNR were measured for all the participants. Both ANL and SNR were better with the use of FM system followed by the use of directional microphone. In addition, both ANL and SNR were dependent on the noise characteristics. Temporal and spectral characteristics of various noise affected speech recognition and ANL differently. Hence, the result should be interpreted differently for different noises. Further it was observed that ANL and SNR procedures were not different. Hence it can be concluded that ANL procedure can be used as an alternative measure to SNR procedure.

Introduction

Annoyance from amplified background noise is one of the most common performance related complaints with hearing aids (Kirkood, 2005). Hearing aid users have reported difficulty with background sounds as the most critical issue related to hearing aid benefit, satisfaction, and use (Surr, Schuchman, & Montgomery, 1978). The major reason for dissatisfaction with hearing aid is the background* noise (Surr, Schuchman, & Montgomery, 1978). Unfortunately, for individuals with hearing impairment, traditional amplification strategies may provide little or no improvement in noisy environment. Hearing aid use improves speech perception in quiet conditions mainly due to increased audibility. However, in presence of noise, there are reports of both benefit (Alcantara, Moore, Kuhnel, & Launer, 2003) as well as of no benefit (Gustafsson & Arlinger, 1994) from hearing aid use in speech recognition tasks. There are several noise reduction technologies that have been shown to improve speech intelligibility on noise (Crandell & Smaldino, 2000). These technologies include directional microphones, digital noise reduction and personal frequency modulation (FM) systems. Directional microphones in the hearing aids improve the Signal to noise ratio (SNR) by taking the advantage of spatial differences between speech and noise. Many studies have assessed directionality and have found that aided speech recognition in noise is improved significantly with directional microphones in comparison to omnidirectional microphones (Ricketts, Henry & Gnewikow, 2003). An FM system delivers desired sound

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directly to the ear by reducing the background noise. FM system enhances the speech to noise ratio (SNR) at the listener’s ear and thereby facilitates speech recognition.

Traditionally these two technologies are evaluated for their benefit using speech perception in noise measures (SNR). Speech in noise test measures an individual’s ability to understand speech in the presence of noise which is quantified by estimating the signal to noise ratio required to achieve a certain degree of intelligibility, such as 50% correct scores. Poor correlation have been found between speech perception scores in noise (SNR) and hearing aid benefit, satisfaction, or its use (Humes, Halling, & Coughlin, 1996). Nabelek, Tucker, and Letowski (1991) hypothesized that the willingness to listen to speech in background noise may be more indicative of hearing aid use than speech perception scores obtained in background noise. This hypothesis led to the development of a procedure called “acceptable noise level” (ANL), which is a measure of willingness to accept background noise while listening to speech. This procedure was originally termed as tolerated signal to noise ratio. The ANL was defined as the difference between the most comfortable listening level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept. Nabelek, Tampas, & Burchfield (2004) reported that ANLs vary from approximately 0 to 30 dB in both individuals with normal hearing as well as individuals with hearing impairment. They demonstrated that hearing aid use was related to an individual’s ability to accept background noise and individuals who accepted high levels of background noise (i.e., had low ANL i.e., 7dB or less) were likely to become successful hearing aid users than individuals who could not accept background noise (i.e., had high ANL i.e., 13dB or more) were likely to become unsuccessful hearing aid users.

Environmental noise such as cafeteria noise and speech babble are the common background interfering noise which many people encounter in real life environment. So there is a need to measure the speech recognition ability of an individual in different environmental noises. Benefits provided by the directional microphone and FM system in various environmental noise needs to be investigated.

Hearing aid fitting procedure should include a complete description of the negative effects of noise on speech perception. This includes not only speech recognition performance (SNR) but also a measure of acceptance of noise (ANL) which measures the hearing aid outcome objectively. Nabelek, Tampas, and Burchfield (2004) reported that ANL and Speech perception in noise scores were not significantly correlated. On the other hand, Nabelek, Burchfield, & Webster, (2003) reported that individuals with hearing impairment who exhibit low acceptance of background noise when listening to speech (i.e., persons with large ANLs) demonstrate dissatisfaction with hearing aids consistently and tend to use them occasionally or reject them altogether. This dissatisfaction with hearing aids is similar to difficulty exhibited by individuals with abnormally high SNR loss, as described by Killion, (1997). Hence the relation between speech recognition performance and acceptable noise levels needs to be explored. Further it would be of interest to see if there is similar effect of directional microphone and FM system on ANL and SNR, as there is a dearth of literature in comparing the ANL and SNR using directional microphone and FM system.
Objectives of the study

The present study has the following aims:

1. To evaluate the effect of directional microphone and frequency modulation system (FM) on SNR using two different competing stimuli (Cafeteria noise & Speech babble).
2. To evaluate the effect of directional microphone and frequency modulation system (FM) on ANL using two different competing stimuli.
3. To compare ANL and SNR using directional microphone and frequency modulation system using two different competing stimuli.

Method: 28 participants (21 male & 7 female) in the age range of 20-60 years with bilateral moderate to moderately severe sensorineural hearing loss were included in the study. All participants were naïve hearing aid users with Speech identification scores (SIS) of ≥ 80%.

Test environment: All the tests were conducted in a sound treated double room situation. The ambient noise levels were within permissible limits as per ANSI S3.1 (1991).

Instrumentation: A calibrated dual channel diagnostic audiometer (Madson orbiter 922) with TDH-39 headphone and two Martin (c115) free field speakers was used. A non linear 4 channel digital behind the ear hearing aid with the fitting range from mild to severe degree of hearing loss was used. The hearing aid had an option for directional microphone and telecoil setting for coupling the FM system through the neck loop. Directional Microphone used in the present study had a hyper cardioid polar pattern.

Material: The speech material used for the purpose of determining the ANL included five different passages in Kannada. The passages were spoken in conversation style by a male native speaker of Kannada and were digitally recorded in an acoustically sound treated room using audobe audition (version no. 2) with sampling frequency of 44.1 kHz in a 16 bit analog to digital converter. The speech material used for determining the SNR included phonetically balanced word list in Kannada developed by Yathiraj and Vijayalakshmi (2005). The speech material were spoken in conversation style by a female native speaker of Kannada.

Background competing stimuli: Two types of background competing stimuli were used. Kannada speech babble developed by Manjula and Anitha (2005) was used as one of the competing stimulus in the study. Other competing stimulus was the Cafeteria noise which was recorded digitally at a restaurant.

Both speech and competing stimuli were recorded and stored on to a personal computer (PC) and was routed through the auxiliary input of the double channel audiometer. The speech materials were presented through one channel of the audiometer at 0° azimuth and the two background competing stimuli were presented through the other channel of the audiometer at 180° azimuth from the loud speaker.
Procedure

**Audiological evaluation:** The pure tone thresholds were measured between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction on a 2 channel diagnostic audiometer (OB922). Speech recognition scores were obtained using “The Common Speech Discrimination Test for Indians” developed by Maya Devi (1974) and Speech identification scores were obtained using “Phonetically Balanced Word List” developed by Vandana (1998).

**Hearing aid fitting and FM fitting:** The hearing aid was programmed either for the right/left ear depending on the SIS scores. The hearing aid chosen for the study had 3 programs. In the first program, the directional microphone was deactivated. In the second program, the directional microphone was activated and in the third program, the telecoil mode was activated for using it with the FM system. These three different programs were saved in the hearing aid for each of the participant. Other parameters of the hearing aid were kept at default settings. In addition to the hearing aid fitting, the participant was also fitted with the FM receiver by placing the neck loop. Synchronization of the FM transmitter and the receiver was done according to the protocols specified by the manufacturer. The FM transmitter was placed at a distance of 7.5 cm from the loudspeaker and at a height of 0.5 meters to simulate ideal user position.

The present study was conducted in 2 different phases for three different aided conditions (hearing aid with and without directional microphone and FM system) using two different background competing stimuli (cafeteria noise & speech babble).

- **Phase 1:** Determining the Acceptable noise level (ANL)
- **Phase 2:** Determining the Signal to noise ratio (SNR)

**Phase I: Determining Acceptable noise level (ANL)**

The conventional ANL procedure (Nabelek, Tucker, & Letowski, 1991) was involved in determining the ANL. Here the examiner adjusted the level of the passage to the most comfortable listening level (MCL) of the participant. Then, a background noise was introduced, and the examiner had to adjust the noise to a level at which the participant would be willing to accept or “put up with” without becoming tense or tired while following the words of the passage. This level was called as the “background noise level (BNL)”. The ANL was calculated by subtracting the BNL from the MCL.

In order to obtain the MCL, an Independent Hearing Aid Fitting Forum’s 7-point categorical scale (Mueller & Hall, 1998) was used. The scale consisted of 7 different response options. They were uncomfortably loud (7), Loud, but OK (6), Comfortable, but slightly loud (5), Comfortable (4), Comfortable, but slightly soft (3), Soft (2), and Very soft (1). The participants were shown these different rating options at the outset of the experiment.
before they were given verbal instructions for the MCL. The options were also visible as a printed material to the participants throughout the test sessions.

Establishing MCL

The passages were initially presented through the loudspeaker at the level of the SRT, which was determined during the audiological assessment. The level of the speech in the passage was increased in steps of 10 dB until the listener indicated that it was “very loud.” It was then decreased by 10 dB until the participant indicated that it was “very soft.” At this point, the level of the passage was adjusted up and down in 5 dB increments until the participant’s MCL was found. After establishing the MCL, subject’s Background Noise Level (BNL) was determined.

Establishing BNL

The passages were presented at the subject’s MCL through the loudspeaker at 0° azimuth. Noise was presented along with the passage through the loudspeaker located at 180° azimuth. The loudness level of the noise was started at 0 dB HL and was increased in steps of 10 dB until the participant indicated that the noise was “too loud”. The level of the noise was then decreased by 10 dB until the participant indicated that the noise was soft enough that the speech was “very clear.” At this point, the level of the noise was adjusted up and down in 2 dB increments until the participant indicated that it had reached the highest level which could be accepted while following the words without becoming tense or tired. This level was considered as the participant’s BNL.

The ANL was calculated by subtracting the BNL from the MCL (ANL = MCL - BNL). The BNL procedure was repeated twice for every participant (within the same test session). The average of the two ANLs was taken as the final ANL.

In the first phase, data was collected in the following different aided conditions.

a) Determining the aided ANL with directional microphone turned off using two different background competing stimuli.

b) Determining the aided ANL with directional microphone turned on using two different background competing stimuli

c) Determining the aided ANL with FM system using two different background competing stimuli.

The order of measuring ANL for different aided conditions was counterbalanced to account for the order effect.
Phase II: Determining the Speech recognition threshold in noise to obtain Signal to Noise Ratio (SNR).

The modified version of the Tillman and Olsen, (1973) procedure was used for determining the SNR, in which the SNR was defined as the level at which the participant was able to repeat two out of four words (50% criterion) in the presence of noise. Recorded PB word list was presented from a loudspeaker at 0° azimuth and background competing stimuli were presented at 180° azimuth. The participants were asked to repeat the words presented.

An adaptive procedure was used to establish the SNR. The intensity of the speech was held constant at 40 dBHL. The noise level was initially presented 15 dB below the speech level and the PB words were presented. If the participant correctly identified two words out of four words, the noise was increased by 2 dB steps until the participant missed three consecutive words out of four words presented. At this level, noise was reduced by 2 dB until the participant repeats two words out of four words. This noise level was subtracted from the speech level to find the SNR. Both cafeteria noise and speech babble noise were used as competing background stimuli for obtaining the SNR.

In phase II, the data was collected in the different aided conditions using two background competing stimuli

1. Determining the aided SNR with directional microphone turned off using two different background competing stimuli.
2. Determining the aided SNR with Directional microphone turned on using two different background competing stimuli.
3. Determining the aided SNR with FM system using two different background competing stimuli.

To account for possible order effects, the presentation of the type of background noise was randomized in different aided conditions.

Results and Discussion

Analysis: SPSS version 16 was used to make statistical calculations. Descriptive statistics, One way repeated measure Analysis of Variance (ANOVA), Two way repeated measure ANOVA, Bonferroni multiple comparisons and Paired sample t test was used for analysis of the data.
Table 1. Mean and Standard Deviation (SD) of MCL, BNL and ANL (in dB HL) Obtained Using Cafeteria noise (CN) and Speech-Babble (SB) in Hearing aid With Directional microphone off (HA), Hearing aid With Directional microphone on (DM) and FM system.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>MCL/BNL/ ANL</th>
<th>CN/SB</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hearing aid without directional microphone</strong></td>
<td>MCL</td>
<td>-</td>
<td>44.82</td>
<td>4.99</td>
</tr>
<tr>
<td></td>
<td>BNL</td>
<td>CN</td>
<td>36.00</td>
<td>6.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>34.67</td>
<td>6.56</td>
</tr>
<tr>
<td></td>
<td>ANL</td>
<td>CN</td>
<td>8.82</td>
<td>3.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>10.14</td>
<td>3.95</td>
</tr>
<tr>
<td><strong>Hearing aid with directional microphone</strong></td>
<td>MCL</td>
<td>-</td>
<td>44.82</td>
<td>4.99</td>
</tr>
<tr>
<td></td>
<td>BNL</td>
<td>CN</td>
<td>38.17</td>
<td>6.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>37.39</td>
<td>6.15</td>
</tr>
<tr>
<td></td>
<td>ANL</td>
<td>CN</td>
<td>6.64</td>
<td>3.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>7.42</td>
<td>3.29</td>
</tr>
<tr>
<td><strong>Frequency modulation system</strong></td>
<td>MCL</td>
<td>-</td>
<td>41.78</td>
<td>6.69</td>
</tr>
<tr>
<td></td>
<td>BNL</td>
<td>CN</td>
<td>41.42</td>
<td>7.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>40.78</td>
<td>7.16</td>
</tr>
<tr>
<td></td>
<td>ANL</td>
<td>CN</td>
<td>0.35</td>
<td>4.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SB</td>
<td>1.00</td>
<td>4.72</td>
</tr>
</tbody>
</table>

Note. MCL was obtained without the presence of noise (CN / SB)

A. Comparison of Most comfortable level (MCL) in all the three aided conditions.

Table 1 shows the mean MCLs for all the three aided conditions. It is evident that the mean MCL was same for hearing aid with and without directional microphone. The mean MCL for FM condition was lower when compared to hearing aid with and without directional microphone by an average of 3 dB HL.

Results of the repeated measure ANOVA showed a significant main effect of various aided conditions (Hearing aid with and without directional microphone & FM system) [F (2, 54) = 12.28, p<0.001]. To evaluate the significant differences in three different aided conditions, Bonferroni’s multiple comparison was used. No significant difference (p > 0.001) was observed between hearing aid with and without directional microphone. However, unlike the expected findings, there was a significant difference between the FM system and the other two different aided conditions (p < 0.001).

In the present study the MCL was significantly lower for the FM system compared to aided condition with and without directional microphone. The MCL did not show significant difference between hearing aid with and without directional microphone. The lower MCL for the FM system may be attributed to the increase in gain in the FM system. This increase in gain may be due to the increase in overall intensity level of the speech with FM microphone than microphone of the personal hearing aid (Hawkins, 1984). The possible reason for
identical MCL for the hearing aid with and without directional microphone could be that the directional microphone may not have provided any benefit in the absence of noise.

**B. Comparison of Background noise level (BNL) in all the three aided conditions in two background competing stimuli (Cafeteria noise & Speech Babble).**

The mean and the standard deviation given in Table 1 clearly reveal that, the BNL was maximum for the FM condition and minimum for Hearing aid without directional microphone. On comparison between hearing aid with and without directional microphone, the BNL was comparatively more for hearing aid with directional microphone than hearing aid without directional microphone. These findings were observed for both cafeteria and speech babble. Further it was observed that the BNL was higher for the cafeteria noise and lower for the speech babble for all the three aided conditions.

To assess the difference in background noise levels across the three aided conditions in two noises (cafe, speech babble), two-way repeated measure ANOVA was done. Results showed a significant main effect \[ F(2, 54) = 23.90, p<0.001 \] of different aided conditions. Further results revealed that there was no significant interaction \[ F(2, 54) = 0.75, p>0.001 \] between different aided conditions and two noises.

To evaluate the significant difference between three different aided conditions, Bonferroni multiple comparison test was administered. Results revealed that there was a significant difference between hearing aid with and without directional microphone (p < 0.001), hearing aid with directional microphone and FM system (p < 0.001) and hearing aid without directional microphone and FM system (p < 0.001). To find the difference in BNL between the two background competing stimuli among three aided conditions, paired t test was done. Results of the paired t test showed that there was a significant difference in BNL between two background competing stimuli in hearing aid with and without directional microphone. However, there was no significant difference between the two background competing stimuli in FM system (p> 0.05).

The results of the present study is in consensus with the previous literature which has documented that technological advances such as directional microphone and FM system in hearing instrument design strive to diminish the effects of noise for hearing aid wearers (Kochkin, 1993). Directional microphone reduces the negative effects of background noise by providing greater amplification for signals arriving from the front of the listeners compared to signals arriving from the rear and/or sides of the listener (Kuk et al., 2000; Dillon, 2001). The close proximity of the FM microphone also minimizes the effects of reverberation and noise on speech perception (Crandell, Smaldino, & Flexer, 1995). Due to the reduction in noise, it may be inferred that the participants were able to accept more background noise with these technologies.

The results of the BNL for aided condition without any noise reduction technology are in agreement with the study done by Nabelek, Tampas and Burchfield (2004). The possible reason for the lower BNL obtained in the present study in the hearing aid condition
without any noise reduction technology may be due to the amplification of both speech and noise.

The lower BNL obtained in the present study for speech babble in comparison to cafeteria noise might be attributed to the spectrum of the two noises. Multi talker babble creates a difficult listening environment because there is minimal amplitude modulation of the envelope, and it is aperiodic (Wilson, 2003). There was no difference between two different noises in FM system as expected.

C. Comparison of Acceptable noise level (ANL) in all the three aided conditions in two background competing stimuli.

From the Table 1 and Figure 1 it can be observed that the mean ANL was minimum for the FM condition and maximum for the Hearing aid without directional microphone. On comparison of hearing aid with and without directional microphone, ANL was comparatively lower for hearing aid with directional microphone than the hearing aid without directional microphone. Further it was observed that the ANL was lower for the cafeteria noise and higher for the speech babble for all the three aided conditions.

![Figure 1. Mean ANL and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.](image)

Results of the two-way repeated measure ANOVA showed a significant main effect of different aided conditions \[F (2, 54) = 83.31, p<0.001\]. Further results revealed that there was no significant interaction between various aided conditions and two types of noises \[F (2, 54) = 0.75, p>0.001\]. To evaluate the significant differences between three different aided conditions, Bonferroni’s multiple comparison was used. Results revealed that there was a significant difference between aided condition with and without directional microphone \((p < 0.001)\), hearing aid with directional microphone and FM system \((p < 0.001)\), hearing aid without directional microphone and FM system \((p < 0.001)\). To see if the differences in mean ANL scores across the two background competing noises were significantly different, paired t test was done for all the three aided conditions. The results revealed a significant difference between the ANL for two different noises in hearing aid with and without directional microphone \((p <0.05)\). However, unlike the expected findings, there was no significant difference in ANL between two noises in the FM system \((p>0.05)\).
There is a lack of literature on the effect of FM system on ANL. However, efficacy of FM system has been assessed using various satisfaction scales (Chisolm, McArdle, Abrams, & Noe, 2004). It was observed that the listening abilities were much better with FM system than hearing aids alone. Since ANL and satisfaction scales tap the same aspect of successfulness of the FM users it can be further extrapolated that participants who showed satisfaction with FM system tend to get reduced ANL.

The findings of the present study with regard to the effect of directional microphone on ANL in agreement with the study done by Freyaldenhoven et al (2005). They too had reported a mean directional benefit of 3.5 dB for ANL. The possible reason for the reduced ANL in the directional mode seen in the present study may be due to the low frequency roll off in the directional hearing aid and the consequent reduced output level in the low frequencies in the directional hearing aid. This low frequency roll off could have contributed to the reduction of annoying sounds which in turn would have lead to a greater listening comfort. Due to this listening comfort the participant would have accepted more background noise.

The results of the present study showed a larger ANL (5 dBHL-12 dBHL for cafeteria noise and 6 dBHL-14 dBHL for speech babble with the aided condition without any noise reduction technology. These results support the findings of Lytle (1994). While establishing the ANL, the MCL was kept constant and therefore the magnitude of ANL was dependent on the BNL. The hearing aid amplifies both speech and noise. Due to the amplification of noise, the BNL that a listener was willing to accept has reduced which would result in larger ANL. Hence the larger ANL obtained in the hearing aid condition without any noise reduction technology may be attributed to the amplification of noise.

The results of the present study revealed a significant difference of about 1.3 dB between the two noises in hearing aid without directional microphone and 0.7 dB HL for hearing aid with directional microphone. The observed results are in accordance with the study done by Freyaldenhoven et al., (2006), who reported that, the mean ANLs obtained using speech babble were approximately 2dB lower than the mean ANLs obtained using speech spectrum noise.

The possible reasons for the obtained ANL differences in two noises could be due to the cognitive load to differentiate between two different noises. Cognitively the two different signals (passages and cafeteria noise) may be easier to process simultaneously than simultaneously presented passages and speech babble. Hence, the ANL may be higher in the speech babble than the cafeteria noise. As expected there was no difference in ANL between two different noises in FM system.
Phase II: Speech recognition threshold to evaluate signal to noise ratio (SNR).

Table 2. Mean and SD of SNR (in dB HL) obtained using Cafeteria noise and Speech-Babble using Hearing aid with directional microphone (DM), hearing aid without directional microphone (HA) and FM system.

<table>
<thead>
<tr>
<th>Condition</th>
<th>CN/SB</th>
<th>Mean</th>
<th>S.D</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA</td>
<td>CN</td>
<td>9.71</td>
<td>3.57</td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>10.92</td>
<td>3.65</td>
</tr>
<tr>
<td>DM</td>
<td>CN</td>
<td>7.25</td>
<td>3.93</td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>8.03</td>
<td>4.09</td>
</tr>
<tr>
<td>FM System</td>
<td>CN</td>
<td>1.00</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>1.07</td>
<td>5.38</td>
</tr>
</tbody>
</table>

From the Table 2 it can be observed that the mean SNR was minimum for the FM condition and maximum for Hearing aid without directional microphone.

Figure 2. Mean SNR and standard deviation (S.D) for hearing aid with and without directional microphone and FM system obtained for cafeteria noise and speech babble.

From the Figure 2 it can be observed that the SNR was lesser (better performance) with the FM condition than the other two aided conditions. To assess the difference in SNR across the three aided conditions in two noises, two way repeated measure ANOVA was done. Results showed a significant main effect of the three aided conditions \([F (2, 54) = 110.6, p < 0.001]\). Further results revealed that there was no significant interaction between various aided conditions and two noise \([F (2, 54) = 0.75, p > 0.05]\). To evaluate the significant differences in three different aided conditions, Bonferroni’s multiple comparison was used. Results revealed that there was a significant difference between hearing aid with and without directional microphone \((p < 0.001)\), hearing aid with directional microphone and FM system \((p < 0.001)\) and hearing aid without directional microphone and FM system \((p < 0.001)\).

To find the difference in SNR across the two background competing noises, paired t test was done for all the three aided conditions. The results showed that there was a significant difference \((p< 0.05)\) in SNR between two noises in hearing aid with and without
directional microphone. However there was no significant difference (p> 0.05) in SNR between two noises in FM system.

The results of the present study with regard to the effect of FM system on SNR is in consonance with the study done by Fabry (1994) who reported that remote FM microphone improved SNR by nearly 10dB over the hearing aid condition using Environmental Microphone. Similar results were also found by Hawkins, 1984.

Lesser SNR in FM system was obtained in the present study in comparison to the directional microphone. These results are in agreement with the study done by Lewis et al., (2004). The improved SNR in FM condition than the other aided condition might be attributed to the proximity of the FM transmitter to the desired signal.

The results of the present study are in fair agreement with the study done by Valente et al., 1995 who reported an improvement of 6 to 8 dB in the directional microphone relative to omnidirectional microphone condition. The present study reported a directional benefit of 3 dBHL for both cafeteria noise and speech babble. The benefit of directional microphone in the present study may be due to the specific characteristics of the listening situations since the signal source was located to the front of the listener and spatially separated from the source of the background noise. Directional microphone provided a benefit as it reduces the negative effects of background noise (Kuk et al., 2000; Dillon, 2001).

The results of the present study showed an SNR of 10 dBHL and 11 dBHL for cafeteria noise and speech babble respectively in the aided condition without any noise reduction technology. These findings are in consonance with the study done by Dubno, Dirks, & Morgan (1984).

The effect of different noises on SNR was similar to the findings of the past investigator (Sperry et al., 1997). The possible reason for getting higher SNR (poor performance) for speech babble than cafeteria noise in the present study can be attributed to the informational masking which occurs when the speech and the competing noise is similar in their temporal and/or semantic structure (Brungart, 2001). The other possible reason for the differential effect of noise may be due to the temporal variation of the noises. Speech babble is a modulated masker. Poorer performance with this modulated masker may be due to the poorer temporal resolution in the participants with sensorineural hearing loss (Bacon & Gleitman, 1992). Hence, the participants in the present study would have showed a higher SNR in the speech babble due to the reduced temporal resolution.

Thus it can be concluded from these findings that SNR was better with the use of FM system followed by the directional microphone. In addition, it can be said that temporal and spectral characteristics of various noise varies which affects speech recognition differently. Hence, the result should be interpreted differently for different noises.
Phase III: **Comparison of ANL and SNR in all the three aided conditions in presence of two background competing stimuli.**

To know significant difference between ANL and SNR among three different aided conditions for two background competing stimuli, paired t test was done.

Table 3. Paired t test for (ANL) and (SNR) across two background competing Stimuli in three aided conditions.

<table>
<thead>
<tr>
<th>Different aided Conditions with noises</th>
<th>t (27)</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ANL)HA-CN-(SNR)HCN</td>
<td>1.77</td>
<td>0.08</td>
</tr>
<tr>
<td>(ANL)HA-SB-(SNR)HSB</td>
<td>1.27</td>
<td>0.21</td>
</tr>
<tr>
<td>(ANL)DMCN-(SNR)DMCN</td>
<td>1.02</td>
<td>0.31</td>
</tr>
<tr>
<td>(ANL)DMSB-(SNR)DMSB</td>
<td>1.11</td>
<td>0.27</td>
</tr>
<tr>
<td>(ANL)FMCN-(SNR)FMCN</td>
<td>1.19</td>
<td>0.24</td>
</tr>
<tr>
<td>(ANL)FMSB-(SNR)FMSB</td>
<td>0.13</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Note: HA- Hearing aid without directional microphone, DM- Hearing aid with directional microphone, FM- FM system, SB- speech babble, CN-Cafeteria noise.

From the Table 3 it can be concluded that there was no significant difference (p<0.05) in Acceptable noise level (ANL) and signal to noise ratio (SNR) between two different noises in hearing aid with and without directional microphone and FM system.

The present study reported a mean ANL of 9 dB HL and 10 dB HL for cafeteria and speech babble for hearing aid without any noise reduction technology. Similarly the mean SNR of 10 dB HL and 11 dB HL was observed in the same condition. These findings are in consensus with the study done by Freyaldenhoven et al., (2005) which had a similar methodology to the present study. They reported a mean ANL of 3.5 dB HL and mean SNR of 3.7 dB HL which was not significantly different. The possible reasons that could be attributed to the similar SNR and ANL obtained in the present study are,

1) Cooper & Cutts (1971) indicated that maximum word recognition is achieved at a SNR of +10dB to + 15dB. The mean ANLs reported in a number of studies also have been found to be in the + 10dB to + 15 dB range (Nabelek, 2006). From these findings it can be inferred that, on average, ANL measured at MCL occurs somewhere near the SNR for optimal word recognition. Hence, it may be possible that there is a common psychological or physiological variable that influence the performance of ANL and SNR. This findings need to be explored further.
2) Patients with lower ANL are likely to become successful, full time hearing aid users, patients with midrange ANLs may either be successful or unsuccessful users and patients with high ANLs are likely to become unsuccessful hearing aid users. Persons with hearing impairment who exhibit low acceptance of background noise when listening to speech (persons with large ANLs) consistently demonstrate dissatisfaction with hearing aids and tends to use them occasionally or reject them altogether (Nabelek et al., 2003). Individuals with poor speech understanding ability in noise also tend to show dissatisfaction with hearing aids. Killion (1997) reported that individuals who exhibit abnormally high SNR loss demonstrate dissatisfaction with hearing aids. Thus it may be possible that perceptual tasks required by ANL measurement is directly analogous to those required by the SNR test, since the individuals with larger ANL as well as high SNR loss show dissatisfaction with hearing aids.

Conclusion

From the results of the present study it can be concluded that FM system is most effective in reducing the background noise followed by the directional microphone. While establishing the ANL noise used should be consistent and ANLs measured with different noises should not be compared directly. Lesser the ANL value and SNR score, better will be the hearing aid benefit and satisfaction. Different real life noises should be used to evaluate the SNR and ANL which gives an insight into the real world benefit in adverse listening conditions. However, Speech babble is most preferable to be used while measuring SNR and ANL since it creates a difficult listening environment for individuals using amplification devices. ANL and SNR procedures are not different. Hence it can be concluded that ANL procedure can be used as an alternative measure to SNR procedures.

References


Dichotic Word (CVCV) Test in Native Kannada Speaking Children

Gurdeep Singh & N. Devi*

Abstract

The present study was taken up with the aim of developing preliminary data for dichotic word test in Kannada language. The test was developed using the word list developed by Yathiraj and Vijayalakshmi (2005). These words were paired in such a way that they differed in initial syllable and were either voiced or voiceless and total duration of each word in a pair was similar. Test consists of two lists of 25 word pairs each, with five word pairs as practice items. Word pairs were played simultaneously in both ears. A total of 100 children with 20 in five age groups with equal number of males and females in each age group (7 years - 12 years) were evaluated on the dichotic word list developed. All the children evaluated had native language as Kannada. Normal auditory functioning was ensured. Responses were scored in terms of single correct scores (right (RCS) & left ear (LCS)) and double correct scores (DCS). The raw data was subjected to statistical analysis. The mean and the standard deviation were also calculated for both the list across the age groups. There was significant difference found for both single correct scores and DCS between the age groups from 9yrs to 12 yrs. No statistically significant difference between the two lists for RCS, LCS and DCS. The single correct scores were much higher than the DCS for all the age groups considered in this study. Within the single correct scores RCS were greater than the LCS with statistical significance. With increase in age there was more increase in LCS and DCS than RCS. Even with the eldest age group (11yrs-12yrs) the RCS were significantly greater than the LCS suggesting presence of right ear advantage even with eldest age group.

Introduction

Central auditory processing is described as "what we do with what we hear" (Katz, Stecker & Henderson, 1992). Auditory processing disorders (APDs) refers to problems in the perceptual processing of auditory information by the central nervous system as demonstrated by difficulties in one or more of the following skills: sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, auditory performance in competing acoustic signal, and auditory performance in degraded acoustic signals (American Speech–Language–Hearing Association, 2005).

In India, it has been found that percentage of children to have dyslexia ranges from 3% (Ramaa, 1985) to 7.5 % (Nishi Mary, 1988; cited in Ramaa, 2000). Dichotic listening test are among the most powerful of the behavioral test battery for assessment of hemispheric function, inter-hemispheric transfer of information, and development and maturation of auditory nervous system in children and adolescents, as well as the identification of lesions of the central auditory nervous system (Keith & Anderson, 2007). Binaural integration is the

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ability of the listener to process different information being presented to each ear at the same time (Musiek, 2006).

Of the variety of speech stimuli available to measure dichotic listening (e.g., digits, words, consonant-vowels and sentences), digits are the most utilized. However, they are a closed-set task that may tend to overestimate dichotic speech recognition ability. A more difficult task is Dichotic Consonant-Vowel test (CV) developed by Berlin, Lowe-Bell, Jannetta, and Kline (1972). Monosyllabic words (other than digits) may offer several advantages as a dichotic stimulus (1) monosyllabic words are meaningful components of speech that limit the use of syntactical cues (Committee for Hearing, Bioacoustics and Biomechanics [CHABA], Working Group on Speech Understanding and Aging, 1988); (2) recorded monosyllabic word lists offer a standardized test of word recognition that are commercially available and in widespread use; (3) there is a large normative database for these monaural word-recognition materials (Dubno, Lee, Klein, Matthews, & Lam, 1995; Dubno, Mills, Matthews, & Lee, 1997; Sperry, Wiley, & Chial, 1997; Wiley et al, 1998; Stoppenbach, Wilson, Craig, & Wilson, 1999; Stockley & Green, 2000); and (4) unlike digits, words are an open stimulus set that may result in recognition performance in the middle of the difficulty continuum.

Need for the study

It is ideal to have speech tests in all languages as the individual perception of speech is influenced by their first language/mother tongue (Singh & Black, 1966). There is no specific data for dichotic word test in Kannada language, which is one of the Dravidian languages spoken in Southern India for assessing the auditory processing. Hence there is a need to develop a test and to detect their problems which is appropriate for Indian children. The need for developing Dichotic Word Test (DWT) is crucial because the auditory system is undergoing maturation, thus age-specific data are required to help in making decisions about whether a child’s auditory system is developing normally or otherwise. The availability of age-specific normative data also enables clinicians to monitor a child’s performance over time (Keith, 2000). To incorporate the Dichotic word test as part of the CANS evaluation battery, since dichotic measures have demonstrated good sensitivity in identifying and differentiating cerebral level lesion (Berlin, 1976; Noffsinger, 1979). According to Musiek, Gollegly, & Ross, (1985), normative data from a representative population is required to ensure if it is a valid and reliable measure of auditory processing ability would be a prerequisite.

Aim of the study

The study was conducted with the following aims:

1. To develop dichotic word test in Kannada language.
2. To develop preliminary data for the Dichotic Word Test (in Kannada) for group of normal children in the age range of 7 years to 12 years.
3. Investigate the effect on different stimulus list.
4. Investigate if the scores are different across age and gender.
5. Investigate if there is any ear difference on the score of the dichotic word test.

Method

The study was conducted in two phases.

**Phase – I: Construction of test material for dichotic word test.**

The Dichotic Word test was constructed using the bi-syllabic word list developed by Yathiraj & Vijayalakshmi (2005) for Indian children. This word list contains four different word lists of equal difficulty, each containing 25 bi-syllabic words, which are phonemically balanced. The words spoken in a conversational style by a female native speaker of Kannada were digitally recorded in an acoustically treated environment on a data acquisition system with a 16 bit analogue to digital convertor at a sampling frequency of 44.1 kHz. Using this recorded words two lists of twenty five pairs of bi-syllabic words were prepared. The material was edited and scaling was done using Adobe Audition (version 2) software to ensure that the intensity of all sounds were at the same level.

**Dichotic Word List**

Duration of each of the 100 words was calculated and words with equal duration were paired together such that the onset and the offset of the words overlapped. The maximum difference in the duration of each word in a pair was not greater than 0.2ms. This duration was taken on basis of study by Lamm, Share, Shatil and Epstein, (1999) in which they used maximum difference in onset for two channels of 1msec. Two word lists of 25 bi-syllabic words paired in the above manner was obtained. It was ensured that each word occurred only once in the presentation of 100 words. As per the guidelines given by Roup, Wiley, & Wilson (2006) care was taken that two words in a pair never had a same starting phoneme. Two different sets of single word pairs consisting of five practice word pairs followed by twenty test word pairs were formed. Inter-stimulus interval of 10 seconds is added between word pairs to function as the response time. A specific instruction was recorded in both channels three seconds before the beginning of each word set/list. A 30-second, 1000 Hz calibration tone was recorded at the beginning of the compact disc at a level equal to the average intensity of the words.

**Preparation of the Dichotic Tests on a Compact Disc (CD)**

Each word of a word pair was recorded in two different channels on a CD, such that, one word got presented to the right ear and the other to the left ear simultaneously. The CD consists of two lists of 25 word pairs. The subjects were instructed to repeat both words, in a free recall manner.

**Administration of developed test material**

Data was collected from native Kannada speaking children in age range of 7 to 12 years old. A total of 120 children (20 in each age group) were tested with equal males and
females in each age group. Class teachers assisted in identifying children with any language, behavioural problems and children with below average academic performance. These children were excluded from the study. Parental consent was obtained before the children participated in the study. A rapport was built with the child to avoid any apprehensions.

**Subject selection criteria**

Subjects were selected based on the following criteria:

1. Bilateral normal-hearing thresholds (0-15 dB HL) at frequencies from 250 Hz to 8000 Hz for air conduction thresholds and 250 Hz to 4000 Hz for bone conduction thresholds.

2. Speech recognition threshold should be ±12 dB (re: PTA of 0.5,1 and 2 kHz).

3. Speech identification score of > 90% at 40 dB SL (re: SRT) in both ears.

4. Bilateral type-A tympanograms and normal acoustic reflexes (ipsi and contra) in both ears.

5. A report from teachers indicating no language or behavioural difficulties or poor academic achievement.

6. Passed the Screening Checklist for Auditory Processing (SCAP) developed by Yathiraj & Mascarenhas (2003) to rule out any auditory processing deficit.

7. No history of hearing loss and no otologic/neurologic problems.

8. No illness on the day of testing.

**Testing environment**

All the testing were carried in a sound treated double room situation and noise levels maintained within permissible limits as per ANSI S 3.1-1991.

**Instrumentation**

A Calibrated two channel diagnostic audiometer ORBITER 922 version 2 (OB-922) coupled with acoustically matched TDH 39 headphones housed in MX-41/AR and Radio ear B-71 bone vibrator were used to estimate the pure tone threshold, Speech recognition thresholds, Speech identification scores and Uncomfortable level for speech. Audiometer was calibrated according to ANSI 1996 standards. Calibrated middle ear analyzer GSI- Tympstar version 2 was used for Tympanometry and reflexometry. Pentium IV computer with Adobe Audition (version 2.0) software for presenting the developed test material.

**Test administration procedure**

SCAP was administered in the classroom. This checklist has 12 questions concerning
the symptoms of deficits in auditory processing (Auditory perceptual processing, Auditory Memory and other miscellaneous symptoms). The class teacher was asked to score on a two point rating scale (Yes/No). Each answer marked ‘Yes’ carried one point and ‘No’ carried zero point. Children who scored less than 50% (<6/12) were considered for the study (passed SCAP). Pure tone thresholds were obtained at octave intervals between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction (Mastoid placement) using modified version of Hughson and Westlake procedure (Carhart and Jerger, 1959). The minimum intensity at which the child was able to respond was calculated and the average was taken for 500, 1000 and 2000 Hz. Speech recognition threshold was obtained using the spondee word list in Kannada developed by Rajshekhar (1978). The intensity at which spondees presented was 20 dB SL (re: PTA) and the children were asked to repeat the spondees. The minimum intensity at which the children were able to repeat two out of three spondees correctly was considered as speech recognition threshold of children. Speech identification score was carried out at 40dBSL (re: SRT) using the monosyllabic words in Kannada developed by Mayadevi (1978). The children tasks were to correctly repeat the words presented lively. Each correct response was given a score of 4%. The total correct response was calculated and termed as speech identification score. Tympanometry and reflexometry were carried out to rule out the middle ear pathology. Children were made to sit comfortably and were asked not to swallow during the testing period. Initially tympanometry was carried out at 226 Hz and then acoustic reflex was done at 500, 1000, 2000 and 4000 Hz ipsilaterally and contralaterally.

**Phase II – Administration of dichotic word test**

The dichotic word test material was played through Pentium IV computer connected to the calibrated OB 922 audiometer. Equipment testing was done at the beginning of each test session to ensure appropriate routing of signals, and channel balancing. Intensity setting was set to a most comfortable level (40dB SL re SRT). Each child was asked to listen to the instructions for dichotic tasks that were recorded before each set of dichotic words on the compact disc. Instruction given to the child was ‘you will be hearing two words, one to both ears at the same time. You should repeat both the words that you hear. You may repeat words from any ear first, ‘Pay attention, this won’t take long’. Task understanding was ensured using the practice items before proceeding to the real test. Verbal responses were taken from all the children that participated in the study. They were instructed to repeat the two words that they hear in both the ears, irrespective of which ear they hear first. Tester noted down the response on the data sheet.

**Calculation of scores for dichotic word tests**

A correct response was allocated to each word that was repeated correctly, irrespective of the order required. The right-ear score (RES), left-ear score (LES) and double correct score (DCS) were calculated for both the list. A score of one was given to each correct pair and also each correct word. The possible total correct response for each test paradigm was 20 for each ear, since out of 25 word pairs, 20 were the test items and 5 were
the practice items. Practice items were not scored for the testing. The RES was defined as the total number of correctly repeated words in the right ear. The LES was calculated in a similar manner. The DCS was calculated as total number of correctly repeated words in both ears in any order.

**Test retest Reliability & Analysis**

The test retest reliability of dichotic word tests was examined by repeating the tests on 20 randomly selected subjects 4 from each age group (2 males and 2 females), two to four weeks after the administration of the first test. Mean and Standard Deviation (SD) for RES, LES, and EA (Ear advantage) for each test condition was calculated. Retest analysis was done for the data. All the statistical analysis was performed using SPSS 17.0 software.

**Results and Discussion**

**List effects:** The mean and SD for single correct scores and DCS were obtained for the two lists across five age groups and are tabulated in Table 1.

Table 1. Descriptive statistics for single and double correct scores for two lists.

<table>
<thead>
<tr>
<th>Age Group(Yrs)</th>
<th>Right Correct Score</th>
<th>Left Correct Score</th>
<th>Double Correct Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>List I</td>
<td>List II</td>
<td>List I</td>
</tr>
<tr>
<td>7 – 7.11</td>
<td>Mean</td>
<td>11.85</td>
<td>12.10</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.25</td>
<td>2.14</td>
</tr>
<tr>
<td>8 – 8.11</td>
<td>Mean</td>
<td>11.55</td>
<td>12.05</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.08</td>
<td>2.43</td>
</tr>
<tr>
<td>9 – 9.11</td>
<td>Mean</td>
<td>13.85</td>
<td>14.25</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.05</td>
<td>1.72</td>
</tr>
<tr>
<td>10 – 10.11</td>
<td>Mean</td>
<td>16.70</td>
<td>16.90</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.89</td>
<td>1.97</td>
</tr>
<tr>
<td>11 – 11.11</td>
<td>Mean</td>
<td>18.10</td>
<td>18.40</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.25</td>
<td>1.45</td>
</tr>
</tbody>
</table>

From Table 1, it can be seen that there is slight difference in the mean values for the right ear correct scores, left ear correct scores and double scores for the two lists. Mixed ANOVA results showed no significant effect on lists for single correct scores \[F (1, 90) = 1.47 \ p > 0.05\] and DCS \[F (1, 90) = 0.01 \ p > 0.05\] but there was an interaction seen for single correct score between list, ear and gender \[F (1, 90) = 4.24 \ p < 0.05\] and also list, ear, gender and group \[F (4, 90) = 3.83 \ p < 0.05\]. So to explore these interactions, paired t test was done to evaluate the difference in scores between two lists across age groups. Results for the paired t test are tabulated in Table 2.
Table 2. t value, degrees of freedom and its significance between the two lists across the all age groups

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Pairs</th>
<th>Dependent variable</th>
<th>t – value</th>
<th>df</th>
<th>Sig.(2 tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 – 7.11</td>
<td>1</td>
<td>RCSI – RCSII</td>
<td>0.52</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LCSI – LCSII</td>
<td>0.12</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>DCSI – DCSII</td>
<td>0.54</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>8 – 8.11</td>
<td>1</td>
<td>RCSI – RCSII</td>
<td>1.05</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LCSI – LCSII</td>
<td>0.38</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>DCSI – DCSII</td>
<td>0.17</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>9 – 9.11</td>
<td>1</td>
<td>RCSI – RCSII</td>
<td>1.69</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LCSI – LCSII</td>
<td>1.32</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>DCSI – DCSII</td>
<td>2.02</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>10-10.11</td>
<td>1</td>
<td>RCSI - RCSII</td>
<td>1.28</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LCSI - LCSII</td>
<td>1.14</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>DCSI - DCSII</td>
<td>1.83</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td>11 – 12</td>
<td>1</td>
<td>RCSI - RCSII</td>
<td>1.24</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LCSI - LCSII</td>
<td>0.59</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>DCSI - DCSII</td>
<td>0.49</td>
<td>19</td>
<td>p &gt; 0.05</td>
</tr>
</tbody>
</table>

Note. RCSI – Right Correct Score for List I; RCSII - Right Correct Score for List II, LCSI – Left Correct Score for List I; LCSII - Left Correct Score for List II, DCSI – Double Correct Score for List I; DCSII - Double Correct Score for List II.

It can be seen from table 2 that paired t test revealed no significant difference between two lists for both single correct scores and DCS. This trend is seen in all the age groups which indicate that aligning the two words in two different channels at 0 ms lag time does not alter the performance of the subjects between the lists. Both the lists have equal difficulty and hence any of the two lists can be used in clinical practice.

**Gender effect:** Mean and SD for males and females across the two lists for all the five age groups were calculated and are tabulated in Table 3.

Table 3. Mean and Standard Deviation (SD) for Males and Females across Lists and Age group

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Gender</th>
<th>List I</th>
<th></th>
<th></th>
<th>List II</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RCS</td>
<td>LCS</td>
<td>DCS</td>
<td>RCS</td>
<td>LCS</td>
<td>DCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>7.11 – 8.11</td>
<td>M</td>
<td>12.00</td>
<td>2.44</td>
<td>8.10</td>
<td>1.44</td>
<td>4.50</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>11.70</td>
<td>2.16</td>
<td>7.60</td>
<td>2.83</td>
<td>4.20</td>
<td>3.01</td>
</tr>
<tr>
<td>8.11 – 9.11</td>
<td>M</td>
<td>10.90</td>
<td>2.13</td>
<td>7.00</td>
<td>1.33</td>
<td>4.30</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>12.20</td>
<td>1.93</td>
<td>9.00</td>
<td>1.69</td>
<td>5.60</td>
<td>1.89</td>
</tr>
</tbody>
</table>
From the above Table 3, it can be seen that mean scores for males and females are almost similar for single and double correct scores. This similarity is seen in almost all the age groups for both the lists. The mixed ANOVA was done to find out the overall effect on gender. Results of mixed ANOVA revealed no significant difference in gender for single correct scores \([F (1, 90) = 1.47, p>0.05]\) as well as for the DCS \([F (1, 90) = 0.01 p > 0.05]\).

Reports in the literature in the area of gender and language proficiency are not equivocal. McCoby, & Jacklin, (1974) reported that girls have more verbal ability than boys though it is not obvious until about the age of 11 years. On the other hand, Dionne, Dale, Boivin, & Plomin, (1998) reported that language performance is generally better among females than among males, even in children as young as 2-3 years. Lynn, (1992) further stated that females have advantages for both verbal and as well as written persisting through the school years. Hyde, (1994) concluded that although there appears to be a gender difference favoring a better language proficiency in females, this difference is relatively small and thus has little significance (Hyde, 1994).

The results of present study are also indicating that there exist no significant difference between the performance of the males and females across age and lists for the Dichotic listening task and is well supported by the literature on various dichotic listening tests. Geffen, (1987) studied dichotic listening tests using 1, 2, 3, or 4 pairs of digits and reported no gender difference in terms of right ear advantage. Hertrich, Mathiak, Lutzenberger, and Ackermann, (2002) noted gender-related differences for the consonant-vowel dichotic test with artificial stimuli, but not with natural speech. Bellis, & Wilber (2001) in their study using dichotic listening tests in adults using the consonant-vowel, also reported of no gender effect on the dichotic listening task. Dichotic Studies done with words by Roberts et al. (1994) and Meyers, Roberts, Bayless, Volkert, and Evitts (2002) also report of the similar findings. Hence, it can be concluded that boys and girls in the age range of 7 to 12 years develop in similar manner, in the way they develop the binaural integration task.

**Age effect:** Since there was no difference in the scores of males and females, the data of both the gender were combined to see the overall age effect for both the lists. The means, SD and

<table>
<thead>
<tr>
<th>Age Group</th>
<th>M</th>
<th>14.20</th>
<th>2.20</th>
<th>9.6</th>
<th>2.71</th>
<th>7.40</th>
<th>2.59</th>
<th>14.40</th>
<th>1.34</th>
<th>10.10</th>
<th>2.55</th>
<th>7.70</th>
<th>2.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.11-10.11</td>
<td>F</td>
<td>13.50</td>
<td>1.95</td>
<td>10.30</td>
<td>2.54</td>
<td>7.40</td>
<td>2.31</td>
<td>14.30</td>
<td>2.21</td>
<td>10.6</td>
<td>2.17</td>
<td>7.90</td>
<td>2.42</td>
</tr>
<tr>
<td>10.11-11.11</td>
<td>M</td>
<td>17.00</td>
<td>1.76</td>
<td>15.10</td>
<td>2.68</td>
<td>13.30</td>
<td>2.09</td>
<td>17.30</td>
<td>1.82</td>
<td>15.30</td>
<td>2.56</td>
<td>13.50</td>
<td>2.06</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>16.40</td>
<td>2.06</td>
<td>14.30</td>
<td>3.71</td>
<td>12.50</td>
<td>3.56</td>
<td>16.50</td>
<td>2.12</td>
<td>15.10</td>
<td>2.13</td>
<td>12.50</td>
<td>3.56</td>
</tr>
<tr>
<td>11.11-12.11</td>
<td>F</td>
<td>18.20</td>
<td>1.47</td>
<td>17.10</td>
<td>2.37</td>
<td>16.50</td>
<td>2.59</td>
<td>18.30</td>
<td>1.05</td>
<td>17.00</td>
<td>1.69</td>
<td>16.60</td>
<td>2.22</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>18.00</td>
<td>1.05</td>
<td>17.30</td>
<td>1.33</td>
<td>17.00</td>
<td>1.41</td>
<td>18.50</td>
<td>1.43</td>
<td>17.70</td>
<td>1.63</td>
<td>17.40</td>
<td>2.01</td>
</tr>
</tbody>
</table>

**Note.** RCS – Right Correct Score; LCS - Left Correct Score; DCS – Double Correct Score
range across the age groups for both the list were obtained and are tabulated in Table 4.

Table 4. Mean, standard deviation and range across age groups for both lists.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>List I</th>
<th>List II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCS</td>
<td>LCS</td>
</tr>
<tr>
<td>7-7.11 years</td>
<td>Mean</td>
<td>11.85</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>8-16</td>
</tr>
<tr>
<td>8 – 9 years</td>
<td>Mean</td>
<td>11.55</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>8-16</td>
</tr>
<tr>
<td>9 - 10 years</td>
<td>Mean</td>
<td>13.85</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>10-18</td>
</tr>
<tr>
<td>10 - 11 years</td>
<td>Mean</td>
<td>16.70</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>14-20</td>
</tr>
<tr>
<td>11 - 12 years</td>
<td>Mean</td>
<td>18.10</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>16-20</td>
</tr>
</tbody>
</table>

Note. RCS – Right Correct Score; LCS – Left Correct Score; DCS – Double Correct Score

From Table 4, it can be seen that the mean scores for RCS, LCS and DCS increased as the age increased. RCS is greater than compared to LCS and DCS indicating right ear advantage for both the list. Also we can find that the mean DCS are lesser for all the age groups compare to single correct scores.

Mixed ANOVA was done to evaluate overall significant difference between the groups. Mixed ANOVA results revealed significant main effect on age \( [F (4, 90) = 70.00, p < 0.01] \) for single correct scores. There was also significant interaction between ear and group \( [F (4, 90) = 21.92, p < 0.01] \). However, there were no statistically significant interactions between group and gender \( [F (4, 90) = 0.88, p > 0.05] \), group and list \( [F (4, 90) = 0.49, p < 0.05] \), group, list and gender \( [F (4, 90) = 0.25, p > 0.05] \), ear, group and gender \( [F (4, 90) = 0.96, p > 0.05] \), list ear and group \( [F (4, 90) = 0.20, p > 0.05] \), list, ear, gender and group \( [F (4, 90) = 1.29, p > 0.05] \). Similarly for double correct scores, there was a significant difference seen for the group \( [F (4, 90) = 115.11, p < 0.001] \). However, there was no significant interaction seen for group and gender \( [F (4, 90) = 0.68, p > 0.005] \), group and list \( [F (4, 90) = 0.48, p > 0.005] \) and group, list and gender \( [F (4, 90) = 0.15, p > 0.005] \) for the double correct score.

MANOVA was done to further investigate the significant difference in the different age groups within each list. Results of MANOVA revealed significant difference across the age groups for Right ear correct scores \( [F(4,98)=44.98,p<0.01] \). Left ear correct scores \( [F(4,95)= 62.08,p<0.01] \) and Double correct scores \( [F(4,95)= 111.20, p<0.01] \) for list one and
Right ear correct scores \([F(4,98)=42.78,p<0.01]\), Left ear correct scores \([F(4,95)=82.54, p<0.01]\) and Double correct scores \([F(4,95)=111.21, p<0.01]\) for list two. To further explore within the age groups, to see which of the groups are significantly different, Duncan Post-Hoc analysis was done. Means of the groups were presented in homogeneous subsets depending on the result of Post-Hoc analysis. Except for the first two groups Duncan’s post Hoc analysis showed significant difference across all the age groups at 95% of the confidence level for right correct scores, left correct scores and double correct scores. The mean scores for all age groups fall into different subsets indicating a significant difference between all the age groups except the first two groups which were in the same subset.

There was improvement seen in the dichotic word scores as the age increased and this could be due to the differential myelination of the sub-cortical from the cortical structures. Dichotic listening performances do not reach adult values approximately 10 to 11 years of age. This functional development time is consistent with the myelination time course (Yakovlev & Lecousis, 1967). Myelinogenesis of Corpus callosum and some other auditory association areas may not have completed until 10 to 12 years or older. Similarly, Hayakawa et al, (1991) reported that corpus callosum becomes adult like by the age of 11 years-12 years, whereas Johnson, Farnsworth, Pinkston, Bigler, and Blatter (1994) reported that growth and efficiency of corpus callosum increases till early adult years. There is also evidence from somatosensory evoked potentials, which are used to measure inter-hemispheric transfer time by comparing ipsilateral to contralateral stimulation latencies indicating that, corpus callosum maturity ranges from 10 to 20 years (Salamy, Mendelson, Tooley, & Chapline, 1980). Pujol (1993) also reported corpus callosum as the last structure to be fully developed and also one among to show the age related changes.

The effect of age on dichotic listening of higher cortical structures is that, there is not much information passed on to the higher levels at an younger age due to incomplete maturation of corpus callosum and thus scores may be reduced in the lower age group. As age increases, the myelination of the cortical structures especially corpus callosum might get completed and thereby resulting in increase in the scores on the dichotic tests.

The mean scores for left ear are less compared to right ear scores. This poor left ear performance on dichotic listening in children may reflect a decreased ability of the corpus callosum to transfer complex stimuli from the right hemisphere to the left hemisphere. As the child becomes older and myelination of the corpus callosum is completed, the inter-hemispheric transfer of information improves and left ear scores approach to those found in adults (Musiek, Gollegly, & Baran, 1984).

The double correct scores are less compared to single correct scores in all the age groups. It is suggested that the single correct scores should be used to calculate the norms rather than double correct scores. Dermody, Mackie, and Katach, (1983) also found that the double correct scores do not provide information about the differential ear effects compared to ear correct scores.
Along with the maturation of the sub-cortical and cortical structures, the effect of age on dichotic listening may be different depending on the type of stimuli used. Dichotic listening requires communication between the cerebral hemispheres and functional integrity of both temporal lobes (Kimura, 1963, 1967). Bellis, (1996) stated that, more the linguistically loaded stimuli presented, more pronounced the maturational effects.

The present study is in good agreement with the study done by Berlin et al (1973) where the number of CV stimuli presented to both the right and the left ear increased significantly with age which is suggests that with increase in age there is corresponding increase in the brain’s ability to process two channel stimuli. Similar findings were seen by Willeford and Burleigh, (1994) using sentences dichotically. However, ear advantage reported in the above two studies varied for the type of the stimuli used. The dichotic CV had higher right ear advantage (Berlin et al., 1973) where as dichotic sentences had right ear advantage which reduced with age (Willeford and Burleigh, 1994).

A possible explanation for these findings lie in degree of complexity of stimuli utilized. CV nonsense syllable are less linguistically loaded than sentences. Thereby, processing demands on two hemispheric and inter-hemispheric connections would be much less complex. In contrast dichotic sentences are more linguistically loaded so require more inter-hemispheric communication via corpus callosum as well as integrity of both temporal lobes. But dichotic word are an open stimulus set that may result in recognition performance in the middle of the difficulty continuum that is neither too easy (like the CV’s) nor too difficult (like sentences), yet sensitive to performance difference between ears and groups (Roup, Wiley & Wilson, 2006).

**Ear Effect**

The means and standard deviation (SD) for right and left ear across the age groups for both the list are tabulated in Table 1. From the Table 1, it can be inferred that mean score of right ear was greater than that of left ear in both the lists irrespective of the age groups. Mixed ANOVA was done to investigate the difference in scores across two ears in both the lists. Results of mixed ANOVA revealed significant difference in scores between right and left ear \[F(1, 90) = 113.37, p < 0.001\] for both the lists. There is also interaction seen for the ear, gender, and group \[F(4, 90) = 3.37, p < 0.05\], list, ear, and gender \[F(1, 90) = 4.24, p < 0.05\] and also list, ear, gender, and group \[F(4, 90) = 3.83, p < 0.05\]. Hence, Paired t test was done to further evaluate difference in the scores between the two ears across age groups for both the lists. Results of paired T test revealed a significant difference between the right ear scores and the left ear scores for all the age groups except for the list I in 11 to 12 year group, where it reached to a significance level but did not show a significant difference.
Table 5. Paired t Test showing t value and its significant difference across two ears

<table>
<thead>
<tr>
<th>Age group</th>
<th>Pairs</th>
<th>T</th>
<th>Df</th>
<th>Sig. (2 tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 – 7.11 years</td>
<td>RCSI – LCSI</td>
<td>8.71</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>RCSII - LCSII</td>
<td>11.18</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>8 -8.11 years</td>
<td>RCSI – LCSI</td>
<td>8.21</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>RCSII - LCSII</td>
<td>11.37</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>9 – 9.11 years</td>
<td>RCSI – LCSI</td>
<td>8.85</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>RCSII - LCSII</td>
<td>11.75</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>10 – 10.11 years</td>
<td>RCSI – LCSI</td>
<td>5.62</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>RCSII - LCSII</td>
<td>5.84</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>11 – 12 years</td>
<td>RCSI – LCSI</td>
<td>4.15</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>RCSII - LCSII</td>
<td>4.47</td>
<td>19</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>

Results of present study of having right ear advantage are in consonance with earlier literature on dichotic listening (Musiek et al., 1989; Wexler and Halwes, 1983 & Berlin et al., 1973). Converging evidence in the field of dichotic listening strongly suggests that the right ear advantage arises through mechanisms postulated by Kimura's structural model (Kimura, 1967). According to this model it is postulated that, it is the bilateral asymmetry in brain function as a function of stimulus type that gives rise to the right ear advantage. This Right ear advantage has been interpreted as resulting from rigid bottom up neural connections (Hugdahl, 2005), that is the contralateral projections of the ascending auditory system consists of more fibers and consequently are more stronger leading to more cortical activity than the ipsilateral projections. Also, the fact that the left hemisphere is dominant foe speech in most cases (Kandel, Schwartz, & Jessell, 1991; Rasmussen & Milner, 1977) explains the right ear advantage. In addition, stronger activity in the contralateral system inhibits the processing on the ipsilateral side (Yasin, 2007) and thus resulting in a better performance for the right ear than the left ear.

Right ear advantage in dichotic listening has also been attributed to proximity of the left temporal lobe which is closer to the left primary than the right anterior temporal lobe (Berlin et al., 1973). It is postulated that owing to the proximity, there is less transmission loss to the left posterior temporal parietal lobe on the basis of proximities within the areas of the brain. Due to this proximity there is efficient interaction between shorter pathways. Similar findings have been reported by Studdert-Kennedy and Shankweiler (1967).

Reliability Measure

The reliability measure for 10% of the total subjects participated was analyzed using SPSS 17.0 using Cronbach's Alpha test. The results of the reliability measure are shown in Table 6.
Table 6. Reliability Measures for Single Correct Scores (right & left) and Double Correct Scores for Both the Lists

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Alpha values</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCSI</td>
<td>0.89</td>
</tr>
<tr>
<td>LCSI</td>
<td>0.85</td>
</tr>
<tr>
<td>DCSI</td>
<td>0.79</td>
</tr>
<tr>
<td>RCSII</td>
<td>0.87</td>
</tr>
<tr>
<td>LCSII</td>
<td>0.80</td>
</tr>
<tr>
<td>DCSII</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Note. RCSI – Right Correct Score for List I; RCSII - Right Correct Score for List II
LCSI – Left Correct Score for List I; LCSII - Left Correct Score for List II
DCSI – Double Correct Score for List I; DCSII - Double Correct Score for List II

The above Table reveals that all the scores obtained on dichotic word test at two different times are having an alpha value of greater than 0.7 which indicates good reliability of the test.

**Summary and Conclusions**

Dichotic listening test are among the most powerful of the behavioral test battery for assessment of hemispheric function, inter-hemispheric transfer of information, and development and maturation of auditory nervous system in children and adolescents, as well as the identification of lesions of the central auditory nervous system (Keith and Anderson, 2007). Dichotic listening tests have long been used in the evaluation of cerebral dominance in both children and adults (Hugdahl, 1988) and also in assessment of cortical lesions (Musiek & Pinherio, 1985). In dichotic tests the two ears are stimulated simultaneously with different speech sounds (Hugdahl, 1995). The task of the subject is to report what is being heard, either in both ears (free recall) or in one of the ears, either left or right (directed attention) (Bellis, 1996). Dichotic listening task has been carried out using various stimuli like digits, non-sense CV syllables, words and sentences (Bellis, 1996). Although dichotic sentence test have more linguistic load than the dichotic CV’s, dichotic CV’s are considered to be more difficult than sentences (Niccum, Rubens, & Speaks, 1981). Hence, the present study was carried out using words which are an open stimulus set that may result in recognition performance in the middle of the difficulty continuum (Roup, Wiley, & Wilson, 2006).

The present study was taken up with aim of developing preliminary data for dichotic word test in Kannada language. The test was developed using the word list developed by Yathiraj and Vijayalakshmi (2005). These words were paired in such a way that they differed in initial syllable and were either voiced or voiceless and total duration of each word in a pair was similar. Test consists of two lists of 25 word pairs each. Five word pairs were used as practice items. These paired words were aligned and imposed on a stereo track in such a way that word pairs were played simultaneously in both ears.
A total of 100 children with 20 in five age groups with equal number of males and females in each age group (7 years-12 years) were evaluated on the dichotic word list developed. All the children evaluated had native language as Kannada. Prior to administration of dichotic word test these children were tested with routine audiometric testing (PTA, SRT, SIS & Immittance) and Screening Checklist for Auditory Processing Disorder (SCAP) to ensure normal auditory functioning.

Responses were scored in terms of single correct scores {right (RCS) & left ear (LCS)} and double correct scores (DCS). The raw data was subjected to statistical analysis. The mean and the standard deviation were also calculated for both the list across the age groups. There was significant difference found for both single correct scores and DCS between the age groups from 9yrs to 12 yrs. No statistically significant difference between the two lists for RCS, LCS and DCS. The single correct scores were much higher than the DCS for all the age groups considered in this study. Within the single correct scores RCS were greater than the LCS with statistical significance. With increase in age there was more increase in LCS and DCS than RCS. Even with the eldest age group (11yrs-12yrs) the RCS were significantly greater than the LCS suggesting presence of right ear advantage even with eldest age group.

The results of the present study are very much in consonance with the available literature on dichotic listening task and so it can be used clinically along with the other battery of tests for evaluation of children in the age range evaluated for central auditory processing disorder. The present study also provides with preliminary data for the age group evaluated which again is of clinical importance.

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Prescription of Hearing Aids using Auditory Steady State Responses (ASSR)

Ismail S Md. & P. Manjula*

Abstract

Hearing aid prescription involves setting the gain at different frequencies and other parameters including compression ratio and compression knee-point. Verification of hearing aid can be done using subjective techniques such as functional gain and objective techniques such as insertion gain or electrophysiological tests. In the present study, intensity-amplitude functions were obtained from measures of loudness growth using Auditory Steady State Responses (ASSR). Using this, the gain and compression ratio of the hearing aid were estimated. The relationship between amplitude and intensity of the ASSR was compared in a group of adults having normal hearing with that adults having moderate and moderately-severe sensorineural hearing loss. This was done to propose a method to derive information on hearing aid characteristics from the amplitude-intensity function of the ASSR. This procedure enabled determination of some basic properties of hearing aids, such as average gain, compression ratio. The study also aimed at comparing the gain and compression ratio estimated by ASSR with that predicted by NAL-NL1 and FIG6 prescriptive procedures. From the results of the study it can be inferred that, the gain prescribed by ASSR-PF can also be useful in prescribing hearing aid gain as it was comparable with other prescriptive formulae. Thus, the ASSR serves as an objective tool in verifying the hearing aid prescription process for difficult-to-test population such as infants, young children in whom reliable behavioural responses cannot be obtained.

Key words: gain, compression, intensity-amplitude function, prescriptive procedures.

Introduction

Hearing aid fitting follows three main steps. They are assessing hearing loss, prescribing an aid to compensate for this hearing loss and verifying that this aid provides adequate benefit (Scollie & Seewald, 2001). Each step has its own contribution in hearing aid fitting. Hearing assessment evaluates the hearing threshold, speech identification, maximum comfort levels (MCL) and loudness discomfort level (LDL) at different frequencies. Prescription sets the gain and other parameters including compression ratio and compression knee-point of a selected aid so that the average spectrum of speech sounds is amplified to levels within the range between the unaided thresholds and the loudness discomfort levels of an individual (Cornelisse, Gagné, & Seewald, 1991; Stelmachowicz, Mace, Kopun, & Carney, 1993; Byrne & Dillon, 1986; Cornelisse, Seewald, & Jamieson, 1995). Verification provides some measurement of how well the sounds are heard when the aid is used at its prescribed settings (Stelmachowicz, Kopun, Mace, Lewis, & Nittrouer, 1995).

Fitting hearing aids in adults and older children with hearing loss can be guided by subjective responses to amplified sounds (Picton, et al., 1998). One of the popular subjective measures for selection of a hearing aid is the ‘functional gain’. The ‘functional gain’ a patient

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receives can be determined by obtaining the difference between the unaided and aided thresholds for a particular stimulus (Dillon, 2001). In the case of difficult-to-test population with hearing loss who are unable to provide behavioral responses, objective methods - such as real ear measures and electrophysiological measures - must be relied upon to guide the hearing aid fitting and verification process.

Over the years, data have begun to accumulate which suggest that the ASSR threshold estimates are reasonably accurate in predicting the behavioral thresholds. A number of investigators have reported that ASSR thresholds correlate well with behavioural thresholds. (Cone-Wesson, Dowell, Tomlin, Rance, & Ming, 2002). The amplitude of the ASSR can be used in the estimation of loudness growth function. This information can be used in setting the hearing aid parameters. The validity of using ASSR in hearing aid selection has been evaluated (Vanaja & Manjula, 2004; Damarla & Manjula, 2007) and it has been found that ASSR can be used in setting the gain of the hearing aid.

Apart from setting the gain of the hearing aid, the ASSR can also be used for setting the compression ratio of the hearing aid. The Auditory Steady State Response - Prescription Formula (ASSR-PF) enables determination of some of the basic properties of hearing aids, such as, gain across frequencies and compression characteristics based on the dynamic range of hearing (Zenker, Fernández, & Barajas, 2005). In this ASSR-PF procedure, the amplitude-intensity function of the ASSR can be used to derive the information on hearing aid characteristics such as gain and compression ratio. The setting of the gain and compression ratio is done by comparison of the amplitude-intensity function of the ASSR for the clients with hearing impairment with that of those with normal hearing.

Recent studies have proposed that assessment of auditory evoked potentials, and specifically ASSRs, could serve as useful tools in the fitting and verification of the hearing aids (Cone-Wesson, Parker, Swiderski, & Ricakrds, 2002; Picton et al., 1998; Zenker, Fernandez, & Barajas, 2006).

**Need for the study**

Fitting the hearing aid includes setting the gain and compression characteristics of the hearing aid depending on the hearing threshold and loudness growth of an individual. For this, ASSR can be used as an objective tool. It has been shown that the FG obtained through ASSR and that obtained through sound field audiometer were highly correlated (Vanaja & Manjula, 2004). Further, the FG obtained through ASSR and the IG were also well correlated (Damarla & Manjula, 2007). There are very few studies that have evaluated the usefulness of ASSR in setting the gain as well as compression parameters of the hearing aid (Zenker, Fernandez, & Barajas, 2005). Thus, the present study aims at evaluating the usefulness of the ASSR in setting the gain as well as the compression parameters of the hearing aid.

**Objectives**

The aims of the present study were
1. To estimate the gain of a hearing aid by the measurement of hearing threshold using ASSR.

2. To estimate the compression ratio of the hearing aid by the measurement of dynamic range, i.e., the difference between the uncomfortable level and the threshold, using ASSR.

3. To compare the gain obtained by ASSR and that estimated by NAL-NL1 and FIG6.

4. To compare the compression ratio obtained by ASSR and that estimated by NAL-NL1 and FIG6.

Method

The following method was adopted to investigate the aims of the study.

Participants

Eighty participants were included in the three groups. Their age ranged from 15 to 55 years, with a mean age of 31.2 years and standard deviation of 3.1 years. The participants were divided into three groups:

- Group I comprised of individuals (N=40) with normal hearing.
- Group II comprised of individuals (N=20) with moderate degree of flat sensorineural (SN) hearing loss in both the ears.
- Group III comprised of individuals (N=20) with moderately severe degree of flat sensorineural (SN) hearing loss in both the ears.

Instruments used

- A calibrated double channel diagnostic audiometer for pure tone audiometry and speech audiometry.
- A calibrated diagnostic immittance meter to confirm the normal middle ear function through tympanometry and acoustic reflex measurement.
- GSI Audera (version 2.6) to record the ASSR through insert earphones.

Procedure

The testing was carried out in a sound treated environment. Pure tone audiometric thresholds were obtained using modified Hughson - Westlake procedure (Carhart & Jerger, 1959). Speech audiometry was performed to establish the speech reception threshold, speech identification scores and uncomfortable level for speech. Immittance evaluation was carried out to ensure normal middle ear functioning. These measurements were carried out on each participant to ensure that the participants met the selection criteria.
The data were collected in two phases.

**Phase I: Calculating the hearing aid parameters using NAL-NL1 and FIG6.**

Phase II: Calculating the hearing aid parameters using ASSR-PF.

**Phase I: Calculating the Hearing Aid Parameters using NAL-NL1 and FIG6**

The gain for moderate level sounds (65 dB SPL) was calculated at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. For each participant, the gain for moderate level sounds at these four frequencies was computed manually, for both NAL-NL1 and FIG6 using the respective prescriptive formula. The compression ratio was calculated by feeding the audiogram information into the NOAH (3.0) software and simulating a double channel hearing aid with appropriate gain. The default values for the compression ratio at 500 Hz and 2000 Hz as prescribed by NAL-NL1 and FIG6 were noted.

**Phase II: Calculating the hearing aid parameters using ASSR-PF**

The participant was made to sit comfortably on a reclining chair. He/she was instructed to relax, close the eyes and sleep, if possible while recording the ASSR using the calibrated GSI Audera equipment. The site of electrode placement was prepared with skin preparing paste. Disc type silver coated electrodes were placed with conduction gel. The non-inverting electrode (+) was placed on high forehead (Fz), ground electrode was placed on non-test ear mastoid and the inverting electrode (-) was placed on the test ear mastoid. It was ensured that the impedance of each electrode was less than 5 k Ohms and that the inter-electrode impedance difference was less than 2 k Ohms. The ASSRs were recorded using the insert earphones. ASSR measurements were performed using high modulation frequency of 74, 81, 88, 95 Hz for 500, 1000, 2000 and 4000 Hz respectively, with an amplitude modulation rate of 100% and frequency modulation of 10%.

To find out the dynamic range through ASSR, the testing was initiated at the behavioural threshold level and the intensity was increased in 10 dB steps till the intensity level of UCL–5dB was reached. This was done separately for each of the four test frequencies, i.e., 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The amplitude level of the ASSR at each measurement was noted down for the participant.

For participants in Group I, the intensity - amplitude curve was obtained at the four different frequencies, i.e., 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. For participants in Group II and III, the gain at the four frequencies and the compression ratio at 500 and 2000 Hz were determined using the ASSR-PF formula. This procedure namely the Auditory Steady State Response-Prescription Formulae (ASSR-PF) enables determination of some basic parameters of hearing aids, such as dynamic range, frequency response, gain, compression factor, Input-Output function and Maximum Power Output (Zenker, Fernandez, & Barajas, 2005). In the present study, the gain at four frequencies and compression ratio at two frequencies using ASSR-PF were computed for each participant in Group II and Group III.
The ASSR-PF gave information about some critical parameters for fitting hearing aids. First, the hearing dynamic range established from the ASSR hearing threshold and loudness discomfort level; second, the hearing aid characteristics supposed to amplify the entire range of speech into the dynamic range of a particular hearing loss; third, the difference between the hearing loss and the lower limit of the speech dynamic range provided the amount of the gain required by the hearing aid; fourth, the compression factor determined by the degree of hearing loss relative to the long-term average speech spectrum (LTASS) based on the amplitude growth function of the electrophysiological Auditory Steady State Response of the participants.

The dynamic range, gain and compression ratio were obtained from the amplitude projection procedure (APP) as depicted in the Figure 1. The amplitude level function for the group of participants with normal hearing (Group I) was represented by the solid line curve and the amplitude level functions for the group of participants with moderate and moderately severe hearing impairment (Group II & III) were represented by dashed and dotted curves respectively.

![Fig. 1: The amplitude projection procedure (APP) for calculation of gain and compression ratio at 500 Hz.](image)

The dynamic range of speech (40 to 80 dB) was projected upward from the abscissa to the normal amplitude intensity function for each of frequency. Then, the gain requirement is estimated as the difference between the point at which the dotted line (A or B) intersected the X-axis and the lower limit of the input dynamic range (i.e., 40 dB). The compression ratio is given by the ratio of output dynamic range of the participant to the input dynamic range.
From Figure 1, for the group with moderate hearing loss, the gain was calculated as the difference between the hearing loss (59 dB, A) and the lower limit of the LTASS (40 dB), or 59 – 40 = 19 dB. The compression ratio was calculated by the ratio of the normal speech dynamic range (80–40 = 40 dB, C) to the ratio of the dynamic range of the participant (85–59 = 24, D). Thus, the compression ratio was 40/24 = 1.6.

The gain at all the four frequencies obtained by NAL-NL1 prescriptive rule was compared with the gain at all the four frequencies obtained through Auditory Steady State Response-Prescriptive Formula (ASSR-PF). The compression ratio (CR) prescribed by NAL-NL1 was compared with the values obtained by ASSR-PF for all the participants at 500 Hz and 2000 Hz. The same procedure was repeated for FIG6 also. This was done in order to compare ASSR based hearing aid prescription with that of NAL-NL1 and FIG6 prescription in terms of gain and compression ratio.

Results and Discussion

The data collected were statistically analyzed, using statistical package for social sciences (SPSS). These results are being discussed below.

The target gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were within 6 dB of each other for the moderate hearing loss group (Group II). The results of the present study, for moderate hearing loss (Group II), indicated that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz. At 1000 Hz and at 2000 Hz, there was a significant difference between ASSR-PF and FIG6. At 4000 Hz, there was no significant difference in the amount of gain prescribed between any of the three prescriptive formulae.

The target gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were within 14.3 dB of each other for the moderately severe hearing loss group (Group III). The results of the present study, in moderately severe hearing loss (Group III), indicated that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz. At 1000 Hz and 2000 Hz, the results indicated that there was no significant difference between NAL-NL1, FIG6 and ASSR-PF. At 4000 Hz, there was a significant difference between ASSR-PF and FIG6.

In Group II, the results indicated that there was a significant difference between the compression ratio values at 500 Hz and 2000 Hz. In Group III, Bonferroni multiple comparison tests indicated that there was no significant difference between the compression ratio values obtained by ASSR-PF and NAL-NL1 at 500 Hz. In Group III, the results indicated that there was a significant difference between the compression ratios at 2000 Hz prescribed by ASSR-PF, NAL-NL1 and FIG6. The gain and compression ratio for Groups I, II and III are discussed below.
I. Moderate hearing loss (Group I)

A. Gain

The target gain prescribed by ASSR-PF, NAL-NL1, and FIG6 were within 10.9 dB of each other. Zenker, Fernandez, and Barajas (2005) in their study, reported that there was a significant difference between the gain prescribed by ASSR-PF and NAL-RP, POGO, and Berger formulae. The results of the present study indicate that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz only. ASSR – PF provided more gain than NAL-NL1. Picton (2003) has reported that this can be because the difference between the physiological threshold and behavioural threshold is higher at low frequencies. Here, the ASSR over estimates the threshold at 500 Hz and this will lead to increase in the amount of gain at that frequency. To overcome this, a correction factor can be incorporated in the present ASSR-PF to obtain the better estimation of gain at 500 Hz.

Dillon (2001) reported that the gain prescribed by NAL-NL1 is relatively lower at 500 Hz when compared to the other prescriptive formulae such as DSL i/o, FIG6 and IHAFF. As the NAL-NL1 formula tends to maximize the speech intelligibility, the low frequency parts of the speech which are more intense and less important than the high-frequency parts, i.e., relatively little low-frequency gain is required to maximize contribution to the Speech Intelligibility Index (SII) at the low frequencies. As the other procedures tend to normalize the loudness, they do not reduce the gain because they attempt to place speech at each frequency at the level needed to give normal loudness for that frequency.

The gain obtained at 1000 Hz, 2000 Hz and 4000 Hz was not significantly different between ASSR-PF and NAL-NL1, although the gain prescribed by NAL-NL1 was higher than that of ASSR-PF. As the ASSR-PF formula is based on the dynamic range of the LTASS. It gives more emphasis to the speech frequencies. The underlying rationale of NAL-NL1 prescription procedure is to maximize the speech intelligibility, subject to the overall loudness of speech at any level being more than that perceived by a person with normal hearing.

The gain obtained by ASSR-PF and FIG6 was not significantly different at 500 Hz and 4000 Hz although ASSR-PF prescribed higher gain. This may be attributed to the fact that FIG6 procedure prescribes a flat frequency response, for all input levels, for a flat audiogram. In the present study also, the participants had a flat configuration of audiogram.

The gain obtained by ASSR-PF and FIG6 was significantly different at 1000 Hz and 2000 Hz. At these frequencies, ASSR-PF prescribed significantly higher gain than FIG6. This may be because the FIG6 procedure specifies the gain to normalize loudness, whereas, the ASSR-PF prescribes the gain based on the long-term average speech spectrum, (LTASS).
B. Compression ratio

The compression ratio obtained by ASSR-PF was significantly lower than NAL-NL1 and FIG6 at 500 Hz and 2000 Hz. This may be attributed to the fact that ASSR-PF prescription is based on intensity-amplitude function wherein at higher intensities the amplitude of ASSR in individuals with hearing impairment equals that of individuals with normal hearing leading to reduction in the dynamic range and thus the compression ratio.

II. Moderately severe hearing loss (Group III)

A. Gain

As in the group with moderate hearing loss, the results in this group also indicated that there was a significant difference between the gain of ASSR-PF and NAL-NL1 at 500 Hz. ASSR-PF provided significantly higher gain than NAL-NL1. Picton (2003) reported that this can be because of the difference between the physiological threshold and behavioural threshold is higher. Thus, the ASSR over estimates the threshold at 500 Hz. This will lead to increase in the amount of gain at that frequency prescribed by ASSR-PF than that by NAL-NL1. To overcome this, a correction factor can be incorporated in the present ASSR-PF to get a lower better estimation of gain at 500 Hz, as the low frequency components of speech are louder.

The gain obtained at 1000 Hz, 2000 Hz and 4000 Hz was not significantly different between ASSR-PF and NAL-NL1. Although ASSR-PF and NAL-NL1 formulae are based on the dynamic range of the LTASS, the NAL-NL1 prescribed gain was not significantly higher than that of ASSR-PF.

The gain obtained by ASSR-PF and FIG6 was significantly different at 4000 Hz. As FIG6 is based on the rationale that high-frequency components contribute more to speech intelligibility, it provided significantly higher gain than ASSR-PF.

The FIG6 procedure specifies the gain to normalize loudness, and it is based on average loudness data that relates equal-loudness and threshold curves. Whereas, the ASSR-PF prescribes the gain based on the long-term average speech spectrum.

B. Compression ratio

The compression ratio prescribed by ASSR-PF is significantly lower than that by FIG6 and NAL-NL1 at 500 Hz. Byrne, Dillon, Ching, Katsch, and Keidser (2001) have reported that with the increase in degree of hearing loss, the FIG6 prescribes higher compression ratio than the other prescriptive procedures. However, Dillon (2001) reported that with the increase in degree of hearing loss, the compression ratio should be lesser to make the input-output function more linear.
The compression ratio prescribed by ASSR-PF is significantly lower than that by FIG6 and NAL-NL1 at 2000 Hz. This may be because; the NAL-NL1 tends to use less compression than the other procedures such as DSL-i/o, FIG6 and IHAFF which differ considerably (Byrne, et al., 2001).

Byrne, et al., (2001) reported that for the present, such prescriptions must be based mainly on logic as there is very limited evidence on which compression thresholds (CTs) and ratios (CRs) are best. It is observed that FIG6 procedure prescribes higher compression ratio than other procedures. The FIG6 procedure prescribes more compression at high frequencies.

However, a high degree of compression could result in unacceptable sound quality. There is little information on which to judge the amount of compression needed to maximize comfort or the amount of compression that can be used before sound quality is perceived as being degraded (Moore, et al., 1998). More information can be obtained if done on subjects to see if the prescribed compression ratios are right or to check the quality of speech with different compression ratios.

Conclusions

Several studies have reported that the auditory steady state responses could be used to estimate the frequency specific auditory sensitivity. These studies have reported that there is a good correlation between behavioural thresholds and the thresholds estimated from ASSR. Electrophysiological tests like ASSR can assist in hearing aid prescription since they can measure frequency specific auditory thresholds. Thus, the present study aimed at investigating the gain and compression ratio obtained through ASSR based prescriptive formula (ASSR-PF) proposed by Zenker, Fernandez, and Barajas, (2005). The study also aimed at comparing it with the gain and compression ratio obtained through NAL-NL1 and FIG6 prescriptive procedures.

1. In Group II with moderate hearing loss, the following observations were noted for the gain prescribed by ASSR-PF, NAL-NL1 and FIG6.
   - There was a significant difference in gain between ASSR-PF and NAL-NL1 at 500 Hz (p < 0.001), the mean gain provided by ASSR-PF was 4 dB higher than NAL-NL1.
   - There was no significant difference in gain between ASSR-PF and NAL-NL1 at 1000 Hz, 2000 Hz and 4000 Hz (p > 0.05).
   - There was a significant difference in gain between ASSR-PF and FIG6 at 1000 Hz and 2000 Hz (p < 0.001). The mean gain provided by ASSR-PF was 4.1 dB, and 3.8 dB higher than FIG6 at 1000 Hz and 2000 Hz respectively.
   - There was no significant difference in gain between ASSR-PF and FIG6 at 500 Hz and 4000 Hz (p > 0.05).
2. In Group II with moderate hearing loss, the following findings were observed for the compression ratio prescribed by ASSR-PF, NAL-NL1 and FIG6.
   - There was a significant difference in the prescription of compression ratio by ASSR-PF, NAL-NL1 and FIG6 (p < 0.001) at 500 Hz and 2000 Hz. The mean compression ratio prescribed by FIG6 was 0.6 and 0.1 higher than ASSR-PF and NAL-NL1 respectively.

3. In Group III with moderately severe hearing loss, the following findings for the gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were observed.
   - There was no significant difference in gain between ASSR-PF and NAL-NL1 at 1000 Hz, 2000 Hz and 4000 Hz (p > 0.05).
   - There was a significant difference in gain between ASSR-PF and NAL-NL1 at 500 Hz (p < 0.001), the mean gain prescribed by ASSR-PF was 3.9 dB higher than NAL-NL1.
   - There was a significant difference in gain between ASSR-PF and FIG6 at 4000 Hz (p < 0.001), the mean gain prescribed by FIG6 was 4.5 dB higher than ASSR-PF.
   - There was no significant difference in gain between ASSR-PF and FIG6 at 500 Hz, 1000 Hz and 2000 Hz (p > 0.05).

4. In Group III with moderately severe hearing loss, the following findings were noted for the compression ratio prescribed by ASSR-PF, NAL-NL1 and FIG6.
   - There was no significant difference in the prescription of compression ratio by ASSR-PF and NAL-NL1 at 500 Hz, (p < 0.001), however, there was significant difference in the prescription of compression ratio by ASSR-PF and FIG6 at 500 Hz (p > 0.05), and compression ratio prescribed by FIG6 was 1.1 dB higher than ASSR-PF.
   - There was a significant difference in the prescription of compression ratio by ASSR-PF, NAL-NL1 and FIG6 at 2000 Hz (p < 0.001), FIG6 prescribed 1.1 dB and 0.8 higher than ASSR-PF and NAL-NL1 respectively.

From the results of the study it can be inferred that, the gain prescribed by ASSR-PF can also be useful in prescribing hearing aid gain as it was comparable to NAL-NL1, except at 500 Hz. At 500 Hz a correction factor is required for ASSR-PF to be more efficient for hearing aid prescription. Thus, ASSR serves as an objective tool in verifying the hearing aid prescription process for difficult-to-test population such as infants, young children in whom reliable behavioural responses cannot be obtained.

Clinical implications

Use of ASSR, an objective measure, for prescribing gain and compression ratio for individuals with hearing loss will be highly useful. This is especially true for prescribing hearing aid for the difficult-to-test populations.
References


PAMR: An Objective Tool to Measure Hearing Sensitivity in Individuals with Normal Hearing and Hearing Impairment

Jawahar Antony Periannan & Animesh Barman*

Abstract

The present study was aimed to find the percentage of occurrence of post auricular muscle response (PAMR) in individuals with normal hearing and to estimate the hearing threshold in hearing impairment. The individuals with hearing impairment were divided into two groups. One group with individuals having sensorineural hearing loss and the other group with individuals having auditory neuropathy. PAMR was used to estimate the hearing threshold by using the protocol given by Purdy et al. (2005). The results showed that, for individuals with normal hearing the presence of PAMR at 80 dBnHL was 100% and above 90 % at 20 dBnHL for both males and females. No gender effect and ear effect was found for latency measures in individuals with normal hearing. In individuals with sensorineural hearing loss, the PAMR thresholds were significantly correlated with the puretone averages (PTA1 & PTA2). No ear effect was seen in individuals with sensorineural hearing loss. Hence, the PAMR can be used to estimate the hearing threshold in individuals for whom ABR cannot be done due to increased muscle tension and also for difficult to test population. The results also showed that the PAMR was not an effective tool to measure the hearing sensitivity in individuals with auditory neuropathy as most of the individuals in this group did not have a recordable PAMR.

Introduction

The post-auricular muscle response (PAMR) is a large sound-evoked muscle action potential that can be measured on the skin surface over the muscle behind the pinna. Bickford, Jacobson and Galbraith (1963) and Jacobson, Cody, Lambert and Bickford (1964) showed that a sound evoked myogenic potential could be recorded from electrodes placed over the post auricular muscle located behind the pinna. The PAMR can be evoked bilaterally from monaural sound stimuli such as clicks or tonebursts (Yoshie & Okudaira, 1969). The unique advantage of the PAMR was the sound-evoked PAMR is a large bipolar muscle action potential recorded at the skin surface just behind the ear. The PAMR can be much larger than the ABR, with amplitude that changes with the muscle tone in the post auricular muscle (Gibson, 1975).

There were many reports on the variability in recording the PAMR responses (Cody & Bickford, 1969; Picton, Hillyard, Krausz & Galambos, 1974; Bochenek & Bochenek, 1976). Until recently, because of the large variability in recording PAMR within and between the subjects it was not used for the threshold estimation. Patuzzi and O’Beirne (1999b) observed that the variability in recording PAMR was due to the uncontrolled eye movement and PAMR can be enhanced by turning the eyes towards the stimulation ear since there is a direct connection between the muscle tension and PAMR.

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Purdy, Agung, Hartley, Patuzzi and O’Beirne (2005) found the percentage of occurrence of PAMR in individuals with normal hearing is above 80% at the softest intensity levels when the eyes are turned towards stimulated ear. And also, good correlation between the PAMR threshold and the behavioral audiometric threshold were found in individuals with sensorineural hearing loss. Hence, the authors also suggest that the PAMR can be used as a screening tool with complement to ABR.

Need for the study

Though PAMR is acoustically elicited, it has not been extensively studied about its consistency and its clinical utility. If click evoked PAMR found to give consistent result, it can be used as quick tool to predict behavioral threshold. PAMR can be well recorded in almost 80% of the normal population near the threshold (Purdy et al., 2005). Hence, extensive studies on hearing loss population might testify the importance of PAMR as a clinical tool. If found reliable, it can also be used for other group of subjects such as difficult to test population since it has greater amplitude than ABR and also, can be recorded even when they are active (Purdy et al., 2005).

As the ABR is absent in individuals with AN/AD, it is difficult to estimate the threshold in children where behavioral threshold cannot be established. The PAMR may help us to estimate the threshold in these children if it is found to be an effective tool in adults. And also the classification of degree of individuals with auditory neuropathy may not be possible in most of the cases because responses were inconsistent and had peaked audiograms. Responses from 40% of the patients are judged as inconsistent (Kumar & Jayaram, 2006). PAMR, if found reliable, can be used to estimate the threshold since ABR will be absent in these subjects and cannot be used for threshold estimation. Thus, the current study was taken up.

Aim of the study was to:

- Estimate the percentage of normal hearing individual having PAMR responses.
- Find the PAMR responses in individuals with sensorineural hearing loss and individuals with auditory neuropathy.
- Establish the relationship between behavioral thresholds with the click evoked PAMR threshold in individuals with hearing impairment.
- Compare the PAMR parameters in individuals with normal hearing sensitivity and individuals with hearing impairment.

Method

The subject group was divided into three. Group I consisted of 30 individuals (60 ears) with normal hearing with the age range of 18 to 54 years (Mean - 22.4 years), group II consisted of 14 individuals (25 ears) with sensorineural hearing loss with the age range of 23
to 77 years (Mean - 47.2 years) and group III consisted of 10 individuals (20 ears) with bilateral auditory neuropathy with the age range of 18 to 40 years (Mean - 25.2 years).

**Subject selection criteria**

**Group I**

All subjects had hearing sensitivity within 15 dBnHL in both ears at frequencies 250 to 8 kHz with ‘A’ type tympanogram with normal of acoustic reflexes. TEOAEs were present and no abnormality in click evoked ABR in all of these subjects.

**Group II**

All subjects had hearing loss and the severity ranged from mild to profound degree with speech identification scores proportional to severity of hearing loss and air-bone gap not exceeding 10 dBHL. All had ‘A’ type tympanogram with present, elevated or absent acoustic reflexes and absent transient otoacoustic emissions. Latencies of click evoked ABR waves were appropriate to the degree of their hearing loss with good wave morphology at higher repetition rate in all of them.

**Group III**

All subjects had hearing sensitivity ranging from normal hearing to profound hearing loss and Speech identification scores were disproportionate to severity of hearing loss in all of them. All had ‘A’ type tympanogram with absent acoustic reflexes but presence of transient otoacoustic emissions. Absent ABR or poor ABR wave morphology with prolonged latencies were observed in all these subjects and were disproportionate to their degree of hearing loss. All of these subjects were diagnosed as primary auditory neuropathy by an experienced neurologist.

All the subjects participated in the present study did not have any symptoms or history of middle ear dysfunction and the middle ear pathology was ruled out by an otologist.

**Instrumentation**

A calibrated two channel diagnostic audiometer (OB 922- version 2.0) with TDH-39 head phone and B-71 bone vibrator were used to obtain pure tone thresholds and speech identification scores. A calibrated immittance meter (GSI- tympstar) was used to assess the middle ear function. ILO V6 OAE instrument was used to measure the TEOAEs. An evoked potential system [Intelligent Hearing System (USB Jr.)] was used to record the ABR and post auricular muscle response.

**Procedure**

The pure tone thresholds for both AC and BC were tracked using modified Hughson and Westlake method (Carhart & Jerger, 1959). Speech identification scores (SIS) were calculated in percentage at 40 dB SL from SRT by using the speech material developed by Vandana (1998). Tympanometry was carried out using 226 probetone and acoustic reflexes
were found for frequencies 500, 1 k, 2 k and 4 kHz. TEOAEs were measured using the default setting in ILO V6 TEOAEs with 260 sweeps and non linear click trains at 85 dBpeSPL.

ABR was recorded in all the subjects participated in the study at two repetition rates (11.1/sec & 90.1/sec). PAMR was recorded in all the subjects by seating them in a comfortable chair. The inter electrode and intra electrode impedance were maintained at 2 kohm and 5 kohm respectively. They were instructed to turn the eyes towards the stimulated ear during the stimulus presentation. The PAMR was recorded by using protocol given by Purdy et al. (2005).

Table 1: Parameters used to record PAMR

<table>
<thead>
<tr>
<th>Stimulus parameters</th>
<th>Acquisition parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulus type</td>
<td>Clicks</td>
</tr>
<tr>
<td>Stimulus duration</td>
<td>100 microsec</td>
</tr>
<tr>
<td>Stimulus rate</td>
<td>17.1/sec</td>
</tr>
<tr>
<td>Polarity</td>
<td>Alternating</td>
</tr>
<tr>
<td>Intensity</td>
<td>80 dB, 50 dB and 20dB nHL for normal hearing subjects. Variable for subjects with SN hearing loss and auditory neuropathy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Transducer</th>
<th>Insert (ER -3A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Monaural stimulation</td>
<td></td>
</tr>
<tr>
<td>Electrode type</td>
<td>Disc electrode</td>
<td></td>
</tr>
<tr>
<td>Electrode montage</td>
<td>- ve : post auricular muscle(on the test ear mastoid) + ve: behind the pinna of the test ear. Ground: forehead</td>
<td></td>
</tr>
<tr>
<td>Analysis window</td>
<td>40 ms</td>
<td></td>
</tr>
<tr>
<td>Filter settings</td>
<td>10 Hz – 300 Hz</td>
<td></td>
</tr>
<tr>
<td>Notch filter</td>
<td>On</td>
<td></td>
</tr>
<tr>
<td>No. of sweeps</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>No of channels</td>
<td>Single channel</td>
<td></td>
</tr>
<tr>
<td>Gain</td>
<td>10,000</td>
<td></td>
</tr>
</tbody>
</table>

For individuals with normal hearing three intensity levels were taken for finding the percentage of occurrence of PAMR (80, 50 and 20 dBnHL). For individuals with hearing impairment the threshold were estimated using PAMR by decreasing the intensity levels from 80 dB steps till PAMR was not observed and increasing in 10 dB steps till PAMR was observed. If not observed at 90 dBnHL the PAMR was recorded at 99 dBnHL. The minimum intensity at which the responses were observed was considered as the PAMR threshold.

The pi, ni and pii were marked in the obtained waveform based on the agreement between three experienced audiologists. The absolute latency and absolute amplitude were measured for each of these peaks. The data obtained were analyzed using SPSS (Version 16) software. Descriptive statistics was done to all the parameters of PAMR for each intensity level.
Results

Individuals with normal hearing:

The major peaks observed in individuals with normal hearing are pi, ni and pii across three intensity levels. The PAMR response could be recorded from almost 100% of the normal hearing population at 80 dBnHL and approximately 90% at 20 dBnHL either from right or left ear (Figure 1). However, the pii peak was not commonly observed in individuals with normal hearing.

Figure 1: The percentage of PAMR occurrence in right and left ear and also for the both ears together (overall) obtained at 80, 50 and 20 dBnHL in individuals with normal hearing.

The effect of intensity, ear and gender on pi and ni latencies of PAMR was determined by Mixed ANOVA results. There was significant effect on pi latency \([F (2, 48) = 103.74, p < 0.001]\) and ni latency \([F (2, 48) = 35.942, p < 0.001]\) when the intensity is decreased from 80 dBnHL to 20 dBnHL. The Bonferroni post hoc analysis showed there were significant difference between 80 and 50 dBnHL, 50 and 20 dBnHL and also 80 and 20 dBnHL at \(p < 0.001\) for both pi and ni latencies.

The Mixed ANOVA also revealed no significant difference in pi and ni latency between the males and females and also between right and left ear. The data of pi and ni latencies of males and females were combined and shown in the Figure 2.

There was a large amount of variation seen in the amplitude of ni which can be seen in Figure 3. Mixed ANOVA was used to determine intensity, ear and gender difference on pi and ni amplitude. The results revealed that, there was significant effect on pi amplitude \([F (2, 48) = 35.015, p < 0.001]\) and ni amplitude \([F (2, 48) = 28.03, p < 0.001]\) when the intensity is decreased from 80 dBnHL to 20 dBnHL. The Bonferroni post hoc analysis showed there were significant difference between 80 and 50 dBnHL, 50 and 20 dBnHL and also 80 and 20 dBnHL at \(p < 0.001\) for both pi and ni amplitude.

The results also revealed a difference between the ears in ni amplitude when the intensity is decreased. Hence, paired t-test was administered and the results showed that there was significant difference between two ears at 50 dBnHL \((p < 0.05)\) and at 20 dBnHL \((p < 0.01)\).
Figure 2: The Mean, SD of overall (Males & females combined) pi and ni latency obtained at 80, 50 and 20 dBnHL from right and left ear in individuals with normal hearing.

The Mixed ANOVA showed no difference between the genders and hence the data of pi and ni was combined and shown in the Figure 3. The results also showed that there was no interaction between the intensity, ear and gender for both pi and ni latencies and amplitudes.

Figure 3: Mean and S.D of Overall (Males & Females combined) pi and ni amplitude for right and left ear obtained at 80, 50 and 20 dBnHL in individuals with normal hearing.

The percentage occurrence was around 40% for right ear and 15% for the left ear at 80 dBnHL and it even reduced in both ears at 20 dBnHL. Wilcoxon signed rank test results indicated that there was a significant difference in latency when the intensity was decreased from 80 to 50 dBnHL in the left ear (p < 0.05). It also indicated that there was a significant difference in amplitude when the intensity is decreased from 80 to 20 dBnHL for right ear (p < 0.01) and left ear (p < 0.05). However, no significant difference was found in other intensities for both the ears and also between the ears for pii latency and amplitude.
Figure 4: The click evoked PAMR obtained at 80, 50 and 20 dBnHL in a normal hearing individual.

**Individuals with sensorineural hearing:**

The PAMR was present in 19 ears out of 25 ears of sensorineural hearing loss tested. The PAMR was recorded in mild, moderate, moderately severe, severe hearing loss and profound sensorineural hearing loss. All the individuals who had mild, moderate and moderately severe sensorineural hearing loss had PAMR peaks. However, all the four ears with profound hearing loss did not have any recordable PAMR. Two out of five ears with severe hearing loss also did not have any PAMR.

Karl Pearson correlation coefficient revealed that there was a significant correlation between PTA 1 (average of 500, 1 K and 2 kHz AC thresholds) and PTA 2 (average of 1 K, 2 K and 4 kHz AC thresholds) and PAMR threshold for both right ear and left ear. The results were shown in the Table 2.

Table 2: Karl Pearsons rank correlation coefficient and Mean difference of PTA1 & PTA2 with PAMR thresholds.

<table>
<thead>
<tr>
<th>Thresholds</th>
<th>R - PAMR</th>
<th>L - PAMR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-value</td>
<td>Mean Diff. (dB)</td>
</tr>
<tr>
<td>R - PTA 1</td>
<td>0.844**</td>
<td>4.48</td>
</tr>
<tr>
<td>R - PTA 2</td>
<td>0.816*</td>
<td>5.53</td>
</tr>
</tbody>
</table>

[** p < 0.001 and * p < 0.05]

Note: R-PAMR: Right PAMR thresholds; L-PAMR: Left PAMR thresholds.
R-PTA1: Right PTA (500 Hz, 1 kHz & 2 kHz); L-PTA1: Left PTA (500 Hz, 1 kHz & 2 kHz).
R-PTA2: Right PTA (1 k, 2 kHz & 4 kHz); L-PTA 2: Left PTA (1 kHz, 2 kHz & 4 kHz).

The data obtained for left ear at 50 dBnHL was one and hence, the data obtained at 60 dBnHL was taken for the analysis instead of 50 dBnHL. So, between the ears comparison at 50 dBnHL could not be done. Wilcoxon signed Rank test results showed that there was a significant difference in the pi and ni latency in both ears when the intensity is decreased...
from 90 to 70 dBnHL (P < 0.05). However, there was no statistically significant difference in latency for other intensities in both ears.

Wilcoxon signed rank test also revealed that there was a significant difference was obtained for ni amplitude between 90 and 70 dBnHL for both ears (p < 0.05). Whereas, only for the right ear, there was a significant difference in pi amplitude at 90 and 70 dBnHL (p < 0.05). No other conditions such as between the intensity levels within the ear or between the ears at the same intensity level could show a significant difference.

Figure 5: The click evoked PAMR recorded in a mild sensory neural hearing loss individual.

**Individuals with auditory neuropathy**

PAMR is recorded in 20 ears with auditory neuropathy. Out of 20 ears, only 3 ears had PAMR peaks. One subject who had normal hearing sensitivity in puretone air conduction threshold (both PTA1 and PTA2) in both ears had PAMR responses bilaterally. In right ear, the PAMR threshold was 30 dBnHL and left ear it was 50 dBnHL. Another subject who had mild hearing loss with the PTA 1 of 36.6 dBHL and PTA 2 of 28.3 dBHL also had PAMR response at 90 dBnHL. There was no trend seen in the latency and amplitude of pi and ni with respect to the intensity levels. The amplitudes obtained were much lesser. However, statistical analysis could not be done due to less number of data.

**Group comparisons**

The comparison was made at 80 dBnHL and 50 dBnHL between Group I and Group II. At 50 dBnHL only right ear comparison was made since, the number of data in left ear at 50 dBnHL in group with sensorineural hearing loss was too less. The individuals with auditory neuropathy were not compared with the control group since the number of data available was less and hence statistical analysis could not be done. Mann Whitney U test revealed that there was no significant difference between the two groups in latency and amplitude for both ears.
Discussion

The overall PAMR could be observed in 90% of the individuals with normal hearing at softest intensity levels. The results obtained in this study were consistent with the results obtained by Purdy et al. (2005). The possible reason could be the Excitatory Post Synaptic Potentials (EPSPs) from the auditory neurones probably add to the EPSPs from the eye-rotation neurones to reach action potential threshold with eye rotation (Patuzzi & O’Beirne, 1999 a, b).

The latency of pi and ni is significantly prolonged when the intensity was decreased. The results were consistent with the findings of Yoshie and Okudaira (1969); O’Beirne & Patuzzi (1999) & Purdy et al. (2005). The possible reason could be due to the larger excitatory post-synaptic potentials (EPSPs) in one or more of the neurones in the neural pathway reaching a firing threshold sooner with the higher intensity stimuli than with lower intensity stimuli, thereby initiating action potentials earlier (O’Beirne & Patuzzi, 1999).

The amplitude of pi and ni increased significantly when the stimulus intensity is increased. The findings were similar to the findings by O’Beirne & Patuzzi (1999) and Purdy et al. (2005). There was also large variations seen in the amplitude of pi and ni was seen in the current study. The possible reason could be due to the small average amplitude of the PAMR over many presentations was because of sporadic appearance of the PAMR, rather than by a small PAMR amplitude in every trace (O’Beirne & Patuzzi, 1999). Hence, for the clinical use of PAMR the amplitude measure may not be considered because of its larger variability.

There was a significant difference in ni amplitude across the ears. There was also mean difference noticed in pi amplitude between the ears which was not statistically significant. O’Beirne and Patuzzi (1999) reported that there was an increase in electromyography in the left post auricular muscle with eye rotation to the left and the EMG was largest in the right PAM with eye rotation to the right in two of the subjects tested. However, these authors do not mention about the amplitude difference between the two ears.

The occurrence of pii peak in normal hearing individual was less and even lesser in left ear compared to the right ear. This is in contradiction to the findings of Purdy et al. (2005) where they found about 80% occurrence of pii peaks at 20 dBnHL. The possible reason for lesser percentage of occurrences of pii peak of PAMR in left ear could be due to the lesser amplitude of ni which was significant. Since there is a difference found in the pi and ni amplitude between the two ears with left ear having lesser amplitude the ongoing EMG level would have obscured the presence of pii peak more in left ear. This could be evident since the pii peaks were observed in individuals who had quite larger pi and ni amplitudes and not in the individuals who had lesser pi and ni amplitude.

There was no gender difference seen in individuals with normal hearing. As expected, the same origin would be responsible for the generation of PAMR for both the genders.
The possible reason for the observable PAMR peaks in individuals with severe sensorineural hearing loss could be that the PAMR is a large muscle potential and largely dependent on the EMG rather than the compound action potential of auditory pathway which is responsible for the other neurogenic responses. The stimulus used was greater than their hearing loss and could have been sufficient to produce the PAMR responses through the eye rotation.

The PAMR was not obtained in any of the ears with profound hearing loss. The possible reason could be that PAMR is a myogenic response which is mediated by the auditory pathway. The subjects tested had no responses in behavioral threshold in most of the frequencies. The residual hearing was above 100 dBHL. As the stimulus is not conveyed to the auditory pathway the PAMR did not occur. Hence, the results strongly suggest that the PAMR responses are mediated by the auditory system.

The threshold obtained using the PAMR is highly correlated with the PTA1 and PTA2 of individuals with sensorineural hearing loss. The results were consistent with the findings of Thorton (1975b) and Purdy et al. (2005) were they found significant correlation with 2 kHz and PTA 2 respectively. The possible reason could be that it is likely the high-frequency cochlear regions dominate the click-evoked PAMR, as is seen for click-evoked ABR (Purdy et al., 2005). This could account for the PTA 2 correlation. In the present study PTA1 also well correlated with PAMR thresholds. This could be due to the subject’s pattern of hearing loss. Most of the individuals with hearing loss had flat pattern. There was also very high correlation between PTA1 and PTA2 in the present study. The latency increased and amplitude decreased with decrease in intensity similar to individuals with normal hearing. Possibly, same mechanism would have involved in both the groups.

Hence, PAMR can be used as an alternative tool to measure the hearing sensitivity in hearing impairment when ABR could not be done due to increased level of EMG. PAMR can also be used for threshold estimation for difficult to test population since the PAMR thresholds were better correlated with audiometric threshold.

The number of individual with auditory neuropathy for whom the PAMR was observed was meagre. The possible reason for absence of PAMR in individuals with auditory neuropathy could be due to the altered temporal processing and auditory dysynchrony of the auditory nerve. From this finding it is clear that PAMR is not an effective objective tool to measure the hearing sensitivity in individuals with auditory neuropathy.

The latency of pi and ni obtained in one individual did not show any trend with respect intensity levels. For decrease in latency with increase in the intensity levels greater degree of synchronous firing of auditory nerve is required. Since there was a dysynchrony in the firing of the auditory nerve the threshold for reaching the action potential for PAMR would have been similar across the intensity levels. However, it requires more number of data to confirm these findings.

There is no statistically significant difference in latency and amplitude of pi and ni between the individuals with normal hearing and individuals with sensorineural hearing loss.
The possible reason could be that the cochlear damage may not disrupt the neural processing to that extent where the trigger for PAMR is affected, unlike the auditory dysynchrony. Moreover, the synchrony of the auditory nerve could have been preserved in individuals in sensorineural hearing loss.

**Conclusion**

It could be concluded from the study that PAMR is an effective tool to measure the hearing sensitivity when recorded with eyes turn condition. It can be used to estimate the behavioral threshold precisely when the subjects are more tensed and may not relax and also when the ongoing EMG activity is very high. It can also be used to estimate the behavioral threshold in difficult to test population since it requires lesser time than other evoked potentials. PAMR is not an effective tool to estimate the behavioral threshold in auditory neuropathy.

**References**


Verification of Hearing Aid Selection Using Visible Speech and Speech Intelligibility Index

Kurode Nikhil Prakash & Dr. P. Manjula*

Abstract

Verification of hearing aid selection is a major step in the hearing aid fitting process. For verification of hearing aid performance, functional gain measurement for warble tone or speech material and real ear measurements (REM) using tones, composite signals and speech like stimuli are used. The traditional REM utilizes composite noise signals which are not encountered routinely in real life situations and hence inappropriate for testing high end digital hearing aids. The present study was taken up to verify the selection of hearing aids using actual speech. Visible speech measure along with speech intelligibility index was utilized for verification of hearing aid selection. The participant group comprised of 30 naïve hearing aid users, with post-lingual onset of hearing loss. Individuals with hearing impairment were divided into three groups based on degree of hearing loss. Fonix 7000 hearing aid analyzer was used for the traditional real ear measurement protocol which utilizes ANSI-digi speech as stimulus while the visible speech protocol used actual recorded speech. Speech intelligibility index was also tabulated from the visible speech display screen. Speech identification scores were obtained in two different conditions, i.e., when the hearing aid was optimized using traditional real ear aided gain using ANSI-digi speech signal, and other condition was when the hearing aid was optimized using visible speech measure. Findings of the present study reveal that verification of hearing aid using visible speech protocol led to higher speech identification scores. Also, there was a positive correlation between speech identification scores and speech intelligibility index. Hence, verification of hearing aid selection using visible speech protocol and speech intelligibility index yield better performance in individuals with varying degree of hearing loss.

Key Words: Traditional REM, ANSI-digi speech signal, Speech identification scores.

Introduction

The major components in selection and fitting of hearing aid include hearing assessment, pre-selection of hearing aid, fitting, verification, orientation or counselling, and real-world validation (Mueller, 2005). The verification forms one of the major components of this comprehensive protocol. For verification of hearing aid performance, (i) predetermined set of data or fitting target, (ii) functional gain measurement for warble tone and speech material (Burney, 1972), (iii) Real ear measurements (REM) using tones, composite signals and speech like stimuli (Dillon & Keidser, 2003). Of late, real speech or visible speech is being used as a stimulus in REM for the verification of the hearing aid. In addition, Speech intelligibility index (SII) is also being used as one of the reliable verification methods for the selection of hearing aid selection (Cox, Alexander & Revera, 1991).

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The visible speech measure can be used to accomplish verification of hearing aid selection during real ear measurements (Ross & Smith, 2005). ‘Visible Speech’ also known as ‘Live Speech Mapping’ (LSM) is the fitting processes that uses probe microphones and live / recorded real-time speech to allow the client and their family members to immediately see and understand the benefits of hearing aids and fitting adjustments. The visible speech utilises “real-time speech”, that of a family member, friend, or familiar third party, for real-ear measurements. One key difference between this technology and other verification tools is that it allows the client and family to clearly understand the results and realize an immediate and positive impact on their hearing as the programming of their hearing aid is changed.

The SII is calculated from the speech spectrum, the noise spectrum, and the listener’s hearing threshold. The SII is determined by accumulation of the audibility across the different frequency bands, weighted by the band importance function. The resulting SII is a number between zero and unity. The SII can be seen as the proportion of the total speech information available to the listener. An SII of zero indicates that no speech information is available to the listener; an SII of unity indicates that all speech information is available.

Need for the study

They are many shortcomings of functional gain measurement in the fitting of the hearing aids. The FG is a subjective test. When speech is used for the measurement of functional gain, it does not assist in making frequency-gain adjustments and also does not reflect which electro-acoustic characteristics that would contribute to better or poorer aided performance. On the other hand, there are various limitations of REM such as they are often made with either tonal or noise stimuli rather than the actual speech. The non-linear digital hearing aids do not faithfully produce the actual gain or output when such test signals are being used. Also, clients find it difficult to relate the data shown on insertion gain and the audibility of actual speech (Poe & Ross, 2005).

To overcome this disadvantage of REM, the REM is carried out using the actual speech that may aid in hearing aid selection. Visible Speech allows the professional to record and demonstrate the appropriateness of the hearing aid fitting while reviewing, demonstrating, and explaining the process in terms the patient understands - based on human speech and the Speech Intelligibility Index (SII). Hence, visible speech along with SII would be of great value to audiologists in determining the performance of a client in real-life situations. It would add to the objectivity and better understanding of the hearing aid benefit by the client.

Aims

The aim of the present study was to investigate the usefulness of visible speech during real ear measurements for selection of hearing aid by

1. Comparing the verification of hearing aid selection done by visible speech with that of real ear aided gain measurements.
2. Comparing the verification of hearing aid selection done by visible speech with that of speech identification scores.

3. Comparing the verification of hearing aid selection done by visible speech with that of speech intelligibility index.

**Method**

**Participants**

30 individuals with hearing loss in the age range from 18 years to 75 years (mean age of 52.6 years) participated in the study. They had hearing loss of post-lingual onset and native speakers of Kannada with had adequate speech-language skills. They had flat configuration and sensori-neural type of hearing loss with pure-tone average (PTA) ranging from 41 to 90 dB HL. Their speech identification scores were ≥70%. In the present study, flat type of configuration was operationally defined as the configuration in which the maximum threshold difference between any of the frequencies on the audiogram being not more than 20 dB HL (Pittman & Stelmachowicz, 2003). Individuals with indication of retro-cochlear involvement or central auditory processing disorder or cognitive deficits were excluded from the study. The participants were divided into three groups - moderate, moderately-severe and severe hearing loss group - based on the degree of hearing loss.

**Instrumentation**

A calibrated sound field audiometer, two commercially available digital BTE hearing aids, two personal computers, one connected to the auxiliary input of the audiometer for presentation of speech material which was recorded on a CD. The other personal computer, with NOAH (version 3.1.2) and hearing aid specific software connected to the HI-PRO, was used to programme the digital hearing aids. In addition, this latter personal computer with WinCHAP software was used to perform the real ear measurements in all the participants. A calibrated Fonix 7000 hearing aid testing system was used for performing the real ear measurements through WinCHAP.

**Test material**

The phonemically balanced (PB) word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used in the study. The speech material consisted of four phonemically balanced word lists and each list had 25 words. The speech material was digitally recorded using Adobe Audition - 2 software in an acoustically treated room, on a data acquisition system using 44.1 kHz sampling frequency and 16 bit analog to digital converter. A standardized recorded Kannada story (Sairam, 2002) with all the speech sounds of the language was used as the stimulus for the measurement of visible speech and speech intelligibility index.
Procedure

The testing was carried out in an air-conditioned single or double room sound treated environment. The experiment was carried out in the three stages for each of the two hearing aids, for each participant.

Stage 1. Hearing aid programming to for NAL-NL1 prescription

Stage 2. Optimization of hearing aid using

2.1. Traditional real ear measurement protocol
2.2. Visible speech protocol

Stage 3. Verification using speech identification scores

3.1. Speech identification scores: Hearing aid optimized for traditional real ear measurement protocol
3.2. Speech identification scores: Hearing aid optimized for visible speech protocol

Stage 1: Hearing Aid Programming for NAL-NL1 prescription

The participant was fitted with programmable digital behind-the-ear (BTE) hearing aid. The hearing aid was connected to a personal computer through a HI-PRO interface unit. The NOAH software (version 3.1.2) along with hearing aid specific software (Electone Connexx V6.1 & Aventa 2.6) was used to programme the hearing aid for the participant. Initially, the hearing aid was programmed with NAL-NL1 using the first fit feature in the software. It should be noted that the fine-tuning of the hearing aid was not attempted at this stage.

Stage 2: Optimization of hearing aid

Hearing aid was optimized using the traditional real ear measurement protocol and the visible speech protocol.

2.1 Optimization of hearing aid using traditional real ear measurement protocol

In this stage, the hearing aid was optimized for NAL-NL1 targets using traditional real ear measurement protocol which utilizes ANSI-digi speech like stimulus as the input signal.

Once the equipment was set-up, the traditional real ear measurement was carried out using Fonix 7000 and WinChap. That is, the real ear unaided measurement for ANSI digi speech signal at 65 dB SPL was carried out. The 65 dB SPL ANSI-digi speech signal that was presented through the loudspeaker of Fonix 7000 was picked up by the probe tube mic in the unaided ear canal. The Fonix 7000 measured this signal in the unoccluded ear canal.

For real ear aided gain (REAG), the hearing aid was fitted on the participant without disturbing the length of probe tube in the ear canal. The hearing aid was switched on. The test protocol as shown in Table 1 was followed for REAG measurement. The probe tube microphone in the aided ear canal picked up the sound from the ear canal for REAG
measurement. During the measurement, it was ensured that the REAG matched the NAL-NL1 targets at most of the frequencies. This was done by optimizing the hearing aid parameters to meet NAL-NL1 the target at moderate level input.

Table 1: Protocol for REUG / REAG and Visible Speech.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>REUG / REAG Protocol</th>
<th>Visible Speech &amp; SII protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of the Stimulus</td>
<td>Digi-Speech, ANSI</td>
<td>Recorded paragraph in Kannada</td>
</tr>
<tr>
<td>Level of stimulus :</td>
<td>65 dB SPL</td>
<td>65 dB SPL</td>
</tr>
<tr>
<td>Location of integrated probe microphone set :</td>
<td>Participant’s pinna</td>
<td>Participant’s pinna</td>
</tr>
<tr>
<td>Reference microphone :</td>
<td>Enabled, located over pinna</td>
<td>Enabled, located over pinna</td>
</tr>
<tr>
<td>Prescriptive formula:</td>
<td>NAL-NL1</td>
<td>NAL-NL1</td>
</tr>
<tr>
<td>Output limiting:</td>
<td>125 dB SPL</td>
<td>125 dB SPL</td>
</tr>
</tbody>
</table>

2.2 Optimization of Hearing Aid using Visible Speech Protocol

In this particular stage, the hearing aid was optimized for NAL-NL1 targets using visible speech protocol which utilizes actual speech as the input signal. The participants was seated in the calibrated position in the sound field with speech material (Standardized Kannada passage) being presented through the loud speaker of the audiometer positioned at $45^\circ$ Azimuth and at a distance of 1 meter. The hearing aid was fitted on the participant without disturbing the location of probe tube in the ear canal. The hearing aid was switched ‘on’.

The participant’s audiogram was entered in the Fonix 7000 to generate mid-level target (65 dB SPL). The external signal, a Kannada story passage was played through windows media player in the computer. This was routed through an audiometer. The output from audiometer was given to the loudspeaker. This signal was picked up by the hearing aid worn by the participant. The Visible Speech measurement on the Fonix 7000 analyzer was initiated.

If the output of the hearing aid did not match the desired target level, then the hearing aid was further optimized. The hearing aid was optimized to match the visible speech targets based on the visible speech procedure. Once the hearing aid output matched the real ear NAL-NL1 targets at most of the frequencies then the following data that was displayed on the monitor of PC were tabulated for each participant for the purpose of analysis.

1. RMS amplitude in dB SPL, of the response of visible speech spectrum.
2. Response amplitude in dB SPL, of visible speech spectrum at 250 Hz, 500 Hz, 750 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz.
3. Speech Intelligibility Index, SII (re: ANSI S3.5 - 1997). The SII ranged from 0 to 100, 0 indicating that no audibility of speech signal and 100 indicating the complete audibility of speech signal.
Stage 3: Verification of Hearing Aid using Speech Identification Scores

Speech identification scores were obtained with the hearing aid being optimized with traditional REAG with ANSI-digi speech as well as with visible speech measure.

3.1 Speech identification scores with hearing aid optimized using traditional real ear measurement protocol

Speech identification scores (SIS) were obtained in aided conditions when hearing aid was optimized using traditional real ear measurement protocol, i.e., ANSI-digi speech. The aided speech identification scores were obtained once the hearing aid real ear aided gain matched the NAL-NL1 targets, using traditional real ear measurement protocol. The participant was comfortably seated in the test room at a distance of 1 meter and 45° Azimuth from the loudspeaker of the audiometer on the side of the aided ear. The presentation level was kept constant at 45 dB HL.

The participant was instructed to repeat the recorded words being presented through the loudspeaker of the audiometer. The responses were scored on a response sheet as the number of words correctly identified. The maximum score was 25 as each list consisted of 25 words. Each correct response was given a score of 1 and each incorrect response was given a score of 0.

3.2 Speech identification scores with hearing aid optimized using visible speech protocol

Speech identification scores were obtained in aided condition when hearing aid was optimized using visible speech protocol. The aided speech identification scores were obtained once the hearing aid output matched NAL-NL1 targets using recorded speech as the input signal. The same procedure as described above was followed to obtain SIS in this stage.

Results and Discussion

Statistical Package for Social Sciences, SPSS (version 16 for windows) was used for analyses of the data. To compare the REAG for ANSI-digi speech signal, visible speech measure, speech intelligibility index and speech identification scores, the correlation analysis was done both collectively on all the participants and independently on each group.

Real Ear Aided Gain using ANSI-Digi Speech Signal
Table 2: Mean and Standard Deviation (SD) of target gain and REAG with two hearing aids, HA 1 & HA 2, for the three groups of participants.

<table>
<thead>
<tr>
<th>Freq. (Hz)</th>
<th>HA</th>
<th>Group I (N= 10)</th>
<th>Group II (N= 10)</th>
<th>Group III (N= 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target Gain (dB)</td>
<td>REAG (dB)</td>
<td>Target Gain (dB)</td>
<td>REAG (dB)</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>250</td>
<td>HA1</td>
<td>7.52</td>
<td>7.01</td>
<td>2.87</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>6.85</td>
<td>3.51</td>
<td>12.72</td>
</tr>
<tr>
<td>500</td>
<td>HA1</td>
<td>15.06</td>
<td>17.34</td>
<td>3.09</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>15.48</td>
<td>5.56</td>
<td>22.99</td>
</tr>
<tr>
<td>1000</td>
<td>HA1</td>
<td>27.97</td>
<td>31.24</td>
<td>3.05</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>30.86</td>
<td>2.52</td>
<td>36.56</td>
</tr>
<tr>
<td>1500</td>
<td>HA1</td>
<td>33.27</td>
<td>36.26</td>
<td>2.70</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>37.15</td>
<td>2.67</td>
<td>44.22</td>
</tr>
<tr>
<td>2000</td>
<td>HA1</td>
<td>38.5</td>
<td>39.65</td>
<td>3.01</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>40.85</td>
<td>3.22</td>
<td>48.44</td>
</tr>
<tr>
<td>3000</td>
<td>HA1</td>
<td>37.56</td>
<td>36.89</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>36.20</td>
<td>2.72</td>
<td>44.67</td>
</tr>
</tbody>
</table>

The mean and standard deviation (SD) of the REAG for ANSI-digi speech signal for the three groups of participants with two hearing aids (HA1 & HA2) is given in Table 2. It can be observed from the Table 2 that the target gain as per NAL-NL1 is least in the group with moderate hearing loss (HL). As the hearing loss increased, target gain was increased and the group with severe HL showed highest target gain values. The measured real ear aided gain showed the similar trend as that of the target gain. The real ear aided gain was least in group with moderate HL and highest in the group with severe HL.

Bryne and Dillon (1986) performed real ear measurements recommended by NAL fitting method. In their opinion, the fitting was considered acceptable if the difference between the target and the measured values is within ±10 dB. In another study by Aahz and Moore (2007), the frequency-gain response of the hearing aid was modified to better match the NAL-NL1 target better. The investigators had used ±10 dB criteria to consider that the target gain and measured REAG were matched. In the present study too, the difference between the mean target gain and mean measured REAG values for the two hearing aids was within ±10 dB at all the frequencies. Hence, it can be inferred that the REAG matched the NAL-NL1 target at all the frequencies in Group I. Similar results were obtained in the other two groups of participants (Groups II & III).
Visible Speech

The mean and standard deviation (SD) of the Visible Speech amplitude is shown in Table 3. It can be observed from the Table 4.2 that the target values as per NAL-NL1 were least in group with moderate HL.

Table 3: Mean and Standard Deviation (SD) of target and aided VS response with two hearing aids, HA1 & HA2, for three groups of participants.

<table>
<thead>
<tr>
<th>Freq. (Hz)</th>
<th>HAs</th>
<th>Groups based on severity of hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Group I (N= 10)</td>
</tr>
<tr>
<td></td>
<td>Target Response</td>
<td>Mean</td>
</tr>
<tr>
<td>250</td>
<td>HA1</td>
<td>58.60</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>60.40</td>
</tr>
<tr>
<td>500</td>
<td>HA1</td>
<td>65.40</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>66.00</td>
</tr>
<tr>
<td>1000</td>
<td>HA1</td>
<td>74.90</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>74.80</td>
</tr>
<tr>
<td>1500</td>
<td>HA1</td>
<td>78.50</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>80.00</td>
</tr>
<tr>
<td>2000</td>
<td>HA1</td>
<td>83.00</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>82.10</td>
</tr>
<tr>
<td>3000</td>
<td>HA1</td>
<td>78.70</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>77.70</td>
</tr>
<tr>
<td>4000</td>
<td>HA1</td>
<td>75.70</td>
</tr>
<tr>
<td></td>
<td>HA2</td>
<td>73.20</td>
</tr>
</tbody>
</table>

As the hearing loss increased, the target values increased, and the target values were highest in the group with severe HL. The visible speech measure showed the similar trend as that of the target curve. The visible speech measure was least in the group with moderate HL and highest in the group with severe HL. This finding is similar to that noted for the traditional REAG.

The investigators in the past have used ±10 dB criteria to determine if the targets are matched by the measured real ear measures (Bryne & Dillon, 1986; Aahz & Moore, 2007). In the present study, the difference between the target and measured visible speech measures was within ±10 dB except at 2 kHz for hearing aid 1 and at 4 kHz for both the hearing aids, in the group with severe HL. Visible speech measures requires more amplification in high frequencies than the traditional real ear aided gain. In groups with moderate and moderately-severe HL, further increase in high frequency gain was possible in both the hearing aids which helped in matching the target curve at high frequencies also. In contrary to that, hearing aid gain could not be further increased in group with severe HL to match 2 kHz and 4 kHz targets as the maximum gain limit of the hearing aid in these frequency regions was reached.
Speech Intelligibility Index

Speech intelligibility index (SII) was tabulated from the visible speech display screen of Fonix 7000 for all the participants. The speech intelligibility index showed variability across different groups in mean and standard deviation (SD), as shown in Table 4. As expected, the SII was maximum in the group with moderate hearing loss (HL) followed by groups with moderately-severe and severe HL, for both the hearing aids.

The SII reflected the amount of acoustic cues available to the participants with hearing loss, in the aided condition. Thus, the speech intelligibility index decreased as the amount of hearing loss increased. The SII is also based on the audibility of the signal presented to the individual with hearing loss (Cox, Alexander & Rivera, 1995). In participants with moderate hearing loss, more acoustic cues were available compared to those with higher degree of hearing loss. Hence, individuals with moderate degree of hearing loss obtained a higher SII compared to the other two groups.

Table 4: Mean and Standard Deviation (SD) of Speech Intelligibility Index with two hearing aids, HA1 & HA2, for three groups of participants.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Hearing Aids</th>
<th>Groups based on severity of Hearing Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Group I</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>SII</td>
<td>HA 1</td>
<td>84.40</td>
</tr>
<tr>
<td></td>
<td>HA 2</td>
<td>81.30</td>
</tr>
</tbody>
</table>

Speech Identification Scores

Speech identification scores were measured in two different conditions, i.e., when the hearing aid was optimized using REAG for ANSI-digi signal and later when the hearing was optimized using visible speech measurement. Mean and standard deviation (SD) of the aided speech identification scores revealed variations in the aided speech identification scores across the groups and conditions as shown in Table 5.

Table 5: Mean and standard deviation (SD) of the aided speech identification scores (SIS).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hearing Aids</th>
<th>Aided SIS (Max = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Group I</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>HA optimized using REAG</td>
<td>HA 1</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>HA 2</td>
<td>17.8</td>
</tr>
<tr>
<td>HA optimized using Visible Speech</td>
<td>HA 1</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>HA 2</td>
<td>19.8</td>
</tr>
</tbody>
</table>
The mean SIS with the hearing aid optimized using visible speech condition was slightly greater than that when the hearing aid was optimized using REAG for ANSI-digi speech signal condition. This suggests that the hearing aid optimized using visible speech yielded a higher SIS than compared to hearing aid optimized using ANSI-digi speech signal. In group III, the difference in SIS was the least when the hearing aid was optimized with REAG using ANSI-digi speech signal and when optimized using visible speech. This reflected the fact that the available gain or audibility was not sufficient to improve the SIS for group with severe HL. This reflected the difference in mean target and visible speech response for the group with severe HL.

The paired t-test was performed to determine the significant difference between the two experimental conditions, i.e., when the hearing aid was optimized using REAG for ANSI-digi signal and later when the hearing was optimized using visible speech measurement. The paired t-test was performed on each group separately. There was a significant difference between SIS obtained when HA was optimized using ANSI-digi speech signal and SIS obtained when HA was optimized using visible speech protocol in the groups with moderate HL and moderately-severe HL (p<0.001), with higher SIS obtained when HA was optimized using visible speech protocol.

The speech identification scores obtained when hearing aid was optimized using visible speech, showed an increase in mean scores of SIS in moderate and moderately-severe groups of participants as against hearing aid optimized using ANSI-digi speech signal. The increase in SIS could be attributed to increased audibility in high frequencies when hearing aid is programmed using visible speech. There was no statistically significant increase in SIS for group with severe HL. This finding can be attributed to the inability to further increase hearing aid gain in high frequencies as compared to REAG condition in the Group III. Overall, there was an improvement in speech identification of individuals with hearing loss when hearing aid was optimized using visible speech.

Comparison of different test measures

Correlation between traditional REAG and Visible speech measure

The real ear aided gain for ANSI-digi speech signal obtained separately at each frequency (250 Hz, 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz & 4 kHz) were correlated with that of the visible speech measure. Pearson’s correlation was administered between the REAG values and VS values for both the hearing aid conditions. A significant positive correlation was obtained between REAG and visible speech measures when the analysis was carried out on all the 30 participants (p<0.01).

Correlation between RMS amplitude of REAG and visible speech measure

RMS amplitude was measured for both the types of real ear measurements, i.e., REAG and visible speech. The mean and standard deviation (SD) of RMS amplitude for REAG and VS are given in Table 6.
Table 6: Mean and Standard deviation (SD) for RMS amplitude for REAG and visible speech measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Hearing Aids</th>
<th>RMS amplitude (dB SPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group I</td>
<td>Group II</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>REAG</td>
<td>HA 1</td>
<td>95.98</td>
</tr>
<tr>
<td></td>
<td>HA 2</td>
<td>94.03</td>
</tr>
<tr>
<td>Visible Speech</td>
<td>HA 1</td>
<td>93.70</td>
</tr>
<tr>
<td></td>
<td>HA 2</td>
<td>93.00</td>
</tr>
</tbody>
</table>

The mean RMS amplitude of REAG and Visible Speech varied across the three groups of participants. The RMS amplitude of both the measures was highest in the group with severe HL and least in the group with moderate HL. In other words, as the degree of hearing loss increased, the RMS amplitude of both the REAG and Visible Speech measures increased. This was due to the hearing aids with higher gain and output used for higher degrees of hearing loss.

Pearson’s correlation was performed on the RMS amplitude of REAG and RMS amplitude of visible speech. A significant correlation was obtained between RMS average amplitude of REAG and visible speech when the analysis was carried out on all the 30 individuals with hearing loss (p<0.01). This suggests that the RMS amplitude of visible speech and REAG measure can be used interchangeably in verification of hearing aid fitting. Further, Pearson’s correlation was carried out separately for each of the three groups. Pearson’s correlation demonstrated no significant correlation between RMS average amplitude of REAG and visible speech in each of the three groups (p >0.05).

Correlation between Speech identification scores, Speech intelligibility index and RMS amplitude of visible speech.

Pearson’s correlation was carried out between speech identification scores, speech intelligibility index, RMS amplitude of visible speech for both hearing aids. Following results were found

a. A significant correlation between RMS amplitude of visible speech and speech identification scores was also revealed when the analysis was carried out on all the 30 individuals with hearing loss (p<0.01).

b. A significant positive correlation was obtained between speech identification scores and speech intelligibility index when the analysis was carried out on all the 30 individuals with hearing loss (p<0.01).

c. A significant correlation between speech intelligibility index and RMS amplitude of visible speech was also obtained when the analysis was carried out on all the 30 individuals with hearing loss (p<0.01).
The visible speech measures would be beneficial to verify hearing aids as it would provide both electroacoustic performance of the hearing aid as well as the speech understanding abilities of the individual through SII. Speech intelligibility index which is being displayed on the visible speech screen would provide necessary information about the amount of audible cues present to the hearing aid user. In the present study, visible speech along with speech intelligibility index has been proved to be a efficient verification tool in the hearing aid selection.

Further, traditional real ear measurements have been clinically adopted for the verification of hearing aids (Hawkins & Cook, 2003; Mueller, 2003, Van Vliet, 2003). But, the major disadvantage of traditional real ear measurements (e.g. REAG) is the use of composite noise signals as an input signal to hearing aids (Moore, 2006). These are the signals which are of lowest concern when hearing aid has to perform in real-life situations. The most common signal one is exposed to is the speech stimuli. Hence, verifying hearing aid fitting with composite signal would not give an indication of the performance of a hearing aid in real-life situations.

Visible speech may be the solution to this problem. According to Moore (2006), using visible speech, effective amplification provided by the hearing aid can be assessed using realistic signals such as speech or music and with the aid in its normal mode of operation (with features such as feedback cancellation and noise reduction enabled). Thus, the influence of factors such as number and bandwidth of channels, compression speed, etc., is automatically taken into account. The gains actually achieved for real-life signals such as, speech and music, may differ considerably from the gains measured with steady signals, such as tones and noise (Moore, 2006). The difference depends on the number of channels in the hearing aid, the speed of the compressors, and the compression thresholds. This is the case even when features such as noise reduction or feedback cancellation are not present or are not activated.

To summarize the results, visible speech measure obtained a good correlation with the traditional REAG and SII. Also, there was a positive correlation between SIS and SII. The speech recognition scores improved when hearing aid was optimized using visible speech protocol than compared to traditional real ear measurement protocol. Hence, visible speech along with SII proves to be a better verification tool for the selection of hearing aid.

From the results of the study, it can be inferred that the visible speech measure proves to be a valuable tool for audiologists. It allows markedly improved accuracy in the verification and fitting of hearing aids. It also provides an immediate indication of the audibility of important everyday signal such as speech, including the speech of family members or relatives. Visible speech measure makes it possible to adjust the parameters of hearing aids to optimize the audibility of speech while avoiding loudness discomfort. It involves the client and their relatives in the fitting process, leading to greater understanding and satisfaction, and it is likely to reduce the number of post-fitting visits, saving time and money.
The findings of the present study have important clinical implications. The visible speech protocol is an effective verification tool for the selection of hearing aids. The implementation of visible speech protocol for verification of hearing aid selection withdraws guesswork of an audiologist about the performance of a hearing aid in the real-life situations. The speech intelligibility index provides an indication of speech intelligibility of a hearing aid user. The SII is also displayed on the visible speech measurement screen. Hence, the visible speech along with SII proves to be a valid objective tool for the verification of hearing aid selection.

References


Development and Standardization of Spondee and Phonetically Balanced (PB) Word Lists in Mizo Language

Lalhmangaihi & Vijayalakshmi Basavaraj*

Abstract

The aim of the study was to develop and standardize Spondees and PB words in Mizo language that can be used to measure the Speech Recognition Threshold (SRT) and Speech Identification Scores (SIS) for native speakers of Mizo, a language spoken in Mizoram, India. Method: Two lists each of Spondees and PB words with high familiarity were developed as per standard procedures and the SRT and SIS evaluated for 100 (one hundred) native speakers of Mizo language in the age ranged between 18 years to 40 years, with normal hearing. Performance – intensity function for each word lists were evaluated at 6 intensity levels (0 to 10 dBSL) in 2 dB increments. To establish the reliability of these materials, 10% of the subjects were retested after a minimum period of 5 days. Results: No significant differences were found between the two Spondee lists and PB word lists for both the right and the left ear across gender. The two lists of spondaic words and PB words yielded equivalent SRTs and SIS (at 40 dB SL, ref: SRT). For the spondees at different presentation levels, there was a significant difference in scores between spondee lists I & II at lower presentation levels (0 dBSL to 4 dBSL). However, as the presentation level increases, no significant difference in scores were found and at 10 dBSL of presentation, the scores of list I & II were equal. There was no significant difference in scores between PB word lists 1 & 2 at six different levels of presentation (0 dBSL to 10 dBSL).

Introduction

Hearing Assessment

A comprehensive evaluation of an individual's hearing acuity requires several different types of diagnostic techniques. A commonly utilized procedure is pure-tone audiometry.

a) Pure Tone Audiometry: This procedure assesses the thresholds at which a listener is able to detect sinusoidal frequencies. Pure-tone testing is a relatively quick and reliable method to obtain an assessment of an individual's ability to detect specific frequencies. However, to accurately evaluate a listener's ability to comprehend the more complex acoustic signals such as speech, additional auditory tests need to be performed.

b) Speech Audiometry: Speech audiometry is a procedure that is used to evaluate a listener’s ability to hear, recognize and understand speech communication (ASHA, 1988; Young, Dudley, & Gunter, 1982). This type of assessment is valuable in the diagnosis of peripheral and central auditory disorders, evaluation of hearing aid candidacy,

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assessment of hearing aid performance, as well as locating possible lesions within the auditory system. In addition, speech audiometry can be used to validate previously obtained pure-tone average (PTA) results.

**Diagnostic significance of Speech Audiometry**

Speech Audiometry serves many clinical purposes. The basic purpose is to quantify the listener's hearing level for speech. Speech audiometry is often utilized as a diagnostic tool in determining whether a hearing impairment exists (Bell & Wilson, 2001) and whether the impairment is conductive, sensory, or neural (Egan, 1979; Hagerman, 1984). It is also helpful in diagnosing central and peripheral auditory disorders (Jerger et al, 1983) as well as being used to assess performance and function of cochlear implants (Dowell et al, 1986; Cowan et al, 1997; Sarant et al., 2001). It provides more information than pure-tone audiometry concerning a person’s hearing impairment because it analyzes not only residual hearing threshold but also sound distortion, loudness, localization, and speech comprehension (Martin, 2001). It serves as a validity check for the pure tone audiometry. Speech Identification (SI) on the other hand makes it possible to evaluate the functional integrity of the auditory system. The poorer the SI scores, greater is the involvement of sensori-neural mechanism. SI scores can be used to differentiate cochlear pathology to retrocochlear pathology in addition with other test results (Goetzinger, 1972).

Using speech audiometry, audiologists set out to answer questions regarding patients’ degree of hearing loss for speech, the levels required for the speech to be most comfortable, uncomfortable loudness levels, the range of comfortable loudness and perhaps most importantly, their ability to recognize the sounds of speech. Speech-language pathologists and audiologists use findings of speech audiometry in both therapy planning and counseling (Martin & Clark, 2003).

Various kinds of speech stimuli have been used to determine the SRT. They are sentences, connected discourse, spondaic words, spoken digits etc. the kind of stimuli used for speech discrimination testing are monosyllables, nonsense syllables, synthetic speech etc. For the estimation of SRT, spondaic words are the most widely used test stimuli and mono syllabic words in case of SI tests (Carhart, 1971).

**Need for the study**

High-quality, standardized speech audiometry materials have been developed and used extensively in English. Since India is a multilingual country, there is a need to develop the language specific test material. Several Speech Recognition Tests have been developed in Indian languages, such as, Spondaic word lists in Tamil, Telugu and Malayalam by Kapur (1971), SRT Test for adults and children in Kannada by Rajashekhar (1976), Speech Test material in Manipuri by Tanuza (1984), SRT Test in Bengali by Ghosh (1986), SRT Test in Gujarati by Mallikarjuna (1990) and SRT Test in Oriya by Behera (2004).

Mizo is a language spoken in the North-Eastern state of Mizoram, with a population of 9 lakhs. This kuki-chin branch of Tibeto-Burman language is unique in the sense that it is tonal in nature, having 5 vowels and 28 consonants.

No speech test material for evaluating the speech recognition threshold and speech identification ability is available in Mizo language. Hence, there was a need to develop and standardize speech material in Mizo for assessing the hearing abilities of subjects who know only Mizo language.

**Aims & objectives of the study**

The main objectives of the study were:

1. Construction of a bisyllabic word list to assess speech reception threshold in Mizo language
2. Construction of a monosyllabic word list to assess speech identification scores in Mizo language.
3. Standardization/normallization of the lists prepared.

**Method**

The study was conducted with an aim to develop and standardize spondees and phonetically balanced word lists for speech recognition and identification tests in Mizo language. The study was carried out in two stages:

Stage I: Construction of test material for the Speech Recognition Threshold Test and Speech Identification Tests.

Stage II: Standardization of the test material using Mizo speaking adult subjects.

**Stage 1: Construction of the test material**

a) Obtaining familiar, equally stressed bisyllabic words and monosyllabic (cvc) words

b) Constructing lists of bisyllabic and monosyllabic words.
a) Procedure of familiarity

In the absence of documents on phonemic and morphophonemic counts in Mizo language, familiar bisyllabic and monosyllabic words were selected randomly from different sources like magazines, newspapers, books and telephonic conversations of individuals fluent in the language. From a corpora of about 1,00,000 words, familiar 713 bisyllabic and 414 monosyllabic words were selected randomly. A linguist who is familiar with Mizo language was consulted to confirm whether the bisyllabic/ monosyllabic words selected were indeed bisyllabic or monosyllabic respectively.

To further ensure familiarity of the words selected, they were given to 20 normal adults in the age range of 18 years to 40 years, whose mother tongue was Mizo. The subjects were asked to rate the words on a three-point scale of familiarity (i.e., most familiar, familiar and unfamiliar). Words rated as ‘most familiar’ to 90% of the subjects were selected for inclusion in the test lists.

b) Construction of the lists:

For the SRT testing, two lists (List I and II) were developed consisting of 25 bisyllabic words each. It was ensured that each list has all the phonemes of the language and equal stress maintained on both the syllables of the bisyllabic word.

For the SI testing, two lists (List 1 and List 2) were developed consisting of 50 monosyllabic words each. The phonemic balance in the word lists were done based on the frequency of occurrence of phoneme in Mizo. Due to unavailability of documents on frequency count of occurrence of a phoneme in Mizo language, the frequency of occurrence of each phoneme in the same corpora was taken. The number of times each phoneme occurred in the corpora was tallied and counted, and then their percentage of occurrence was calculated and ranked in the order of decreasing frequency. The ranking was divided into 4 equal quadrants. The 1st quadrant consisted of sounds occurring very frequently, the 2nd and 3rd quadrants consisted of sounds occurring frequently and the 4th quadrant consisted of sounds not occurring frequently. The relative frequency of occurrence of phonemes in Mizo language was kept in mind while choosing the words with different phones in the list. Thus the phonemic balance was maintained in each of the lists.

Stage II: Obtaining normative data

One hundred (100) adults in the age range of 18 years to 40 years (mean age 25 years) were selected for obtaining normative data. The subjects who participated in the familiarity rating were excluded from this group. The subjects met the following criteria to be considered for the study:
i) Hearing sensitivity within normal limits i.e. air conduction thresholds less than or equal to 15 dBHL at all frequencies from 250 Hz to 8 KHz for both the ears.

ii) Have normal middle ear functioning.

iii) Do not have any history/presence of otological problems.

iv) Do not have any speech problems

v) The mother tongue and language spoken at home is Mizo, a language spoken in the state of Mizoram, in India.

Instrumentation

i) A calibrated two channel diagnostic audiometer (OB 922), with TDH-39 headphones housed in MX-41/AR ear cushion, calibrated in accordance with ANSI, 1996 S3.6 was used for initial hearing assessment as well as to carry out speech audiometry.

ii) A calibrated GSI-Tympstar Immittance meter to ensure normal middle ear condition in the subjects.

iii) Philips CD player, which fed the recorded speech material to the tape input of the audiometer which in turn was fed to the earphone (TDH-39) housed in MX-41/AR cushions.

Test environments

The test was carried out in a sound treated double room situation. The ambient noise levels were within permissible limits, as recommended by ANSI, 1991 S3.1 standards.

Test procedure

i) All the subjects were subjected to routine audiological testing by obtaining air conduction and bone conduction thresholds for the frequencies 250 Hz-8000 Hz and 250 Hz-4000 Hz respectively using modified Hughson & Westlake procedure (Carhart & Jerger, 1959). Only those who obtained normal hearing were selected for further evaluation.

ii) Tympanometry for 226 Hz probe tone was done for all subjects. Ipsilateral and contralateral acoustic reflex thresholds were obtained for 500Hz, 1 KHz, 2 KHz and 4 KHz for all the subjects.

Instructions

The subjects were given the following instructions in Mizo language:

Instruction for SRT testing: “You will hear a word after the sentence, “Sawi rawh le” through your headphones. Listen carefully to each word and repeat them. The words will get softer. If you are not sure of the word, you can guess the word”.
Instruction for SI testing: “You will hear some short words through the headphone. Listen carefully to each word and repeat them”.

Normative data for SRT test material

Using the material developed for SRT, each of the subjects was tested for the following:

a) Establishment of SRT

The ASHA (1988) method for SRT determination was followed to evaluate the speech recognition threshold. The procedure is as follows:

Preliminary phase to obtain starting level:

i) The hearing level was set to 30-40dB above the estimated SRT and one spondaic word was presented to the client. If the response was correct, then the level was descended in 10 dB decrements, presenting one spondaic word at each level until the client responded incorrectly. If the client did not respond correctly to the first spondaic word at the first level, the level was increased in 20 dB steps until a correct response was obtained. Then the 10dB decrements were initiated.

ii) When one word was missed, a second spondaic word was presented at the same level.

This process of descending in 10dB steps was continued until a level was reached at which two consecutive words were missed at the same hearing level.

iii) The hearing level was increased by 10 dB (above the level at which two spondaic words were missed). This defined the starting level.

Test Phase

- Five spondaic words were presented at the starting level and at each successive 5dB decrement.
- This was continued if five out of the six words were repeated correctly.
- If this criterion is not met, the starting level was increased by 4-10 dB.
- The descending series was terminated when the client responded incorrectly to five of the last six words presented.

Then thresholds were calculated for both the ears, as per ASHA (1988) recommendations.

b) Performance intensity function of the spondee word lists

The word recognition of the spondee word lists were established at different intensities, starting from 0 dBSL to 10 dBSL progressing in 2 dB steps. The subjects were instructed to repeat the test words and the responses noted down. At each intensity, both lists (I&II) were
presented. At each intensity level, the order of words in the lists was randomized in order to avoid familiarity effect. The average percentage correct scores for both the lists (I&II) were plotted as a function of intensity. This is called the Performance Intensity function.

**Normative data for Speech Identification (SIS) material**

Using the material developed for Speech Identification Scores, each of the subjects was tested for the following:

**a) Establishment of SIS**

Each list (List 1 and List 2) was presented at intensity, 40 dB SL (ref SRT). All the subjects were tested at this intensity level and each subject was tested in both the ears. The number of monosyllabic words correctly identified in each list was noted.

**b) Performance Intensity- Phonetically Balanced (PI-PB) function of the word lists**

The word identification of the PB word lists were established at different intensities, starting from 0 dB SL to 10 dB SL (reference: SRT) progressing in 2 dB steps. The subjects were instructed to repeat the test words. At each intensity, both lists (1&2) were presented. At each intensity level, the order of words in the lists was randomized in order to avoid familiarity effect. The average percentage correct scores for both the lists (1&2) were plotted as a function of intensity (Performance Intensity function).

**Reliability check**

10% of subjects were subjected to retesting for a time gap of at least five days. Test-retest reliability was calculated using this data.

**Statistical analysis**

Appropriate statistical analyses were carried out for the data.

**Results and Discussion**

The present study was carried out with an aim of developing and standardizing spondees and phonetically balanced word lists for speech recognition and identification tests in Mizo language.
Spondee word lists

Results of mean and standard deviation of SRT for the spondee word lists I & II

Table 1: Mean and Standard deviation (S.D) of SRT for spondee word lists I & II for Right ear and Left ear across gender.

<table>
<thead>
<tr>
<th></th>
<th>Spondee word list I</th>
<th>Spondee word list II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>S.D (dBHL)</td>
<td>3.33</td>
<td>3.49</td>
</tr>
</tbody>
</table>

It is evident from Table 1 that the mean SRT scores for both the lists across both the genders and ears (left & right) are comparable. Figure 1 shows the graphical representation of the same results.

The mean SRT, considering both males & females and right & left ear together using list I was attained at 13.21 dB HL (re: PTA) with a SD of 3.05 and that for list II was attained at 13.30 dB HL (re: PTA) with a standard deviation (SD) of 3.10.

Figure 1: Mean SRT scores for right and left ear for List I & II.

Mixed analysis of Variance (ANOVA) was done to see if there is any statistical difference between the lists, between the ears, between genders. The results of Mixed ANOVA revealed that there was no significant difference between the lists [F (1, 98) = 0.726, p > 0.05], no significant difference between the ears [F (1, 98) = 0.049, p > 0.05] and no significant difference was found for gender [F (1, 98) = 0.264, p> 0.05]. Also, no significant interaction was found between the lists & gender [F (1, 98) = 0.948, p > 0.05], ear & gender [F (1, 98) = 0.013, p > 0.05], list & ear [F (1, 98) = 1.080, p > 0.05] and also for the three factor interactions i.e. list, ear and gender [F (1, 98) = 0.619, p> 0.05].
Thus, the averaged data of the hundred participants showed no significance in scores for spondee word lists I and II for right and left ear across gender at 0.05 confidence levels. Also, the results demonstrated that the two lists of spondaic words yield equivalent SRTs.

The findings of the present study are also in consonance with various studies, Hirsh et al., 1952, Swarnalatha (1972) obtained SRT for spondees at 9 dBHL (re: PTA), Ghosh (1986) obtained SRT at 12 dBHL re: PTA), Tanuza (1984) obtained SRT at 13 dBHL for spondees in Manipuri language and Behera (2004) obtained SRT at 10 dBHL (re: PTA) for Oriya language.

**Performance Intensity function of the Spondee list I & list II**

Mean and SD of performance intensity function for spondee word lists I & II were calculated and are given in Table 2.

Table 2: Mean and SD of scores on spondee lists I & II at different intensity levels (0 to 10 dBSL with reference to pure tone average) across gender (raw scores).

<table>
<thead>
<tr>
<th>Intensity (dBSL)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Spondee List - II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>10.85</td>
<td>2.27</td>
</tr>
<tr>
<td>Two</td>
<td>16.10</td>
<td>2.83</td>
</tr>
<tr>
<td>Four</td>
<td>20.50</td>
<td>2.35</td>
</tr>
<tr>
<td>Six</td>
<td>23.37</td>
<td>1.59</td>
</tr>
<tr>
<td>Eight</td>
<td>24.83</td>
<td>0.51</td>
</tr>
<tr>
<td>Ten</td>
<td>25.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Spondee List - I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>11.47</td>
<td>1.90</td>
</tr>
<tr>
<td>Two</td>
<td>16.66</td>
<td>2.54</td>
</tr>
<tr>
<td>Four</td>
<td>20.85</td>
<td>2.28</td>
</tr>
<tr>
<td>Six</td>
<td>23.68</td>
<td>1.51</td>
</tr>
<tr>
<td>Eight</td>
<td>24.91</td>
<td>0.34</td>
</tr>
<tr>
<td>Ten</td>
<td>25.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

From Table 2 we can see that the performance intensity function increases as the intensity is increased and almost reaches to a saturation level between 8 to 10 dBSL. The scores do not differ across Males and Females. 50% correct criteria was met between 0 & 2 dBSL (ref PTA). The 50% correct criteria for spondee words were obtained at 0 dBHL for normal hearing young adults (ANSI, 1989). The finding of the present study is consistent with the correlation between SRT & PTA reported in the literature, thus validating the speech material developed.
Mixed ANOVA was done to test the statistical significance of the lists across the different intensity levels and also to see the interaction effects between different variables. Mixed ANOVA revealed that at 0 dBSL to 4 dBSL there was a statistical significance between the two spondee lists I & II [F (1, 98) = 8.592, p < 0.01], however, at higher presentation levels of 6 dBSL [t (99) = 1.976, p > 0.05] and 8 dBSL [t (99) = 1.469, p > 0.05], there was no significant difference between the two lists and the scores at lists I & II are equal at 10 dBSL. Also there was a statistical significance between list & level interaction [F (5, 490) = 3.588, p < 0.01]. However, there was no significant difference across genders [F (1, 98) = 0.080, p > 0.05, list & gender interaction [F (1, 98) = 0.017, p > 0.05], level & gender interaction [F (5, 490) = 0.502, p > 0.05] and interaction between lists, levels and genders [F (5, 490) = 0.502, p > 0.05].

Bonferroni Multiple Comparison Test indicates that the intelligibility of the lists improved significantly with increase in presentation level. A study by Hirsh et al. (1952) reported that, with increase in presentation levels, the identification scores for bisyllabic words increases.

Mean SRT across List I and II across the six levels (Figure 2) showed that as the intensity level was increased from 0 dBSL to +10 dBSL, the performance intensity function showed a steeply rising curve from 0 dBSL to 8 dBSL. However, at +10 dBSL, the curve flattens out as the intelligibility reached 100 %. This showed that, there was an increase in scores as the intensity of the presentation level is increased.

The performance intensity function for W-1 showed similar results. The scores reached the 100% point at about +14 dB above threshold.

Table 2 showed that as the presentation level was increased from 0 dBSL to 10 dBSL, the standard deviation (SD) of scores on spondee List I & II reduced from 2.27 to 0 and 1.90 to 0 respectively.
In agreement with our findings, a study on ‘Development and evaluation of Mandarin disyllabic materials for Speech Audiometry in China by Wang et al (2007), SD reduced as the presentation level was increased (from 0 to 15 dB HL) in the mean performance-intensity function test, indicating that at higher presentation levels the subjects’ performance became less variable.

**Monosyllabic Phonetically Balanced Word Lists**

**Results of mean and standard deviation of SIS for monosyllabic PB word lists I & II**

Table 3: Mean and Standard deviation (S.D) of SIS for PB word lists I & II for Right ear and Left ear across gender and across Ear.

<table>
<thead>
<tr>
<th></th>
<th>PB word list-1</th>
<th></th>
<th>PB word list-2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>97.52</td>
<td>99.26</td>
<td>97.24</td>
<td>97.2</td>
</tr>
<tr>
<td>S.D (%)</td>
<td>2.58</td>
<td>2.52</td>
<td>3.90</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td>97.88</td>
<td>97.52</td>
<td>97.28</td>
<td>96.82</td>
</tr>
<tr>
<td></td>
<td>2.38</td>
<td>2.70</td>
<td>2.34</td>
<td>2.84</td>
</tr>
</tbody>
</table>

It is evident from the table that the mean SIS scores across both the genders are comparable and is almost similar across the ears. Thus, the two lists are equivalent. Figure 3 shows the graphical representation of the same results.

![Figure 3: Mean SIS scores for Right and Left ear for PB List-1 and List-2.](image)

Mixed analysis of Variance (ANOVA) was done to see if there is any statistical difference between the lists, between the ears, between genders. The results of Mixed ANOVA revealed that there was no significant difference between the lists [F (1, 98) = 0.647, p > 0.05], no significant difference between the ears [F (1, 98) = 0.159, p > 0.05] and no significant difference was found for gender [F (1, 98) = 1.618, p> 0.05].
Studies in other languages have also yielded similar results, where they found no significance between their lists. Hirsh et al., 1952, Abrol (1971) in Hindi, Kapur (1971) for Tamil PB word lists.

**Performance Intensity function for Phonetically Balanced (PB) word list I & list II**

Table 4: Mean and Standard deviation (S.D) of SI (in %) for PB word lists I & II at different intensity levels (0 to 10 dBSL with reference to SRT) across gender.

<table>
<thead>
<tr>
<th>Intensity (dBSL) (re: SRT)</th>
<th>Subjects (N = 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>List-1</td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>24.48</td>
</tr>
<tr>
<td>Two</td>
<td>43.60</td>
</tr>
<tr>
<td>Four</td>
<td>63.70</td>
</tr>
<tr>
<td>Six</td>
<td>81.00</td>
</tr>
<tr>
<td>Eight</td>
<td>93.70</td>
</tr>
<tr>
<td>Ten</td>
<td>99.78</td>
</tr>
<tr>
<td>List-2</td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>24.06</td>
</tr>
<tr>
<td>Two</td>
<td>43.70</td>
</tr>
<tr>
<td>Four</td>
<td>64.40</td>
</tr>
<tr>
<td>Six</td>
<td>81.14</td>
</tr>
<tr>
<td>Eight</td>
<td>94.04</td>
</tr>
<tr>
<td>Ten</td>
<td>99.78</td>
</tr>
</tbody>
</table>

From Table 4 we can see that mean raw scores of SIS increases as the intensity is increased and also the SIS does not differ across Males and Females.

For PB word lists I and II, the SD was lesser for higher sensation level reflecting lesser variance.

The results are in consonance with findings of Swarnalatha (1972), Mayadevi (1974), Tanuza (1984), Ghosh (1986) and Behera (2004).

As it can be seen from figure 4 that as the intensity level increases, the mean scores of SIS also increases and almost reaches the saturation level between 8 to 10 dBSL. The scores of SI are reaching to 100% at 10 dBSL.
Mixed ANOVA was done to see the statistical significance of the lists across the six intensity levels and also to see the interaction effects between different variables. Mixed ANOVA revealed that there was no statistical significance between the two PB word lists \([F (1, 98) = 0.026, p > 0.05]\), list & level interaction \([F (5, 490) = 1.273, p > 0.05]\), across genders \([F (1, 98) = 2.188, p > 0.05]\), list & gender interaction \([F (1, 98) = 0.026, p > 0.05]\), level & gender interaction \([F (5, 490) = 1.658, p > 0.05]\) and interaction between lists, levels and genders \([F (5, 490) = 1.097, p > 0.05]\). However, there was a statistical significance at the six intensity levels \([F (5, 490) = 2353.716, p < 0.01]\).

Further Paired sample t-test was done to compare the two lists at different intensity levels which revealed that there is no significant difference between list I & II at all the levels.

From this study it can be seen that the mean scores for the SIS is almost similar across the gender and ears. And the mean scores for the intelligibility of the PB word lists at increasing intensities showed that as the intensity level increases, the speech identification scores increases, and reached a score of 100% at 10 dBSL (with reference to SRT) for both the lists. The curve is sharply rising indicating a positive relationship with the percentage scores and the level at which the material is presented. The maximum score on the PI-PB function is called the PB max.

These findings are in high correlation with that of earlier studies done by several authors where essentially a same curve is obtained for normal hearing subjects. Maroonroge and Diefendorf (1984) in their study of speech identification scores for 3 word lists- NU-6, California Consonant Test and Pascoe high frequency word lists found that the speech identification scores tend to improve up to about 30 dBSL for normals.

For the CID Auditory Test W-22, it was found that the scores increased sharply with increasing levels of presentation and scores remained constant at about 40 dBSPL (Hirsh et al., 1952).
Hood & Poole (1980), based on their study had stated that, in normal hearing subjects, the performance intensity function (curve) derived for a single list is no different from that obtained with a number of equivalent lists. Lau and So (1988), on their study of Cantonese Speech Audiometry, stated that, averaged discrimination scores over all lists tends to increase with increase in stimulus level and the Standard deviation decreases as the level increases, they found that at 30 dBHL all the 10 lists have equivalent intelligibility.

Similar findings have been listed on studies relating to Speech Identification for monosyllabic words across different languages.

Reliability

Reliability check was performed on 10% of the obtained data. Cronbach’s Alpha Coefficient was done to check the reliability of the data. Percent reliability of Spondee list I & II and PB list 1 & 2:

SRT list I: 95%, SRT list II: 89%, SI list I: 83%, SI list II: 85.5%.

Cronbach’s Alpha Coefficient thus indicated that there is correlation for SRT and SIS of lists I and II. Thus this shows that the Spondee word lists and the Phonetically Balanced word lists are reliable.

Conclusions

The purpose of this study was to develop and standardize Spondees and PB words in Mizo language that can be used to measure the Speech Recognition Threshold (SRT) and Speech Identification Scores (SIS) for native speakers of Mizo, a language spoken in Mizoram, India. Two lists each of Spondees and PB words with high familiarity were developed as per standard procedures and the SRT and SIS evaluated for 100 (one hundred) native speakers of Mizo language in the age ranged between 18 years to 40 years, with normal hearing.

The results of the study revealed-

- No significant difference in scores between the two Spondee lists and PB word lists for both the ears across gender
- The two lists of spondaic words and PB words yielded equivalent SRTs and SIS
- Significant difference in scores between spondee lists I & II at lower presentation levels (0 dBSL to 4 dBSL). As the presentation level increases, there was no significant difference in scores and at 10 dBSL, the scores were equal
- As the intensity increases, the scores were found to increase (v) There was no significant difference in scores between PB word lists 1 & 2 at six different levels of presentation (0 dBSL to 10 dBSL).
The materials developed were found to have excellent reliability. Thus the Spondee and the PB word lists developed can be used in clinical situations for Speech Audiometry.

**Future research directions**

- There have been no materials developed for speech audiometry for children in Mizo language. So, extensive studies could be carried out to develop speech audiometry materials for different age groups.
- These tests could be used to evaluate the speech perception abilities through different hearing aids and thus, its utility in hearing aid selection can be assessed.
- The tests can be used to assess the utility of different devices such as frequency modulation (FM) systems, cochlear implants etc.
- It can also be used to assess the efficacy of intervention with different therapy programs.

**References**


Kapur, Y. P. (1971). *Needs of the speech and hearing handicapped in India*. Christian Medical College and Hospital, Vellore.


Vestibular Evoked Myogenic Potential (VEMP) in Individuals with Noise Induced Hearing Loss (NIHL)

Manasa Madappa & N. M. Mamatha*

Abstract

The present study was aimed to evaluate the functioning and susceptibility of the saccule in individuals with Noise Induced Hearing Loss (NIHL) using Vestibular Evoked Myogenic Potentials (VEMPs). 30 individuals (60 ears) with normal hearing sensitivity (control group) and 30 (57 ears) individuals with NIHL (clinical group) in the age range of 25-50 years were taken. All the individuals were tested on a test battery including case history, PTA, Immittance, TEOAEs, ABR & VEMP. 2 questionnaires were administered to obtain information about history of noise exposure and presence/absence of vestibular symptoms. The results showed that VEMP in NIHL group was present in 61.4%. There was statistically significant prolongation of p13 but not for the n23 latency, reduced amplitude for both p13-n23 complex and TEOAE for the clinical group in comparison to the control group. VEMP correlated with the vestibular symptoms in 33 out of 57 ears. VEMP did not correlate with the severity of the hearing loss (HL) for both ears. However, for degree of HL from mild to severe, the frequency of presence of VEMP response decreased. The TEOAE amplitudes are highly correlated with the severity of the HL for both ears. To conclude, the two parameters of VEMP, p13 latency and p13- n23 complex amplitude could be considered to show the effect of noise on saccular system which was obtained significantly different. VEMP is expected to be affected or absent in clients with the dysfunction of the vestibular system, as in the current study, all the individuals with symptoms of “Sensation that you are turning or spinning inside” and “Nausea or vomiting” had absent VEMP responses indicating saccular involvement in NIHL. It is also evident that the cochlea is more susceptible to noise in individuals with NIHL as TEOAE was absent in most of the client with NIHL.

Introduction

Hearing is one of the most important senses in human beings. There are a multitude of factors that can affect the hearing of an individual. The most common factor which can have an adverse effect on our hearing is ‘noise’. Since the industrial revolution, an increasing number of ears have been injured by noise via two ways. One is acute acoustic trauma, which is defined as a sudden change in hearing as a result of a single exposure to a sudden burst of sound. Other is the Noise-Induced Hearing Loss (NIHL) which develops slowly over a long period of time as a result of exposure to continuous or intermittent loud noise (ACOEM, 2002). 1.1 million people are estimated to be exposed to excessive noise at work and of these 1 lakh 70 thousand would suffer from significant ear damage as a direct result of noise exposure (South, 2004). Noise has both auditory and non auditory effects. Extreme noise can clearly damage hair cells in the cochlea (Rosler, 1994), the spiral ganglion cells forming the auditory portion of the eighth nerve (Nadol & Xu, 1992) and the central nervous system including the cochlear nuclei, superior olive and inferior colliculus (Kim, Leonard, Smurzynski, & Jung, 1992). Also, negative reactions (Fields, 1994), sleep disturbances

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(Pearsons, Barber, Tabachnick & Fidell, 1995) and detrimental effect on cardiovascular health (Talbott et al., 1996) have been reported resulting from noise exposure. There are battery of audiological tests for evaluating the auditory effects of noise and the early diagnosis of NIHL of which Otoacoustic Emissions (OAEs) provide objectivity and greater accuracy, complementing the behavioral audiogram in the diagnosis and monitoring of the cochlear status following noise exposure (Attias, Abrovitz, Hatib, & Nageris, 2001).

Noise exposure not only damages the cochlea, but threatens the vestibular organs too. (Oosterveld, Polman, & Schoonheyt, 1980). Oosterveld, Polman, & Schoonheyt (1982) reported that individuals with noise exposure could be disabled because of vertigo or balance disorder; an important and perhaps neglected aspect of NIHL. Similar reports of vestibular involvement leading to various vestibular symptoms in individuals exposed to noise have been studied using various test procedures for assessing the vestibular system (Barr, 1886; Chadwick, 1966; Aantaa, Virolainen & Karskela, 1977; Paparella & Mancini, 1983). Vestibular evoked myogenic potentials (VEMPs) which was first described by Bickford, Jacobson & Cody (1964), plays an important role in the vestibular test battery as a non-invasive measure of saccular function (Hall, 2006). VEMPs are mediated by a pathway that includes the saccule, macula, inferior vestibular nerve (IVN), lateral vestibular nucleus (LVN), lateral vestibulospinal tract (LSVT), and motor neurons of the ipsilateral sternocleidomastoid muscle (Halmagyi & Curthoys, 2000).The VEMP waveform consists of two components; of which only the first component (p13- n23) is generated by activation of saccular afferents (Colebatch, Halmagyi & Skuse, 1994).

VEMP has a wide clinical applicability. VEMP has been reported to be useful in the assessment of various peripheral and central vestibular disorders. In a recent study, Wang & Young (2007) reported that patients with bilateral NIHL (bilateral 4 kHz notched audiogram with hearing threshold of 4 kHz > 40 dB) may show abnormal VEMP indicating that vestibular part especially, the sacculocollic reflex pathway has also been damaged. Christina, Kumar & Bhat (2008) also observed abnormal VEMP in 82%, out of which, 36% were having absent VEMP and 46% were having abnormal VEMP, in a total of 6 subjects with noise induced hearing loss.

**Need of the study**

The vestibular end organs and the cochlea both utilize the same basic principle of mechano-electric transduction with the help of the sensory hair cells (Eisen & Limb, 2007). Also, the bony labyrinth is stimulated in response to high levels of occupational noise. Hence, balance system could also have negative effects secondary to long term noise exposure, along with the hearing sensitivity. The saccule has been reported to be the thinnest membrane (0.015mm) after Reissener’s Membrane (0.014mm). Also, saccule can withstand much lesser force (0.57gf/mm) before breakage as against the Reissener’s membrane which can withstand a force of 0.84gf/mm (Tetsuo, Nobukazu, & Terufumi, 1990). Furthermore, the distance of the utricle and saccule from the stapes are 0.65mm and 0.4mm respectively which in turn adds to the probability of the balance system getting affected due to noise. It is also reported that saccular maculae among the vestibular structures, are the most sensitive structure to
sound stimulation (Goldbeg, 2000). Hence, it can be speculated that long-term exposure to noise could also affect the functioning of the vestibular system.

The possible vestibular involvement in patients with NIHL is relatively new and there is a dearth of information regarding the same. Individuals exposed to noise either for short or long duration might exhibit vestibular symptoms. VEMP recording might help to unfold the saccular involvement in individuals who are exposed to noise with or without any vestibular symptoms.

**Aims of the study**
- To evaluate the functioning of the saccule and the IVN in individuals with NIHL
- To assess the susceptibility of cochlea or saccule to noise exposure based on Transient Evoked Otoacoustic Emission (TEOAE) and Vestibular Evoked Myogenic Potential (VEMP) test results.
- To know whether the vestibular system damage is associated with the saccular dysfunction in individuals with NIHL, by correlating the vestibular symptoms and VEMP response.
- To know whether there is any relationship between degree of hearing loss and saccular dysfunction in individuals with NIHL.

**Method**

**Subjects:** Two groups of subjects were taken in the age range of 25–50 years. The control group consisted of 30 individuals (60 ears) with normal hearing sensitivity with no history of exposure to noise (mean age= 38.66 years). The clinical group consisted of 30 individuals (57 ears) with NIHL. The clinical group was further subdivided into two groups based on the vestibular symptoms;

- **Group I:** 15 subjects (28 ears) with a mean age of 39.33 years. All the individuals in this group exhibited at least one of the vestibular symptoms that were given in the Dizziness questionnaire. The duration of noise exposure had a mean of 20.93 ears.
- **Group II:** 15 subjects (29 ears) with a mean age of 42.40 years. No individuals in this group exhibited any of the vestibular symptoms. The duration of noise exposure had a mean of 19.47 ears.

**Selection criteria**

**Control group:** All the subjects had hearing sensitivity within 15 dBHL at octave and mid octave frequencies from 250 Hz to 8000 Hz with ‘A’ type tympanogram and normal acoustic reflexes in both the ears. The uncomfortable levels (UCL) for speech for all the subjects were greater than 95 dB HL with good speech identification (SI) scores (≥ 80%).
Clinical group

The subjects were having either normal hearing sensitivity or sensorineural hearing loss with air bone gap not exceeding 10 dB HL with air conduction notch between 3-6 kHz with any degree of hearing loss. They had noise exposure for duration of 8hrs per day, at least for more than 2 yrs. Immitance measurements showed ‘A’ type tympanogram with presence/elevated or absence of ipsilateral and contralateral acoustic reflexes in both the ears. TEOAEs showed either normal (in individuals with 3-6 kHz notch), abnormal or absent responses (in individuals having hearing loss indicating cochlear pathology). None of them reported to have hypo/hypertension or spondylitis and did not have any evidence of space occupying lesion (decided based on auditory brainstem response results and/or neurological reports). The uncomfortable levels (UCL) for speech for all the subjects were greater than 95 dB HL with good speech identification scores of 80% or proportionate to the hearing loss.

Instrumentation

A calibrated 2-channel diagnostic MADSEN ITERA audiometer was used to estimate the puretone thresholds (for both air conduction and bone conduction), SI scores and UCL for speech. A calibrated immittance meter GSI-Tympstar was used for both tympanometry and acoustic reflexometry. A calibrated OAE system ILO-V6 was used for the measurement of Transient Evoked Otoacoustic Emission (TEOAE). IHS smart EP version 3.94 US Bez (Intelligent hearing system, Florida, USA) instrument was used to record and analyse VEMP and Auditory Brainstem Response (ABR).

Procedure

1) A detailed case history about history of noise exposure was taken for all the individuals in the clinical group by administering the questionnaire developed by Tharmar (1990). To obtain information about the vestibular symptoms, the II section of dizziness questionnaire developed at Maryland hearing and balance center was used.

2) Puretone thresholds were obtained between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction at all the octaves and mid octave frequencies, using the Modified Hughson and Westlake procedure (Carhart & Jerger, 1959). PTA2 (average of 1 kHz, 2 kHz and 4 kHz) was also calculated to account for hearing sensitivity at high frequencies. This was considered for the statistical analysis.

3) The SI scores were obtained at 40 dB HL above the speech recognition threshold using monosyllable list developed by Vandana (1998).

4) The UCLs were determined by presenting the running speech through the headphones (TDH-39) at different intensities using ascending method.

5) Immittance audiometry was carried out with a low probe tone frequency of 226 Hz. The ipsilateral and contralateral acoustic reflex thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz tones.

6) ABR testing was carried out to rule out any space occupying lesions using the Neurodiagnostic ABR test protocol. The Subjects who had both the absolute and the inter-peak
latencies within the normal range, with good waveform morphology for both low and high repetition rates were considered as devoid of any space occupying lesions.

7) The OAEs evoked by click trains presented at 84±3 dB pe SPL for the non linear clicks were recorded using an appropriate sized probe tip. The response was acquired using the averaging method. Responses were accepted with a SNR of +6 dB and response reproducibility of ≥ 80%.

8) The VEMP was recorded by instructing the subjects to sit straight and turn their head to the opposite side of the ear in which the stimulus was presented, so as to activate the ipsilateral Sternocleidomastiod (SCM) muscle and were asked to maintain the same throughout the test run. They were also instructed to avoid any extraneous movements of head, neck and jaw to elude muscle artifacts. While recording the VEMP, the tonic EMG level was maintained for each of the subject between 100 to 200 micro volts. A visual feedback which was available in the instrument was provided to each of the subject to monitor tonic EMG level of SCM muscle. The protocol proposed by Wang & Young (2007) was used in the present study to record the VEMP which is given in Table 1.

<table>
<thead>
<tr>
<th>Stimulus Parameters</th>
<th>Type of stimuli</th>
<th>Tone burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulus frequency</td>
<td>500 Hz</td>
<td></td>
</tr>
<tr>
<td>Stimulus duration</td>
<td>2-1-2 cycle</td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>95 dBnHL</td>
<td></td>
</tr>
<tr>
<td>Repetition rate</td>
<td>3.1/sec</td>
<td></td>
</tr>
<tr>
<td>Polarity</td>
<td>Rarefaction</td>
<td></td>
</tr>
<tr>
<td>Transducer</td>
<td>Insert ear phone (ER-3A)</td>
<td></td>
</tr>
<tr>
<td>Total number of stimuli</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acquisition Parameters</th>
<th>Analysis time</th>
<th>60 msec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter setting</td>
<td>30 Hz -1500 Hz</td>
<td></td>
</tr>
<tr>
<td>Notch filter</td>
<td>Off</td>
<td></td>
</tr>
<tr>
<td>Electrode placement</td>
<td>Non- inverting (positive) - Midpoint of SCM muscle Inverting(negative)- Sternoclavicular junction Ground – Forehead</td>
<td></td>
</tr>
<tr>
<td>Artifact rejection</td>
<td>40 µV</td>
<td></td>
</tr>
<tr>
<td>Amplification</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Number of channels</td>
<td>Single</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Parameters Used to Record VEMP

**Results and Discussion**

**A. VEMP results in the control and the clinical group**

**Control group:** Out of the 60 ears, the VEMP response was present in 51 ears while it was absent in 9 ears. So the response rate for the VEMP was 85%. The overall response rate is consistent with the studies by Townsend & Cody (1971) and Vijayashankar (2008).
The mean, standard deviation (SD) and paired t test results for p13, n23 latency and p13- n23 complex amplitude obtained in individuals with normal hearing were calculated and the results are outlined in Table 2.

Table 2: Mean, Standard Deviation (SD) and t-values with Level of Significance of p13, n23 Latency and p13- n23 Complex Amplitude of VEMP in the Control Group.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right ear</th>
<th>Left ear</th>
<th>t-value (df=33)</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>p13 latency</td>
<td>13.42</td>
<td>1.10</td>
<td>13.29</td>
<td>1.02</td>
</tr>
<tr>
<td>n23 latency</td>
<td>21.40</td>
<td>2.08</td>
<td>21.33</td>
<td>2.30</td>
</tr>
<tr>
<td>p13- n23 amplitude</td>
<td>55.75</td>
<td>16.45</td>
<td>55.59</td>
<td>18.90</td>
</tr>
</tbody>
</table>

From the Table 2, it can be inferred that the mean latencies of p13 and n23 was longer for the right ear as compared to the left ear. The variability for the p13 latency measure was higher for the right ear, while for the n23 latency, it was higher for the left ear. Overall, the variability for the n23 latency was greater as compared to the p13 latency. For the p13- n23 complex amplitude, the mean value was larger for the right ear than the left ear while the variability was higher for the left ear. Paired t test results indicated no significant difference between right and left ears for the p13, n23 latency and amplitude of p13- n23 complex. The mean values of p13 and n23 latencies of VEMP response in the present study are almost in agreement with the studies on VEMP by various authors such as Akin, Murnane & Proffitt (2003), Kumar (2006) and Vijayashankar (2008). The amplitude was in accordance with Vijayashankar (2008), he reported mean p13-n23 complex amplitude value around 50 µV and SD of about 25 µV. The amplitude in the control group is slightly greater and the variation is less in the present study as compared to the study by Vijayashankar (2008). The reason for this could be that the EMG level maintained in Vijayashankar (2008) was lower (30-50 micro volts) than the present study (controlled in the range of 100-200 micro volts). It is possible that the EMG level greater than 50 micro volts would have raised the mean amplitude value of p13-n23.

Clinical group: The VEMP response was present in 35 ears and was absent in 22 ears. So, the response rate for the VEMP was 61.4%.

Response patterns of VEMP latency and amplitude: For the p13 latency, 54.29% had normal latency, 40% had prolonged latency and 5.71% had shortened latency. For the n23 latency, 57.14% had normal latency, 34.29% had prolonged latency and 8.57% had shortened latency. The response patterns for amplitude measure showed that 48.57% had normal amplitude while 51.43% had reduced amplitude. The results of the present study are in consonance with Christiana, Kumar and Bhat (2008). They reported that VEMP was abnormal or absent in 67% and normal in 36.4% ears out of 55 NIHL ears evaluated. Out of the 67% ears, VEMP was absent in 45.7% ears. The latency was prolonged and the peak to peak amplitude was reduced in 54.3% ears. They concluded that the possibility of vestibular dysfunction, especially the saccule pathway is high in individuals with NIHL and that VEMP
VEMP in NIHL Individuals

can be employed in these individuals to assess sacculo-collic reflex. Wang & Young (2007) reported abnormal VEMP responses in 50% of the individuals with NIHL, which included absent VEMPs in 8 and delayed VEMPs in 3 subjects. The absence of VEMP reflects a lesion affecting the sacculocollic reflex pathway, whereas the delayed VEMP latencies are indicative of a retro-labyrinthine or brainstem lesion, especially in the vestibule-spinal tract (Wang & Young, 2006). There are discrepancies seen in the quantitative measures of each of the considered parameter, and this can be attributed to the number of subjects, years of exposure to noise and other recording parameters adopted in different studies.

The mean and the SD for p13, n23 latency and the p13- n23 complex amplitude and the paired t test results obtained in individuals with NIHL was calculated and the results are tabulated in Table 3.

Table 3: Mean, SD and t- values with Level of Significance of p13, n23 Latency and p13-n23 Complex Amplitude in the clinical group.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Right ear</th>
<th>Left ear</th>
<th>t-value (df= 22)</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>p13 latency</td>
<td>14.95 ± 2.68</td>
<td>14.78 ± 1.56</td>
<td>0.17</td>
<td>0.86</td>
</tr>
<tr>
<td>n23 latency</td>
<td>21.33 ± 2.30</td>
<td>22.48 ± 3.82</td>
<td>0.17</td>
<td>0.86</td>
</tr>
<tr>
<td>p13-n23 amplitude complex.</td>
<td>40.10 ± 17.45</td>
<td>39.60 ± 19.18</td>
<td>0.08</td>
<td>0.93</td>
</tr>
</tbody>
</table>

From the Table 3, it can be speculated that the mean latency value and the variability of p13 and p13- n23 complex amplitude was larger for the right ear as compared to the left ear. For the n23 latency, the mean value was smaller for the right ear but the variability was higher for the left ear. Paired t test results indicated that there was statistically no significant difference between right and left ears for the p13, n23 latency and p13- n23 complex amplitude.

B. Comparison of VEMP latency and amplitude measures across the control and the clinical group:

Comparison of p13 latency: The mean and the SD for p13 latency in ms for both the groups are depicted in Figure 1.

![p13 Latency](image)
Figure 1: Mean and SD of p13 latency for right and left ears obtained in both the groups.

It can be seen from the Figure 1 that the p13 latency value obtained for the control group is shorter than the clinical group for both right ear and left ear. Mixed ANOVA results revealed that there was a statistically significant difference in p13 latency values obtained between the control and the clinical group \[F (1, 33) = 14.08, p < 0.05\]. For within subjects, there was neither ear effect \[F (1, 33) = 0.15, p > 0.05\] nor the interaction effect between the group and ear \[F (1, 33) = 0.00, p > 0.05\].

**Comparison of n23 latency:** The mean and the SD for n23 latency for both groups are shown in Figure 2.

Figure 2: Mean and SD of n23 latency for both the control group and the clinical group.

It can be seen from the Figure 2 that the n23 latency value for the clinical group is longer than the control group for both the right and left ear. Mixed ANOVA results revealed that there was statistically no significant difference for n23 latency values between the control and the clinical group \[F (1, 33) = 2.10, p > 0.05\]. For within subjects there was neither ear effect \[F (1, 33) = 0.01, p > 0.05\] nor the interaction effect between the group and ear \[F (1, 33) = 0.06, p > 0.05\]. The results of the present study are in close agreement with the study by Wang and Young (2007) and Christiana, Kumar & Bhat (2008). Wang and Young (2007) reported specific prolongation of p13 latency, but Christiana, Kumar & Bhat (2008) have reported prolongation for both the peak latencies. Another speculation of the p13 latency being prolonged compared to n23 latency being within normal limits may be reasoned due to the SD value. The SD of n23 was greater than that of p13, resulting in a wider normal range of n23 than p13. Also, the literature on the response consistency of VEMP which was reviewed by Ferber, Dubreuil, & Duclaux (1999) based on the studies done by Townsend & Cody (1971), and others suggest that the consistency is more for p13 and less for n23 of VEMP response.

**Comparison of p13-n23 complex amplitude for both the control and the clinical group:** The mean and the SD for p13-n23 complex amplitude for both the groups are presented in Figure 3.
It can be seen from the Figure 3 that the p13- n23 complex amplitude for the clinical group in both the right and the left ear is smaller than the control group. Mixed ANOVA results revealed that there was a statistically significant difference in p13- n23 complex amplitude values between the control and the clinical group \([F (1, 33) = 8.60, p < 0.05]\). For within subjects, there was neither ear effect \([F (1, 33) = 0.01, p > 0.05]\) nor the interaction effect between the group and ear \([F (1, 33) = 0.00, p > 0.05]\). Christiana, Kumar and Bhat (2008) reported the amplitude being reduced in 19 ears accounting for 34.6% of the abnormal responses. The percentage of the reduced amplitude was higher (51.43%) in the present study which may be because of the difference in the duration as well as the intensity of noise exposure in the study group in the two studies. Also, the variation in the amplitude measure may be due to the mean level of the electromyographic activity (Colebatch, Halmagyi, & Skuse, 1994). It has also been reported in the literature that there are variations in VEMP amplitudes, from a few µV to several 100µV, depending on the muscle tension and the intensity of stimuli (Cheng & Murofushi, 2001a, 2001b; Ochi, Ohashi, & Nishino, 2001). Hence, it could be concluded that although reduced VEMP amplitude does indicate abnormality, it cannot be conclusive as long as the intensity of the signal and more importantly the muscle tension is controlled.

Because of the unequal sample size owing to the absence of response in many of the ears considered in the clinical group, Mann Whitney test was done for the group comparisons of p13, n23 latency and p13- n23 complex amplitude between the two groups. The result is in accordance with the mixed ANOVA results.

C. TEOAE response in the Control and the Clinical group

Control group: The TEOAE being one of the criteria for the selection of subjects in the control group, the response rate for TEOAE was 100%. It was observed that the mean amplitude value for the right ear was larger than the left ear. Also, the variability was higher for the right ear as compared to the left ear. Paired t test indicated that there was no significant difference between right and left ears \((t = 2.73)\).

This is in consonance with the literature where prevalence of TEOAE response is reported to be 96%-100% in individuals with normal hearing sensitivity (Probst, Lonsbury, Martin & Coats, 1987). They also reported that right ear OAE’s were much greater than the
left ear OAE’s. Moulin, Collet, Veuillet and Morgan (1993) reported right ear OAE’s being much greater than the left ear OAE’s.

**Clinical group:** The TEOAE was present in 20 ears while it was absent in 37 ears. So, the response rate for the VEMP was 35.09%. It was seen that the mean amplitude value for the right ear was larger than the left ear; whereas the variability for the left ear was higher compared to the right ear. Paired t test results showed no significant difference between right and left ears (t= 1.05). The findings of the study are similar to as reported by Shupak et al. (2007). They reported of reduced TEOAE amplitudes in individuals during the first 2 years of occupational noise exposure. Kowalska and Kotylo (2007) reported that changes in OAE’s exactly follow the changes in audiogram related to noise exposure and that patients with NIHL show amplitude reduction and or complete absence of OAE’s. They stated that the rationale for using OAE’s in patients with NIHL includes the clinical aspect that is confirmation of cochlear lesion.

**D. Comparison of TEOAE response across the Control and the Clinical group**

Mixed ANOVA was done to evaluate the group effects, ear effects and interaction between the group and ear effect for TEOAE amplitude. The mean and the SD for TEOAE amplitude for both the control and the clinical group is shown in figure 4.

![Figure 4: Mean and SD of the TEOAE amplitude for both the control group and the clinical group.](image)

It can be evident from the Figure 4 that the TEOAE amplitude is lesser for the clinical group than the control group for both the right and the left ear. The variability is less for the clinical group than for the control group. Mixed ANOVA results revealed that there was a statistically significant difference in TEOAE amplitude values between the control and the clinical group [F (1, 35) = 23.22, p < 0.05]. For within subjects, there was neither ear effect [F (1, 35) = 0.65, p > 0.05] nor the interaction effect between the group and ear [F (1, 35) = 3.04, p > 0.05]. Mann Whitney t test results are in accordance with the mixed ANOVA results.

**E. Comparison of TEAOE and VEMP responses in the Clinical group:**

To evaluate the susceptibility of the cochlea versus the saccule, the VEMP responses were compared with the TEOAE responses. This was done using the cross tabulations wherein comparison of the frequency of the presence or the absence of the responses for both
VEMP and TEOAE were made. The frequency of presence and absence of VEMP and TEOAE responses in the clinical group are tabulated in table 4.

Table 4: Frequency of presence and absence of VEMP and TEOAE responses in the clinical group.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Number of ears (57)</th>
<th>Percentage of occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEOAE present and VEMP present</td>
<td>14</td>
<td>24.56</td>
</tr>
<tr>
<td>TEOAE present and VEMP absent</td>
<td>5</td>
<td>8.77</td>
</tr>
<tr>
<td>TEOAE absent and VEMP present</td>
<td>21</td>
<td>36.84</td>
</tr>
<tr>
<td>TEOAE absent and VEMP absent</td>
<td>17</td>
<td>29.82</td>
</tr>
</tbody>
</table>

It can be observed from the Table 4 that the condition in which the TEOAE being absent with VEMP present was more prevalent, followed by both TEOAE and VEMP absent whereas, ears with both TEOAE and VEMP present had intermediate occurrence. It is also evident that only a small percentage has TEOAE present with VEMP being absent.

From the above findings, it can be concluded that it is the cochlea which is more susceptible to noise exposure compared to the saccular part of the vestibular system. This is well supported by the anatomical positioning of the cochlea and sacculae wherein the cochlea is at more proximity to the stapes than the saccule. When the ear is exposed to noise, cochlea will be more susceptible. Hence, the outer hair cells of the cochlea would be affected before the macula of the sacculae resulting in abnormal TEOAE’s prior to abnormal VEMP responses. Ceranic (2007) stated that owing to mechanical force of noise exposure, the most extensive morphological changes are expected to be in the cochlea. Wang & Young (2007) reported abnormal VEMP responses in NIHL subjects and explained that the mechanism of NIHL can be classified either as direct mechanical injury or metabolic damage to the organ of Corti. Talasaka & Schacht (2007) reported that the direct mechanical damage is mostly caused due to chronic noise exposure. The extent of noise effect on cochlear blood flow appears to be heavily influenced by the duration and intensity of the noise exposure (Lamm & Arnold, 2000). Although the cochlea receives its blood supply mainly from the common cochlear artery, the sacculae is supplied by anterior and posterior vestibular arteries; all these arteries originate from the labyrinthine artery. Therefore, as the duration and intensity of the noise exposure increases, there is reduction in blood flow which leads to permanent hearing threshold shifts and abnormal VEMP responses.

F. Comparison of VEMP responses with the vestibular symptoms in the clinical group

To compare the VEMP responses with the presence or absence of any vestibular symptoms, cross tabulations were done. Here the frequency of the presence or the absence of VEMP was correlated with the presence or absence of vestibular symptoms. The Table 5 depicts the number of individuals exhibiting the vestibular symptoms in correlation with the absence of the VEMP responses. The subjects exhibited either one or more than one
symptom listed below. Two symptoms (Tullio phenomenon and walking in dark) which were not present in the questionnaire are listed in the table as it was reported by the subjects.

Table 5: Vestibular symptoms and the VEMP response in the clinical group.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Vestibular symptoms</th>
<th>Number of subjects (N)</th>
<th>% of the absent VEMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lightheadedness or swimming sensation in the head</td>
<td>3</td>
<td>66.66%</td>
</tr>
<tr>
<td>2</td>
<td>Blacking out or loss of consciousness</td>
<td>3</td>
<td>33.33%</td>
</tr>
<tr>
<td>3</td>
<td>Tendency to fall</td>
<td>3</td>
<td>33.33%</td>
</tr>
<tr>
<td>4</td>
<td>Objects spinning or turning around you</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Sensation that you are turning or spinning inside</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>6</td>
<td>Headache</td>
<td>5</td>
<td>80%</td>
</tr>
<tr>
<td>7</td>
<td>Pressure in the head</td>
<td>3</td>
<td>66.66%</td>
</tr>
<tr>
<td>8</td>
<td>Nausea or vomiting</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td><strong>Additional symptoms not present in the questionnaire</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Walking in dark</td>
<td>3</td>
<td>66.66%</td>
</tr>
<tr>
<td>10</td>
<td>Tullio phenomenon</td>
<td>2</td>
<td>50%</td>
</tr>
</tbody>
</table>

It can be observed from the Table 5 that the correlation of VEMP response in hierarchical order was maximum for symptom 5 and 8, followed by symptom 6. Further on, VEMP correlated equally for symptom 1, 7 and 9, followed by symptom 10. VEMP responses correlated least with symptom 2 and 3. The frequency of presence or absence of the vestibular symptoms and the VEMP responses in the clinical group are tabulated in Table 6.

Table 6: Frequency of presence or absence of the vestibular symptoms and the VEMP responses in the clinical group.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Number of ears (57)</th>
<th>Percentage of occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestibular symptom present and VEMP present</td>
<td>15</td>
<td>26.32</td>
</tr>
<tr>
<td>Vestibular symptom present and VEMP absent</td>
<td>13</td>
<td>22.81</td>
</tr>
<tr>
<td>Vestibular symptom absent and VEMP present</td>
<td>20</td>
<td>35.09</td>
</tr>
<tr>
<td>Vestibular symptom absent and VEMP absent</td>
<td>9</td>
<td>15.79</td>
</tr>
</tbody>
</table>

It is evident from the table 6 that the condition in which vestibular symptom was absent with VEMP response being present is most prevalent. Also the percentage of occurrence of the vestibular symptom being present with VEMP absent is higher. So, it can be inferred that out of 57 ears tested in the clinical group VEMP correlated with vestibular symptoms in 33 ears (57.89%).
In the present study “headache” was the most prevalent vestibular symptoms and correlation with VEMP was found to be good. Although, there were other vestibular symptoms that were in good correlation with VEMP, the numbers of subjects exhibiting these particular symptoms were less. Also, some individuals exhibited multiple symptoms and abnormal VEMP findings making it difficult to precisely point out the vestibular symptom best correlating with VEMP. This finding is in close relation with the study done by Kumar and Barman (2006). In their study they correlated the different dizziness symptoms with VEMP responses and reported that VEMP can be associated with symptoms like “objects spinning/turning around you”, tendency to fall, loss of balance when walking, nausea or vomiting. They concluded that subjects who complain these symptoms are likely to have saccular pathway lesions. But, they did not correlate VEMP responses with multiple symptoms, as many would have more than one symptom of dizziness. Thus, it can be concluded that vestibular symptoms that would originate from saccular origin and or inferior vestibular nerve pathologies may result in abnormal VEMP responses.

G. Correlation between VEMP responses with the degree of hearing loss in the clinical group: Pearson’s correlation analysis was done to evaluate the correlation between the VEMP & the degree of hearing loss for the clinical group. The results of the correlation analysis for the latency and amplitude measures of VEMP for the clinical group are outlined in Table 7.

Table 7: r Value and Significance Level for p13, n23 Latency and p13- n23 Amplitude w.r.t Degree of Hearing Loss for the Clinical Group.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Parameter</th>
<th>r-</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>p13 right</td>
<td>-0.07</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>p13 left</td>
<td>-0.18</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>n23 right</td>
<td>-0.09</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>n23 left</td>
<td>-0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>Amplitude</td>
<td>p13- n23 right</td>
<td>-0.36</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>p13- n23 left</td>
<td>0.08</td>
<td>0.71</td>
</tr>
</tbody>
</table>

It can be seen from the Table 7 that both the latency as well as amplitude measures are not correlated with the severity of the hearing loss for both right and left ear. The VEMP responses across different degrees of hearing loss are tabulated in Table 7.

Table 8: VEMP responses across different degrees of hearing loss.

<table>
<thead>
<tr>
<th>Severity of hearing loss</th>
<th>Response (No. of ears)</th>
<th>No response (No. of ears)</th>
<th>% of present response</th>
<th>% of absent response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal hearing with 3-6 kHz notch</td>
<td>3</td>
<td>1</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Minimal</td>
<td>15</td>
<td>5</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Mild</td>
<td>12</td>
<td>7</td>
<td>63.16</td>
<td>36.48</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>2</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Moderately severe</td>
<td>2</td>
<td>3</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
It is evident from the table 8 that in ears with normal hearing with 3-6 kHz notch and those with minimal degree of hearing loss showed equal percentages of presence and absence of VEMP responses. For degree of hearing from mild to severe loss, the frequency of presence of VEMP response decreased and occurrence of absence of response increased and for the severe degree of hearing loss none of the ears showed presence of VEMP. The results of the present study revealed that the degree of hearing loss did not correlate with the VEMP results. Similar findings have been reported by Hsu, et al., (2008) who assessed the saccular functioning in guinea pigs that were exposed to noise and concluded that the saccule can exhibit temporary or permanent functional loss. Wang, Hsu and Young (2006) reported that VEMP test may provide another clue for assessing the hearing outcome. He concluded that VEMPs in patients after acute acoustic trauma showed absent or delayed VEMP responses which indicate poor prognosis with respect to hearing improvement. Young and Cheng (2007) reported more absent VEMP responses with increasing degree of hearing loss in subjects with NIHL. In the present study though there was no correlation between the VEMP responses and degree of hearing loss, the trend of response suggested that as the degree of hearing loss increased the frequency of presence of VEMP response decreased and occurrence of absence of VEMP response increased and for the severe degree of hearing loss none of the ears showed presence of VEMP. Wang and Young (2007) reported that in patients who were exposed to noise with bilateral 4 kHz notched audiogram and hearing threshold of 4 kHz ≥ 40 dB showed abnormal (absent or delayed) VEMPs, indicating that the vestibular part, especially the sacculocollic reflex pathway, has also been damaged. Hara and Kimura (1993) attributed the abnormal VEMP findings to the differential sensitivity (possibly because of membrana limitans) of cochlea and saccule from that of other vestibular structures (utricle and saccule). It can be concluded that in general, VEMP does not correlate with degree of hearing loss, but in cases of noise exposure (acoustic trauma and chronic noise exposure) higher degree of hearing loss may affect the VEMP response and thus may be indicative of saccular involvement.

H. Correlation between TEOAE responses with the degree of hearing loss in the clinical group

Pearson’s correlation analysis was done to evaluate the correlation between TEOAE and the degree of hearing loss for the clinical group. The results of the correlation analysis for the TEOAE amplitude measures for the clinical group are outlined in Table 8.

Table 9: r - Value and significance level for TEOAE amplitude for the clinical group.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>r</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEAOE ampl. right</td>
<td>.55**</td>
<td>.00</td>
</tr>
<tr>
<td>TEAOE ampl. Left</td>
<td>.40*</td>
<td>.03</td>
</tr>
</tbody>
</table>

Note. *p< 0.05, **p< 0.01

It can be seen from the table 9 that the TEOAE amplitude is highly correlated with the severity of the hearing loss for both right and left ear. The TEOAE responses across the different degrees of hearing loss are tabulated in Table 9.
Table 10: TEOAE amplitude responses across different degrees of hearing loss

<table>
<thead>
<tr>
<th>Severity of hearing loss</th>
<th>Response (No. of ears)</th>
<th>No response (No. of ears)</th>
<th>% of present response</th>
<th>% of absent response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal hearing with 3-6 kHz notch</td>
<td>5</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Minimal</td>
<td>9</td>
<td>11</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>Mild</td>
<td>6</td>
<td>13</td>
<td>31.58</td>
<td>57.89</td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Moderately severe</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Severe</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

It can be seen from Table 10 that the percentage of presence of TEOAE response reduced as the degree of hearing loss increased. Also, it can be observed that from moderate degree of hearing loss, there was absence of TEOAE response. Findings of the present study are in consonance with literature. Probst, LonsBury, Martin and Coats (1987) demonstrated that noise induced high frequency hearing loss was associated with a reduction in the number of prominent peaks in the spectra of TEOAE’s and that TEOAE’s were absent for hearing loss above 25-30 dB. Desai, Reed, Cheyne, Richards and Prasher (1999) reported that in 56% of the subjects with NIHL, TEOAEs were absent as compared to controls (0%). They concluded that the reduction in incidence of OAEs in the noise exposed group may be associated with sensory cell damage to localized cochlear regions sub-serving specific frequencies. From the above it can be concluded that noise exposure have severe effect on the OHC’s and that TEOAE’s are very sensitive to any damage to the OHC’s. Hence, the strong correlation between TEOAE and degree of hearing loss is rightly justified.

Conclusion

The two parameters of VEMP, p13 latency and p13- n23 complex amplitude parameters of VEMP could be considered to show the effect of noise on saccular system which was obtained significantly different. VEMP is expected to be affected or absent in clients with the dysfunction of the vestibular system, as in the current study, all the individuals with symptoms of “Sensation that you are turning or spinning inside” and “Nausea or vomiting” had absent VEMP responses indicating saccular involvement in NIHL group. It is also evident that the cochlea is more susceptible to noise in these individuals with NIHL as the TEOAE was absent in most of the client with NIHL.

References


VEMP in NIHL Individuals


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Comparison of Functional Gain and Insertion Gain in Linear and Non-linear Hearing Aids

Meenakshi Dayal & P. Manjula*

Abstract

Hearing aid selection and fitting is a step-wise procedure involving hearing evaluation, pre-selection of hearing aid, hearing aid fitting, verification of hearing aid, and validation. As verification is one of the important steps, there is a need to evaluate the subjective and objective verification measures for the linear and non-linear hearing aids. This is because these hearing aids differ in terms of the amount of gain they provide at different input levels. To evaluate the effectiveness of the verification measures, 20 children with hearing impairment using hearing aids participated in the study. These children were in two age groups, Group I with 4+ to 5 years, and Group II with 5+ to 6 years. The results indicated no difference for insertion gain measures between the two age groups. The results also revealed that either the IG or FG can be used as verification measures, for linear hearing aids. This is because both of them provide comparable results for linear hearing aids. However, the values of FG and IG were different for non-linear hearing aids. The IG measures carried out at different levels reflected the non-linear functioning of a hearing aid.

Key words: verification measures, intensity levels, pure tone signal, ANSI digi speech signal.

Introduction

Consistent audibility of speech at levels ranging from soft to loud is a pre-requisite for the development of spoken language. This fact is reflected in the Paediatric Amplification Guidelines (2004) by American Academy of Audiology. These guidelines state that the goal of amplification for children with significant hearing impairment is ‘to provide a hearing aid that makes low, moderate, and high intensity sounds audible but not uncomfortable and provide excellent sound quality in a variety of listening environments’.

A hearing aid amplifies the weak sounds as well as moderate to loud level of sounds. The linear hearing aids apply the same amount of gain to the incoming sounds regardless of the level of sounds entering the hearing aid (Palmer, Lindley, & Mormer, 2000). Whereas in a non-linear hearing aid, more gain is applied to the soft sounds and lesser gain is applied to louder sounds. Thus, the verification of hearing aid fitting should reflect such a change in the response of the client while using these hearing aids.

Currently available hearing aid verification tools such as functional gain measurement which is a behavioral measure, is the difference in the unaided and aided hearing thresholds in a sound field (Stelmachowitz, Hoover, Lewis, & Brennan, 2002). The functional gain (FG) is the measurement done only at one level and hence it reflects the hearing aid gain at

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only one input level or at low input levels. Thus, the FG seems to be more appropriate for evaluation of linear hearing aids that give a constant gain irrespective of the level of the input signal (Kuk & Ludvigsen, 2003). Tharpe, Fino-Szumski, and Bess (2001) reported that approximately 60% of the audiologists verify hearing aid gain and frequency response settings for young children using behavioral measures such as sound field thresholds. In the school settings, nearly 80% of audiologists use these measures to adjust and fit the hearing aids. For evaluating the non-linear hearing aids, one of the limitations of FG lies with the fact that the FG represents only the response of the hearing aid for low level of signal (Tecca, Woodford, & Kee, 1987). Thus, FG is not an appropriate measure to evaluate non-linear hearing aids that provide different gain at different levels of input signals.

In recent years, there has been increased interest in the use of articulation index (AI) not only for assessing the audibility of speech but also for measuring the potential effectiveness of the amplification systems. This interest has been reinforced because of the ability of the AI to explain the amount of difficulty the person with hearing impairment will have in understanding speech (Kamm, Dirks, & Bell, 1985). The practical application of AI also has been fueled by the popularity of prescriptive fitting strategies and the development of computerized probe-microphone measures (Mueller & Kilillion, 1990).

The Real Ear Insertion Gain (REIG) measurements take all these parameters into consideration. The Real Ear Insertion Gain (REIG), an objective equivalent of functional gain measure, is determined by measuring the Sound Pressure Level (SPL) at the ear drum without a hearing aid i.e., the Real Ear Unaided Gain (REUG) and subtracting this from the SPL at the ear drum with the hearing aid in the ear i.e., Real Ear Aided Gain (REAG) (Hawkins, 2004). In order to know how the hearing aid functions at different input levels, insertion gain measurement would be more appropriate. The insertion gain (IG) measurement provides a quick, more reliable and efficient method of quantifying the in-situ performance of hearing instruments than the functional gain method (Stelmachowicz, Hoover, Lewis, & Brennan, 2002).

**Need for the study**

To assess the suitability of different signal processing strategies for children who have hearing impairment from early life, it is important to evaluate the strategies using a representative sample of those children, rather than generalizing or extrapolating from results derived from adult subjects with acquired hearing loss. There is relatively little published research on the use of non-linear amplification for young children, although there are a few studies with older children and adolescents (Bamford, McCracken, Peers, & Grayson, 1999). Hence, there is a need to compare the functional gain measurement with insertion gain measurement, as the functional gain is difficult to obtain from paediatric population.

For evaluation of the non-linear hearing aid, it is possible to measure the gain provided by the hearing aid at different levels of the input signal using insertion gain measurement (ASHA, 1997, Paediatric Working Group, 1996). Objective measures such as
insertion gain can depict the gain provided by different hearing aids at different levels as it can assess the hearing aid circuitry at different levels which is not possible through the subjective measures such as functional gain for warble tone. The current study attempts to compare the usefulness of insertion gain measurement with that of functional gain measurement for verification of the performance of linear and non-linear hearing aids. The prescriptive procedures for non-linear hearing aids use different target gains for different levels of the input signals and the hearing aid gain is adjusted to match these targets. This provides valuable information like audibility of speech over a range of commonly experienced input levels such as soft, average and loud speech. Hence, it is necessary to compare the FG and IG of hearing aids to see if one can be used instead of the other for hearing aids using different technologies (Hawkins, 2004).

The objectives of the study included comparison the insertion gain (IG) of hearing aid across the age groups in children; comparison of different types of signals used for insertion gain measurement; comparison of linear and non-linear program modes using insertion gain measurement; comparison of insertion gain (IG) and functional gain (FG) for linear and non-linear hearing aids; and finally to investigate the relationship between the speech identification scores and the articulation index derived from the insertion and functional gain measures.

Method

Participants

Twenty children with hearing impairment using hearing aids participated in the study. The children used different models of Behind-The-Ear (BTE) hearing aids, and all of them wore their hearing aids through most of their waking hours, i.e., not less than eight hours per day. The participants had moderately severe to profound degree of sensorineural hearing loss. All the participants were native speakers of Kannada language attending the pre-school and/or individual therapy session at All India Institute of Speech and Hearing, Mysore. All the participants were at or above the stage of closed-set word identification. The participants were divided into two groups. Group I consisted of four male and six female children in the age range from 4+ to 4.11 years (mean = 4.4 & SD = 0.33). Group II consisted of two male and eight female children in the age range from 5+ to 5.11 years (mean = 5.56 & SD = 0.37)

Instruments / Material used

A calibrated sound field audiometer (Madsen OB922, version 2) was used. A calibrated hearing aid analyzer (Fonix 7000 Hearing Aid Test System, version 1.8) also used. Aided Testing was done with a digital BTE hearing aid, coupled with custom ear mold. This hearing aid had six channels with a fitting range from moderate to profound degree of hearing loss. The hearing aid was programmed in two different program modes:

i) Non-linear program mode

ii) Linear program mode
Hardware and software was used to program the hearing aids, i.e., a personal computer connected to HIPRO for programming the hearing aid. The NOAH software (version 3.1.2) and the hearing aid specific software (Aventa, version 2.6) along with WinCHAP (Computerized Hearing Aid Program for Windows, version 2.82) software were installed in this personal computer. Picture identification test material in Kannada was developed by Vandana (1998). This had four lists, each with 25 bi-syllabic PB (phonemically balanced) words.

Procedure

The testing was performed in an air conditioned sound treated double or single room environment.

Stage I: Optimization of Parameters for Non-linear and Linear Program Modes

Initially the hearing aid was programmed in ‘auto-fit’ feature for linear mode in the hearing aid specific software. For optimizing the hearing aid program in linear mode, insertion gain measurement was carried out. The hearing aid gain was matched with that of the NAL-R target gain. This was stored as Program 1 (P1) of the hearing aid.

In a similar way, the gain was also programmed for the non-linear mode and the hearing aid parameters were optimized to match the NAL-NL1 prescription (Dillon, 1999). As the NAL-NL1 formula is for non-linear hearing aids, it provides more gain for the soft level of sounds, and lesser gain for higher level of sounds. As there were two separate programs available in the test hearing aid, the NAL-R setting was stored in Program 1 (P1) and the NAL-NL-1 settings was stored in Program 2 (P2) of the hearing aid.

In each age group and for each participant, the measurement was done only for one ear, equal numbers of right and left ears were considered. Custom made soft ear molds were used to couple the test hearing aid to the ear of the participant during the measurement.

Stage II: Verification of Hearing Aid Fitting Through Insertion Gain Measurement

Verification through insertion gain measurement was done using pressure method of sound field equalization. In this method, the reference microphone was placed as close to the hearing aid microphone as possible during the measurement. The reference microphone monitored the SPL reaching the hearing aid from the loudspeaker of the Fonix 7000 hearing aid analyzer.

After setting up the participant and the instrument for insertion gain measurements, the Win CHAP (windows based Computerized Hearing Aid Program) software enabled for storing the participant’s data and hearing aid data. The IG measurement was carried out for pure tone and ANSI digi speech signals for linear and non-linear program modes for each of the participant.
1. Data tabulated from unaided response for pure tone and ANSI digi speech signal included: Real ear unaided gain (REUG) for three input levels (50 dB SPL, 65 dB SPL and 90 dB SPL) at different frequencies.

2. Data tabulated from aided response for pure tone and ANSI digi speech signal for linear and non-linear program modes of the hearing aid included: Real ear aided gain (REAG) for three input levels signal of (50 dB SPL, 65 dB SPL, and 90 dB SPL) at different frequencies.

3. Insertion gain was obtained by subtracting the unaided gain from the aided gain at different frequencies, separately for all the three different levels, i.e., at 50, 65, and 90 dB SPL for linear program mode. The different frequencies at which the insertion gain were noted were 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. For each of the participant, a similar procedure was carried out for non-linear program mode of hearing aid also.

4. Articulation Index (AI) calculation from insertion gain method.

5. The count-the-dot method for calculating the AI was utilized to convert the REIR into the AI values, as recommended by Mueller and Killion (1990). The AI was calculated for three different levels 50, 65, and 90 dB SPL for linear as well as non-linear program modes. Thus, for each participant six AI values - three in linear program mode & three in non-linear program mode - were obtained.

Stage III: Functional gain measurement (FG measurement)

The functional gain, using aided thresholds and Speech Identification Scores (SIS), were measured for linear and non-linear program modes of the hearing aid for each participant.

a. The FG measurement was carried out with a calibrated sound field audiometer. The loudspeaker was located at a distance of one meter and 45 ° Azimuth from the test ear of the participant, in the calibrated sound field. For the measurement of FG, the unaided thresholds for warble tone signals were obtained. The aided thresholds, obtained after fitting the hearing aid in linear program mode and later in the non-linear program mode, were measured at octave and mid-octave intervals from 250 to 6000 Hz. The difference between unaided and aided threshold at each of these frequencies were computed to obtain the functional gain at that frequency.

b. The count-the-dot method for calculating the AI was utilized to convert the aided thresholds into the AI values, as recommended by Muller and Killion (1990). For each participant two AI values (one in linear program mode & one in non-linear program mode) were obtained.

c. Further, the unaided and aided SIS were also obtained, using speech identification test in Kannada (Vandana, 1998), at three levels which was equivalent to the presentation levels used during insertion gain measurement. The SIS was measured for linear as
well as non-linear program modes at 35 dB HL, 50 dB HL, and 75 dB HL (equivalent to 50, 65, & 90 dB SPL respectively).

For each of the participant, a total of 25 words were presented at each of the above mentioned presentation levels. The closed set response mode was used to elicit the responses at each level. Both the order of the test material and level of presentations were randomized. The scoring was done by noting the number of correct pictures being identified. Each word identified correctly was given a score of one and the incorrect identification was given a score of zero. The maximum score was 25 as there were 25 words in the word list. The same procedure was followed for both linear as well as non-linear program modes of the hearing aid, for each participant.

Results and Discussion

Descriptive statistics and the tests of significant difference were carried out on the data using Statistical Package for the Social Sciences (SPSS) software. Results revealed that the insertion gain measure was not significantly different for both the age groups. But the functional gain and insertion gain measures differed with respect to the level of the signal and the program mode used.

1. Insertion gain for pure tone and ANSI digi speech signals in linear and non-linear program modes for Group I and Group II.

In order to know if the difference between pure tone and ANSI digi speech was significant, mixed ANOVA was done. The frequencies were grouped into low (200 and 500 Hz), mid (1000 and 2000 Hz) and high (4000 and 6000 Hz) frequencies. The average IG at the low-, mid- and high- frequency regions in linear and non-linear program modes for pure tone signal along with the significance of difference is given in Table 1.

Table 1. IG difference between Group I and Group II across frequencies at 50 dB SPL, 65 dB SPL, and 90 dB SPL for pure tone signals, in linear and non-linear program modes.

<table>
<thead>
<tr>
<th>Frequencies</th>
<th>Intensity level (in dB SPL)</th>
<th>Significant difference between Group I and Group II</th>
<th>IG for linear</th>
<th>IG for non-linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low frequencies</td>
<td>50</td>
<td>F(1,18) = 0.42</td>
<td>F(1,18) = 0.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 0.00</td>
<td>F(1,18) = 0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 0.65</td>
<td>F(1,18) = 0.52</td>
<td></td>
</tr>
<tr>
<td>Mid frequencies</td>
<td>50</td>
<td>F(1,18) = 0.65</td>
<td>F(1,18) = 0.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 0.04</td>
<td>F(1,18) = 0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 0.09</td>
<td>F(1,18) = 0.61</td>
<td></td>
</tr>
<tr>
<td>High frequencies</td>
<td>50</td>
<td>F(1,18) = 5.18*</td>
<td>F(1,18) = 1.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 0.60</td>
<td>F(1,18) = 1.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 0.17</td>
<td>F(1,18) = 1.27</td>
<td></td>
</tr>
</tbody>
</table>

Note: * = significant difference at p < 0.05 level
For pure tone signals, in linear as well as for non-linear program modes, the mixed ANOVA revealed that there was no significant difference in the mean IG between the two age groups for pure tone signals at all frequencies, with an exception at 50 dB SPL for high frequencies (p<0.05) in linear program mode.

Similarly, for mean ANSI digi speech signal also, mixed ANOVA revealed no significant difference in the mean IG between the two age groups. This was true for the low-, mid- and high- frequency regions at different intensities in linear and non-linear program modes (Table 2).

Table 2: IG difference between Group I and Group II across frequencies at 50 dB SPL, 65 dB SPL, and 90 dB SPL for ANSI digi speech signal, in linear and non-linear program modes.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Intensity level (in dB SPL)</th>
<th>Significant difference between Group I and Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IG for linear</td>
</tr>
<tr>
<td>Low frequencies</td>
<td>50</td>
<td>F(1,18) = 0.06</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 0.34</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 0.13</td>
</tr>
<tr>
<td>Mid frequencies</td>
<td>50</td>
<td>F(1,18) = 0.86</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 3.58</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 1.15</td>
</tr>
<tr>
<td>High frequencies</td>
<td>50</td>
<td>F(1,18) = 2.13</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>F(1,18) = 4.76</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>F(1,18) = 1.49</td>
</tr>
</tbody>
</table>

Bentler (1989) reported that the average external ear resonance characteristics for children (three to thirteen years of age) appeared to be similar as adults, but some small differences were noted above 3000 Hz. The difference in measured SPL between adults and children were 3-5 dB. Whereas Seewald, Cornelisse, and Ramiji (1997) have reported the age related differences in the SPL in the ear canal for children from the birth to seven years of age. The current study findings suggested no significant difference in SPL in the ear canal for 4 + to 4.11 years and 5+ to 5.11 years. This might be attributed to the maturational changes in the resonance properties of the external ear not being significant during the four to six years of age.

As, there was no significant difference obtained between the two age groups for insertion gain measures (for both pure tone and ANSI digi speech signals), the data from the two groups were combined for further statistical analyses.

2. Mean and significant difference between the IG for pure tones and ANSI digi speech signals in linear and non-linear program modes:
Figure 1 depicts the mean insertion gain for pure tone signals in linear and non-linear program modes. The mean was computed at three different levels in order to know whether there was a different trend observed for linear and non-linear program modes for pure tone signal. The mean of IG in linear program mode was obtained and paired t-test was administered in order to know whether there was any significant difference between the mean insertion gain at three different levels for pure tone and ANSI digi speech signals, in linear and non-linear program modes, as depicted in Figures 1 and 2.

For pure tone signals, the mean values for IG at lower levels showed a similar trend for non-linear and linear program modes. This trend was observed for moderate and higher signal levels also. Figure 2 depicts the mean insertion gain for ANSI digi speech signals in linear and non-linear program modes. The mean IG was computed at three different levels in order to know whether there was a different trend observed for linear and non-linear program modes for ANSI digi speech signal.
From Figure 2, it can be inferred that the mean IG for non-linear program mode is higher than the linear program mode at lower levels of signals across the frequencies. The IG reflected the functioning of the non-linear hearing aid by recording more gain at low input signal levels which was not observed for linear hearing aid. Whereas, the mean IG values were similar for mid and higher levels of ANSI digi speech signals, which indicated both linear and non-linear program modes provided similar amount of gain at moderate and higher signal levels.

These results suggested that the gain varies for the linear and non-linear program modes with respect to the type of input signal used for the measurement. For ANSI digi speech signal and pure tone signal in linear program mode there was a significant difference obtained which suggested that pure tone and ANSI digi speech cannot be substituted for one another. It can be attributed to the amount of gain provided by the hearing aid which varies if the signal spectral and temporal characteristics of the signal are different.

In general, the speech-weighted signals provide a closer match to aided speech levels, than constant-level pure tone sweeps, which tend to overestimate aided output. The findings also suggested that aided levels of pure tone signals should not be used to estimate the aided levels of real speech in sound pressure level. The mismatch between the two types of signals was primarily due to the large difference in input levels between the conventional pure tone sweep and real speech across frequencies. Thus, ANSI digi speech signals are to be used for measurement of insertion gain of hearing aids. Hence, for further analyses only ANSI digi speech signal was considered.

The current study also supported the view that the insertion gain for pure tone and ANSI digi speech signals are significantly different because of their different temporal and spectral characteristics.

3. Difference between FG and IG

The difference between the mean FG and IG was analyzed using descriptive statistics and test for significant difference. The difference between the FG and IG at three intensity levels were computed across the frequencies to find out the mean and SD for linear as well as non-linear program modes. The comparison of mean and SD values for the difference in FG and IG, in linear and non-linear modes, across frequencies are depicted in Figure 3.

The difference between FG and IG were analyzed. The mean and standard deviation (SD) of this difference were obtained at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz at one level of functional gain and all three levels of signal for insertion gain including 50 dB SPL, 65 dB SPL, and 90 dB SPL for pure tone signals in linear program mode. At each of the three input levels for IG, the difference of FG and IG was obtained and the mean and SD were calculated.
Figure 3: Mean and standard deviation of the difference between FG and IG for pure tone signals at 50 dB SPL, 65 dB SPL, and 90 dB SPL across frequencies for linear and non-linear program modes.

The negative value for non-linear program mode at 50 dB SPL suggests that insertion gain exceeded the functional gain at three frequencies (500 Hz, 1000 Hz, and 2000 Hz). Whereas, at 4000 Hz the mean functional gain value exceeded the mean insertion gain value. The difference between the functional gain and insertion gain at 65 dB SPL for 500 Hz, 1000 Hz, and 2000 Hz was very minimal for linear program mode. The difference between the FG and IG at 90 dB SPL was a positive value, depicting that the FG values exceeded the IG at all the four frequencies (500 Hz, 1000 Hz, 2000 Hz, & 4000 Hz) for linear program mode. In addition, Figure 3 also depicts the difference between mean functional gain and mean insertion gain at for non-linear program mode. The results showed a similar trend as in linear program mode.
The difference between FG and IG is lesser in linear program mode compared to non-linear program mode. This indicates that FG and IG are parallel measures for the linear hearing aids, especially at moderate level of signal. The difference being more for non-linear program mode indicates that the FG and IG are not similar measures. Further, for non-linear program mode, the IG is a more realistic measure as the IG decreased with increase in input intensity.

The IG measure reflected more gain for soft level of signal and moderate gain for moderate level of signal and lesser gain for higher level of signal. Further, IG is a more realistic measure as IG decreases with increase in input intensity. This is because, in the non-linear hearing aids, there is decrease in gain with increase in input level. This cannot be measured or reflected through the FG. FG is mainly a measure which predicts the gain at low levels (at threshold) or moderate levels of signal. Thus, the amount of gain provided at high level of signals cannot be measured through FG, as the FG measured differed from IG at higher levels.

FG and IG difference at 65 dBSPL in the current study were within 8 dB which was close to 5 dB as reported by Mason and Popelka, (1986). This was observed for three frequencies, i.e., 500 Hz, 1000 Hz and 2000 Hz in linear program mode. The FG can be predicted or substituted by IG if the IG measurement is carried out at moderate level of signals. In other words IG and FG provide similar measurements at moderate levels of signals. As the results depicted that the difference between the FG and IG is more at higher signal levels across the frequencies, it is suggested that, FG and IG measures cannot be substituted for each other at low and high signal levels. It provides insight to the fact that for evaluation of the hearing aid performance at higher signal levels, insertion gain is a more realistic measure, which can reflect the non-linear gain.

To find out if FG and IG difference was significant, paired t-test was administered. In the present study for linear hearing aids, it was noted that there was a significant difference between the FG and the IG at low and high levels for pure tones. At moderate levels, there was no significant difference between the FG and the IG at 500, 1000 and 2000 Hz. For non-linear hearing aids, it was noted that the FG and the IG differed significantly at low and high levels of pure tones. But, FG correlated well with the IG at average conversational level. Thus, it is suggested that insertion gain measurement done at moderate level is a better predictor of functional gain measurement. Jenstad, Seewald, Cornelisse, and Shantz (1999) reported that speech intelligibility testing and loudness rating carried out for linear as well as WDRC resulted in equivalent comfort and intelligibility for average input levels. But FG was considerably different from IG at three input levels for linear as well as for non-linear program modes especially for higher frequencies. This suggested that IG at any level (50 dB SPL, 65dB SPL, and 90 dB SPL) cannot be used as a substitute for functional gain. Both the measures need to be evaluated independently for high frequency FG or IG measurements. In the present study, the insertion gain at moderate intensity and the functional gain are the best predictors of the performance of the hearing aids in linear and non-linear program modes, as the correlation of FG and IG was best at conversational level. But, it’s not always
true with non-linear hearing aids. Because the gain provided by the non-linear hearing aid is considerably high at soft signal a level.

4. Relationship between SIS and AI

For linear mode, the relationship between Speech Identification Scores (SIS) at three levels (SIS$_{35}$, SIS$_{50}$ dB, & SIS$_{75}$ dB) with that of articulation index computed from FG measure (AI$_{FG}$) and articulation index computed from IG measure (AI$_{IG}$) was investigated. This was done only for ANSI digi speech signals as its relationship with SIS was being analyzed. This was also done for non-linear program mode, as shown in Table 3. On Pearson’s correlation analysis, the correlation was higher with AI$_{FG}$ than with AI$_{IG}$ in both the program modes.

Table 3: Correlation of Articulation index from the FG (AI$_{FG}$) and IG (AI$_{IG}$), in linear and non-linear program modes, with Speech Identification Scores (SIS) at different levels.

<table>
<thead>
<tr>
<th>Pearson Correlation between</th>
<th>Linear</th>
<th>Non-linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS$_{35}$</td>
<td>AI$_{FG}$</td>
<td>r = 0.59*</td>
</tr>
<tr>
<td></td>
<td>AI$_{IG,50}$</td>
<td>r = 0.40</td>
</tr>
<tr>
<td>SIS$_{50}$</td>
<td>AI$_{FG}$</td>
<td>r = 0.39</td>
</tr>
<tr>
<td></td>
<td>AI$_{IG,65}$</td>
<td>r = 0.16</td>
</tr>
<tr>
<td>SIS$_{75}$</td>
<td>AI$_{FG}$</td>
<td>r = 0.36</td>
</tr>
<tr>
<td></td>
<td>AI$_{IG,90}$</td>
<td>r = 0.08</td>
</tr>
</tbody>
</table>

Note: * = Significant correlation at p < 0.05 level

The Pearson’s correlation indicated a significant correlation between SIS$_{35}$ and AI$_{FG}$ in linear program mode. Whereas, there was no significant correlation obtained for SIS$_{50}$ with AI$_{FG}$ and SIS$_{75}$ with AI$_{FG}$ in linear program mode. A significant correlation was obtained between SIS$_{35}$ and AI$_{FG}$ in non-linear program mode. Whereas, there was no significant correlation obtained for SIS at other levels and AI$_{FG}$. The overall trend was similar in both the program modes. Jenstad, Seewald, Cornelisse, and Shantz (1999); Marriage and Moore (2003) reported that the linear hearing aid as well as WDRC (non-linear) hearing aids provided more gain at low input levels (soft speech) than for speech at moderate level. But the processing type and presentation level were not statistically significant in most of the participants. The reason for this might be that WDRC used in their study was a hearing aid with single channel and children with profound hearing loss were using hearing aid with linear amplification strategy. They were not given time for acclimatization with the non-linear hearing amplification strategy.

The present study indicated that AI from functional gain correlated better with the lower level of SIS in non-linear as well as in linear program modes, indicating that AI at soft levels can be a predictor for SIS at soft levels.

On Pearson’s correlation analysis, in linear program mode, though there was a positive correlation, it was not significant (p>0.05). For non-linear mode, a significant
correlation between SIS_{35} and A_{IG,50} was noted. Whereas, there was no significant correlation obtained for SIS with A_{IG} at other levels. In the present study, AI from IG at low levels (50 dB SPL) correlated well with the SIS at 35 dB HL in non-linear program mode. Whereas, there was no significant correlation found for linear program mode between A_{IG} and SIS at any of the levels. Scollie and Seewald (2002) suggested that the match between the aided test signal and aided speech was different for high level of signals. For the composite signal, the tests at high intensities tended to underestimate the aided speech levels, primarily in the mid- to high-frequency region for linear as well non-linear hearing aids.

Dillon (1993) reported that speech gain in quiet provided by a hearing aid can be accurately predicted from electro-acoustic information comprising of the participant’s thresholds, internal hearing aid noise and, and the hearing aid’s insertion gain for mild to moderate degree of hearing loss. But, as the hearing loss increases, the distortions such as reduced frequency and temporal resolution makes it less likely that audible energy will continue to be equally useful. This might be the reason in the current study that the IG did not correlate well with the SIS because as the degree of hearing loss increases, the frequency and the temporal resolution become poorer. And also with increase in the degree of hearing loss, more amount of gain is required which in turn induces distortion. Results indicated that in children with moderate to profound degree of hearing loss, the IG measures are not good predictor of the speech measures.

From the study it can be inferred that the IG and FG can be used as verification measures, for linear hearing aids. This is because both of them provide comparative results for linear hearing aids. However, the values of FG and IG were different for non-linear hearing aids. Moreover, the IG measures can be carried out at different levels which provide a better estimation of gain across the frequencies. This is important for evaluating the performance of non-linear hearing aids as it functions differently at different input levels.

For ANSI digi speech signal, the IG were significantly different for linear and non-linear hearing aid indicating that the insertion gain provided by ANSI digi speech differed significantly across the program modes. It revealed functioning of the hearing aid which was different for linear and non-linear program mode though the input level was the same. However, for pure tone signal the insertion gain was similar for linear and non-linear program modes. So, ANSI digi speech signal is a better measure to predict the performance for linear as well as non-linear hearing aid.

For verification of linear and non-linear fitting, the difference between FG and IG was least for moderate level of signals. This suggested that both the measures can be used for verification, if performance of the hearing aid needs to be verified for moderate signal levels. At low and high levels, the difference between FG and IG was more for non-linear program mode compared to linear program mode indicating that the FG and IG should be used as two separate measures. The IG being a better reflector of the hearing aid performance at low and high levels, verification would be effective if performed with IG measure.
The AI from functional gain can be used to predict the SIS for soft signal levels (at 35 dB HL), for linear as well as non-linear program modes. Whereas, AI from functional gain is not a good predictor of SIS at moderate and higher levels (50 dB HL & 75 dB HL).

Clinical Implications

From the results of the present study the following implications can be inferred that:

1) The insertion gain measure can be used as an important tool in order to verify the hearing aid fittings, especially for non-linear hearing aids.
2) Insertion gain can be used as a realistic tool for predicting the hearing aid gain at different signal levels (soft, moderate & loud).
3) As the IG for ANSI digi speech provides more realistic information about real speech, this type of signal should be preferred compared to pure tone signals for verification.
4) Functional gain and insertion both can be used to evaluate the children’s performance with the hearing aid at moderate signal levels as they are comparable at moderate levels.
5) The AI from FG measure can be used to predict the SIS, if the SIS is done at low intensity level.

References


Frequency Discrimination and Speech Identification Abilities in Individuals with and without Cochlear Dead Regions

Megha & S. N. Vinay*

Abstract

The aim of the study was to assess the frequency discrimination and speech identification abilities and also to assess the correlation between the frequency discrimination abilities and speech identification abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies. TEN (HL) test was administered to assess the presence of absence of dead regions. Frequency modulation difference limens (FMDLs) were obtained and consonant-vowels (CVs) both unfiltered and filtered till the edge frequency was presented to both the groups. FMDLs were better in individuals with dead region and better near the edge frequency. The scores for filtered CVs were better in individuals with dead region than for the unfiltered CVs. However, there was no correlation between the FMDLs and the speech identification scores in individuals with dead region. The enhanced frequency discrimination in individuals with dead region might be due to cortical re-organization and better performance in filtered speech conditions helps in further rehabilitation of these individuals.

Key words: TEN (HL), FMDL, Speech identification.

Introduction

Cochlear hearing loss has many causes and it is often seen that the damage is caused to the outer hair cells (OHCs) and inner hair cells (IHCs) in the cochlea (Moore, 2004a). A dead region (DR) can be defined as a region in the cochlea where the IHCs and/or neurons are functioning very poorly, if at all present (Moore, 2001). DRs are relatively common among young and adult people with severe-to-profound sensorineural hearing impairment (Moore et al., 2003; Preminger, Carpenter & Ziegler, 2005; Alexander, Cox, Rivera, Johnson & Gardino, 2007; Vinay & Moore, 2007a; Aazh & Moore 2007).

Cochlear damages have been shown to induce changes in tonotopic maps in the central auditory system of animals. Neurons deprived from peripheral inputs start to respond to stimuli with frequencies close to the cut-off frequency or edge of the hearing loss, which then become over-represented at the neural level (Thai-Van et al., 2007). This neuronal arborization is mainly due to the effect of off-frequency listening, which a common phenomenon is observed in individuals with sensorineural hearing loss (Patterson & Moore, 1986).

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Studies have examined whether discrimination abilities were enhanced near the hearing loss $fe$ in patients with hearing loss of cochlear origin (Buss, Hall, Grose, & Hatch, 1998; Mc Dermott et al., 1998; Thai-Van, Micheyl, Norena, & Collet, 2002). The latter two studies revealed that the difference limens for frequency (DLFs) were found to be significantly enhanced at or near the $fe$ in patients with steeply sloping, high-frequency hearing loss, estimated using the TEN (SPL) test.

Thai-Van, Micheyl, Moore, and Collet (2003) suggested that local improvement in difference limen frequency (DLFs) represents a side effect of neurophysiological mechanisms that have no major perceptual consequences on speech or music perception. However, studies of the intelligibility of low-pass filtered speech for individuals with DRs suggest that this may not be true. Under some filtering conditions individuals with DRs obtain better scores than individuals without DRs (Vestergaard, 2003; Vickers, Baer, Fullgrabe, Vinay & Moore, 2006).

**Need for the study**

The relationship between frequency discrimination abilities and speech identification abilities are not similar in individuals with DR and those without DR. This is proven by the various consequences of DR, like altered perception of loudness, pitch and speech which is different from that of an individual with sensorineural hearing loss without DR. Thus, these phenomenon need to be studied, as these have implications in fitting the amplification devices for individuals with DR.

**Objective of the study**

The objectives of the study are:

1. To assess the frequency discrimination abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies.
2. To assess the speech identification abilities in individuals without and with cochlear dead region at 1 kHz, 2 kHz and 4 kHz edge frequencies.
3. To assess the correlation between the frequency discrimination abilities and speech identification abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies.

**Method**

The present study was conducted with an aim of studying frequency discrimination and speech identification abilities in individuals with and without dead regions. The study also aimed at correlating the frequency discrimination and speech identification abilities in individuals with and without dead regions.
Participant selection criteria

A total of 52 participants (82 ears) between the age group of 20 and 68 years with mean age of 43.6 years (SD =13.72) were taken for the study and they were divided into two groups based on the Threshold Equalization Noise (TEN) test results.

Group 1: Consisted of 38 ears with sensori-neural hearing loss without cochlear dead regions.
Group 2: Consisted of 44 ears with sensori-neural hearing loss with cochlear dead regions.

All the participants had acquired post-lingual sloping sensori-neural hearing loss. Degree of hearing loss varied from minimal to moderate till the start of the slope / edge frequency in both Group 1 and Group 2 respectively. Participants with sharply sloping hearing loss i.e., 15-20 dB threshold increase per octave (Carhart, 1945) were taken in both the groups, with the slope starting from 1 kHz and above. For each ear with a dead region, a matching ear without a dead region was selected, either within the same participant or in a different participant. Participants in Group 2 with fe at 1 kHz, 2 kHz and 4 kHz were matched for the start of slope at corresponding frequency at 1 kHz, 2 kHz and 4 kHz. These frequencies, 1 kHz, 2 kHz and 4 kHz in Group 1 were named ‘A’, ‘B’ and ‘C’ respectively as the term edge frequency is inappropriate for individuals without dead regions. All the participants with speech identification scores greater than 60% were considered for the study.

Participants with no history or present complaints of middle ear disorders, neurological symptoms were selected for the study. All the participants were native speakers of Kannada with good language abilities.

Instrumentation/Material

Following instruments and materials were used for the study:

- Calibrated two channel diagnostic audiometer Orbiter 922 with TDH 39 headphones with MX 14AR cushion for performing the pure tone audiometry, speech audiometry, the TEN test and frequency discrimination test for both Group 1 and Group 2.
- Calibrated GSI Tympstar middle ear analyzer version 2.0 to rule out middle ear pathology.
- TEN (HL) test Compact Disc (CD), developed by Moore et al. (2004) to detect the presence or absence of cochlear dead region.
- Speech material was constructed based on the frequency composition of the Consonant-vowels (CVs). They were divided into low frequency, mid frequency and high frequency based on their frequency composition as per the classification given by Ramaswami (1999). A total of 30 CVs were used, 10 in each category.
- PRATT software version 4.5.16 to record and low pass filter the speech stimuli and Adobe Audition 1.0 to normalize the stimuli.
- Hewlett Packard (HP) laptop with 1.3 GHz Centrino Core 2 Duo processor connected to audiometer through auxiliary input for running the TEN (HL) test and presenting the unfiltered and low pass filtered speech stimuli.

All testing was done in a sound treated double room. The ambient noise levels were within permissible limits as recommended by ANSI (1999).

Procedure

Pure-tone thresholds were obtained at octave intervals from 0.25 kHz to 8 kHz and 0.25 kHz to 4 kHz for air conduction and bone conduction audiometry respectively, using modified Hughson-Westlake procedure developed by Carhart and Jerger (1959). Speech audiometry was done to obtain the speech recognition thresholds and speech identification scores. Immittance using the low frequency probe tone, 226 Hz, and acoustic reflex threshold measurements, both ipsilateral and contralateral thresholds were carried out to rule out the conductive component. The procedure was carried out in three phases.

Phase 1: Diagnosis of presence / absence of cochlear dead regions and to determine the edge frequency (fe)

TEN (HL) test was administered to diagnose cochlear dead regions in participants with sensorineural hearing loss and also to determine the edge frequency. The TEN (HL) level is specified as the level of a one-ERB<sub>N</sub> wide band centered at 1 kHz, where ERB<sub>N</sub> stands for Equivalent Rectangular Bandwidth of the auditory filter determined by using young normal hearing individuals at moderate sound levels (Glasberg & Moore, 1990; Moore, 2003). The TEN (HL) test was carried out as described by Moore et al. (2004), using a procedure similar to manual audiometry, except that masked thresholds were measured using a 2-dB step size. The TEN (HL) test was administered using a CD player run through a HP laptop, connected to an audiometer with TDH 39 earphones. Test frequencies were 0.5, 0.75, 1, 1.5, 2, 3, and 4 kHz. A TEN level of 70 dB HL/ERB<sub>N</sub> was used for most individuals and a lower level of 50 dB HL/ERB<sub>N</sub> was used for individuals with minimal and mild hearing loss, especially if they complained of loudness of the TEN.

A “no response (NR)” was recorded when the subject did not indicate hearing the signal at the maximum output level of the audiometer. The presence or absence of a dead region at a specific frequency was based on the criteria suggested by Moore et al. (2004).

- If the masked threshold in the TEN was 10 dB or more, above the TEN level/ERB<sub>N</sub>, and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was interpreted to be present.
- If the masked threshold in the TEN was less than 10 dB above the TEN level/ERB<sub>N</sub>, and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was interpreted to be absent.
In cases where the TEN (HL) level could not be made high enough to elevate the absolute threshold by 10 dB or more i.e., the individuals with inconclusive results were not taken for the study as the edge frequency could not be determined in these individuals.

**Phase 2: Establishing Frequency Modulation Difference Limen (FMDL)**

Following the TEN test, frequency discrimination test for modulated signal was administered for both Group1 and Group 2 by obtaining the frequency modulation difference limens (FMDLs).

FMDLs were obtained using the two alternative forced choices. Two tones were presented successively, one modulated (0.2 %, 0.5%, 1.0%, 2.5%, 5.0%, 7.5%, 10.0%, 12.5% and 15.0 %) and other unmodulated tone. The level of presentation was 40 dB SL. The stimulus duration was 500ms. The participants were instructed to indicate whether the first tone or the second tone was modulated. The amount of modulation required for detection of the modulation was determined. Catch trials were presented at random to rule out the false responses.

FMDLs were obtained for individuals with dead regions and for individuals without dead regions at two frequencies. One frequency was selected at farther to the edge frequency/ corresponding slope, $F_F$, which can be defined as the nearest octave/ mid-octave frequency that is farther from the edge in DR / corresponding slope in individuals without DR. Another frequency was selected nearer to the edge frequency/ corresponding slope for without dead region individuals, $F_N$, which was $f_e\text{-}\frac{1}{8}\text{th}$ octave, due to the fact that the enhancement is usually seen at this frequency and a farther frequency was taken to cross check this phenomenon. Table 1 depicts the edge / corresponding start of slope frequency and the corresponding frequencies at which the FMDLs were obtained.

Table 1: Different frequencies at which frequency modulation difference limens were obtained for each edge frequency/ corresponding frequency at start of the slope

<table>
<thead>
<tr>
<th>Edge Frequency / Corresponding slope (kHz)</th>
<th>Frequencies tested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_F$ (kHz)</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

**Phase 3: Speech identification testing**

Speech identification test was performed following the frequency discrimination testing. A combination of Consonant-Vowel (CV) stimuli were selected such that the CVs were concentrated in the low frequency, mid frequency and high frequency regions based on the classification given by Ramaswami (1999). Each CV was recorded by a male speaker in
PRATT software, version 4.5.16. All the CVs were normalized to avoid the amplitude variations of the recorded speech stimuli using the Adobe Audition 1.0 software. A total of 30 CVs were taken and were divided into three lists based on their frequency composition. Table 3 shows the different list of CVs taken based on frequency composition of the same.

### Table 2: Speech Stimuli classified according to frequency composition

<table>
<thead>
<tr>
<th>Low frequency stimuli</th>
<th>Mid frequency stimuli</th>
<th>High frequency stimuli</th>
</tr>
</thead>
</table>

The CVs constructed were presented without any filtering known as the unfiltered condition. Thus, there were three unfiltered lists, namely, unfiltered low frequency (ULF), unfiltered mid frequency (UMF) and unfiltered high frequency (UHF). The CVs were low pass filtered (LPF) at different cut-off frequencies to produce the filtered low frequency (FLF), filtered mid frequency (FMF) and filtered high frequency (FHF) speech stimulus. The low pass filtering was done using the PRATT software version 4.5.16. The cut-off frequency of the low pass filtered speech was the edge frequency or the frequency at start of the slope for the three different frequencies (1 kHz, 2 kHz, and 4 kHz). Table 3 depicts the different speech lists presented to participants of both Group 1 and Group 2.

The stimuli were randomized and the order of presentation of lists were also randomized and presented at 40 dB SL for most of the subjects or at the Most comfortable level (MCL) for higher degree of hearing loss, by connecting the CD player of the HP laptop to the audiometer. Written responses were obtained from all the participants.

Analysis of the obtained data was done using the Statistical Package for the Social Sciences (SPSS) version 16 software.

### Table 3: Speech lists and filtering conditions presented to Participants of Group 1 and Group 2 with respect to start of slope /Edge frequencies

<table>
<thead>
<tr>
<th>Edge frequency/ Start of slope (kHz)</th>
<th>Speech filtering condition</th>
<th>Low pass filtering cut off for filtered speech (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ULF, UMF, FLF, FMF</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>UMF, UHF, FMF, FHF</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>UMF, UHF, FMF, FHF</td>
<td>4</td>
</tr>
</tbody>
</table>

### Results and Discussion

The mean scores and standard deviation (SD) for FMDL scores of F_F for individuals with and without DR across the edge frequencies/ corresponding frequencies at the start of slope are shown in Table 4.
Table 4: The mean and standard deviation (SD) for FMDL scores of \(F_F\) and \(F_N\) for individuals with and without dead regions across the edge frequencies/ corresponding frequencies at the start of slope

<table>
<thead>
<tr>
<th>Groups</th>
<th>Frequency (kHz)</th>
<th>N</th>
<th>(F_F)</th>
<th>(F_N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean (%)</td>
<td>SD</td>
</tr>
<tr>
<td>Group 1</td>
<td>1</td>
<td>12</td>
<td>3.20</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>13</td>
<td>2.23</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>13</td>
<td>1.38</td>
<td>0.79</td>
</tr>
<tr>
<td>Group 2</td>
<td>1</td>
<td>16</td>
<td>1.84</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>14</td>
<td>1.53</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>14</td>
<td>1.42</td>
<td>0.85</td>
</tr>
</tbody>
</table>

*Note. 1 kHz, 2 kHz and 4 kHz frequencies in Group 1 refers to ‘A’, ‘B’ and ‘C’ respectively.

Two-way ANOVA was administered to find the effect of frequencies at the start of slope / edge frequencies on the frequency discrimination abilities of \(F_F\) and \(F_N\) in Group 1 and Group 2.

Results of Two-way ANOVA revealed that there was statistically significant difference in FMDL scores of \(F_F\) between Group 1 and Group 2, \(F (1, 76) = 7.78, p<0.05\), and also across the corresponding frequencies at the start of slope / edge frequencies \(F (2, 76) = 7.28, p<0.05\) and also for \(F_N\) between Group 1 and Group 2, \(F (1, 76) = 18.07, p<0.01\), and also between the edge frequencies / corresponding frequencies at the start of slope \(F (2, 76) = 6.33, p<0.05\). However, there was no interaction observed between the Group 1 and Group 2 and the corresponding frequencies at the start of slope / edge frequency for both \(F_F\) and \(F_N\) \(F (2, 76) = 2.86, p>0.05\). However, for both \(F_F\) and \(F_N\) at 1 kHz and 4 kHz for \(F_F\).

Duncan’s post hoc analysis was administered to study if there was a statistically significant difference in FMDL scores of both \(F_F\) and \(F_N\) between the various edge frequencies / corresponding frequencies at the start of slope. Figure 1 depicts the FMDL scores for Group 1 and Group 2 at 1 kHz and 4 kHz for \(F_F\).

Figure 1: The FMDL scores at \(F_F\) for Group 1 and Group 2 at 1 kHz and 4 kHz
It can be seen from Figure 1 that overall mean FMDL scores for Group 2 were lower (Mean = 1.61) than Group 1 (Mean = 2.25), which shows that individuals with DR had better FMDLs than individuals without cochlear dead region.

Figure 2 depicts the FMDL scores for Group 1 and Group 2 at 1 kHz and 4 kHz for $F_N$.

![Figure 2: The FMDL scores at $F_N$ for Group 1 and Group 2 at 1 kHz and 4 kHz and 2 kHz and 4 kHz](image)

It can be seen from Figure 2 that the overall mean FMDL scores for Group 2 were lower (mean = 1.13) than Group 1 (mean = 2.10), for $F_N$, which showed that individuals with DR had better FMDLs than individuals without cochlear dead region. Across the edge frequency / corresponding frequencies at the start of slope, lower the edge frequency / corresponding frequencies at the start of slope, that is, 1 kHz edge frequency / corresponding frequency ‘A’ individuals showed relatively worse FMDLs than 2 kHz and 4 kHz for both Group 1 and Group 2, which was similar to FMDL scores of $F_F$.

Within groups comparison of frequency discrimination abilities in individuals with and without cochlear dead regions.

Paired sample t-tests were administered to study the comparison of FMDL scores of $F_F$ and $F_N$ within Group 1 and the same was carried out within Group 2 at different frequencies at the start of slope / edge frequencies. Table 5 depicts the results of paired sample t-test results across edge frequencies / corresponding frequencies at the start of slope for FMDL scores of $F_F$ and $F_N$ for Group 1 and Group 2.
Table 5: t value and significance across corresponding frequencies / edge frequencies at the start of slope for FMDL scores of $F_F$ and $F_N$ within Group 1 and within Group 2

<table>
<thead>
<tr>
<th>Groups</th>
<th>Frequency (kHz)</th>
<th>N</th>
<th>$F_F$</th>
<th>$F_N$</th>
<th>‘t’ value</th>
<th>Significance (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean (%)</td>
<td>SD</td>
<td>Mean (%)</td>
<td>SD</td>
</tr>
<tr>
<td>Group 1</td>
<td>1</td>
<td>12</td>
<td>3.20</td>
<td>1.95</td>
<td>2.87</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>13</td>
<td>2.23</td>
<td>1.09</td>
<td>2.23</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>13</td>
<td>1.38</td>
<td>0.79</td>
<td>1.26</td>
<td>0.72</td>
</tr>
<tr>
<td>Group 2</td>
<td>1</td>
<td>16</td>
<td>1.84</td>
<td>0.76</td>
<td>1.13</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>14</td>
<td>1.53</td>
<td>0.74</td>
<td>1.17</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>14</td>
<td>1.42</td>
<td>0.85</td>
<td>0.89</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Note. * indicates significant difference at 0.05 level; ** could not be compared as the mean values were equal.

Results of paired sample t-test indicated that there was no statistically significant difference between FMDL scores of $F_F$ and $F_N$ within Group 1 across the frequencies ‘A’, ‘B’ and ‘C’. However, there was statistically significant difference between FMDL scores of $F_F$ and $F_N$ within Group 2 at 1 kHz and 4 kHz edge frequencies, but no statistically significant difference between FMDL scores $F_F$ and $F_N$ at 2 kHz edge frequency. From the mean FMDL scores of $F_F$ and $F_N$ for Group 1 and Group 2, it was seen that the FMDL scores of $F_F$ and $F_N$ were almost similar in Group 1 whereas, in Group 2 the mean FMDL score of $F_N$ was very much lower than the mean $F_F$ values. This indicates that FMDLs were better/enhanced near the edge frequency for individuals with cochlear dead region.

The results obtained in the present study were in support with the study by Kluk and Moore (2006), who studied difference limen for frequency (DLF) in individuals diagnosed to have cochlear dead regions at the higher frequencies. Results indicated that only a very small amount of local DLF enhancement at $f_e$, which reflected the fact that the frequency at which $\text{DLF}_{\text{min}}$ (that is the enhancement of DLF) occurred sometimes above and sometimes below $f_e$. For most of the individuals, the $\text{DLF}_{\text{min}}$ occurred at $f_e - 1/8^{\text{th}}$ octave frequency (Thai-Van et al. 2003; 2007). The DLFs for frequencies below and at $f_e$ showed good consistency across individuals. Thus in the present study, the FMDL at $F_N$ frequency, which was one-eighth octave below $f_e$ for Group 2 showed better scores than $F_F$ frequency, which was very much farther from the edge frequency. These findings were again consistent with the results of Thai-Van et al. (2003) who reported enhanced DLFs at or near $f_{\text{cut-off}}$.

The interpretation of the DLF improvement in a narrow range around $f_e$ draws upon the neuro-physiological finding in animals (Irvine et al., 2001) which says that neighboring hearing-loss cut-off with a narrow frequency range is over-represented on the primary auditory cortex’s tonotopic map and thus more neurons are available for encoding frequencies falling in that range, and discrimination performance is correspondingly better.
Comparison of speech identification scores in different filtering conditions across the edge frequencies/ corresponding frequencies at the start of slope

Paired sample t-test was performed to study the pair wise comparison of speech identification scores of ULF and FLF and UMF and FMF for both Group 1 and Group 2 for frequency ‘A’/ edge frequency 1 kHz.

Table 6 shows the results of paired sample t-test for speech identification scores for speech identification scores of ULF and FLF and UMF and FMF for both the groups for edge frequency 1 kHz / frequency ‘A’.

Results of paired t-tests revealed that for Group 1, there was statistically significant difference between the speech identification scores of ULF and FLF [t (11) = 3.02, p<0.05] but there was no statistical significant difference between the speech identification scores of UMF and FMF. In Group 2, there was statistically significant difference between the speech identification scores ULF and FLF [t (15) = 3.36, p<0.001] and also between the speech identification scores of UMF and FMF [t (15) = 4.71, p<0.001].

Table 6: t value and significance for frequency ‘A’/ edge frequency 1 kHz for different filtering conditions for speech for both groups 1 and 2

<table>
<thead>
<tr>
<th>Speech condition (Comparison Pair)</th>
<th>Group 1</th>
<th></th>
<th>Group 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t value</td>
<td>Significance</td>
<td>t value</td>
<td>Significance</td>
</tr>
<tr>
<td>ULF- FLF</td>
<td>3.02</td>
<td>0.01*</td>
<td>3.36</td>
<td>0.00**</td>
</tr>
<tr>
<td>UMF- FMF</td>
<td>2.02</td>
<td>0.67</td>
<td>4.71</td>
<td>0.00**</td>
</tr>
<tr>
<td>ULF- UMF</td>
<td>0.71</td>
<td>0.49</td>
<td>0.58</td>
<td>0.56</td>
</tr>
<tr>
<td>FLF- FMF</td>
<td>0.89</td>
<td>0.38</td>
<td>1.93</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Note. * indicates significance at 0.05; ** indicates at significance at 0.001 level.

Paired sample t-test was performed to assess the pair wise comparison of speech scores of UMF and FMF and UHF and FHF in frequency ‘B’/ edge frequency 2 kHz in both Group 1 and Group 2. Table 7 shows the results of paired sample t-test for speech identification scores in edge 2 kHz / corresponding frequency ‘B’.

Table 7: t value and significance for frequency ‘B’/ edge frequency 2 kHz for different filtering conditions for speech for both groups 1 and 2.

<table>
<thead>
<tr>
<th>Speech condition (Comparison Pair)</th>
<th>Group 1</th>
<th></th>
<th>Group 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t value</td>
<td>Significance</td>
<td>t value</td>
<td>Significance</td>
</tr>
<tr>
<td>UMF- FMF</td>
<td>0.64</td>
<td>0.53</td>
<td>8.70</td>
<td>0.00**</td>
</tr>
<tr>
<td>UHF- FHF</td>
<td>2.52</td>
<td>0.27</td>
<td>12.31</td>
<td>0.00**</td>
</tr>
<tr>
<td>UMF- UHF</td>
<td>2.88</td>
<td>0.01*</td>
<td>1.58</td>
<td>0.13</td>
</tr>
<tr>
<td>FMF- FHF</td>
<td>0.22</td>
<td>0.82</td>
<td>4.19</td>
<td>0.00**</td>
</tr>
</tbody>
</table>

Note. ** Significant at 0.001 level; * significant at 0.05 level.
Results revealed that there was statistically significant difference between UMF and FMF and between UHF and FHF within the Group 2 \([t (13) = 8.70, p<0.001]\) and \([t (13) = 12.31, p<0.001]\) respectively. However, there was no statistical significant difference between the speech identification scores of UMF and FMF and between the speech identification scores of UHF and FHF within the Group 1 \((p>0.05)\).

Paired sample t-test was performed to compare the speech identification scores of UMF and FMF and UHF and FHF in frequency ‘C’/ edge frequency 4 kHz in both Group 1 and Group 2. Table 8 shows the results of paired sample t-test for speech identification scores in edge frequency 4 kHz / corresponding frequency ‘C’.

Table 8: t value and significance for frequency ‘C’/ edge frequency 4 kHz for different filtering conditions for speech for both groups 1 and 2.

<table>
<thead>
<tr>
<th>Speech condition (Comparison Pair)</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t value</td>
<td>Significance</td>
</tr>
<tr>
<td>UMF - FMF</td>
<td>0.41</td>
<td>0.68</td>
</tr>
<tr>
<td>UHF - FHF</td>
<td>0.39</td>
<td>0.70</td>
</tr>
<tr>
<td>UMF - UHF</td>
<td>1.76</td>
<td>0.10</td>
</tr>
<tr>
<td>FMF - FHF</td>
<td>1.07</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*Note. Significant at 0.01 level

Results revealed that there was statistically significant difference in speech identification scores between UMF and FMF and also between the speech identification scores of UHF and FHF within the Group 2 \([t (13) = 4.22, p<0.01]\) and \([t (13) = 4.58, p<0.01]\). However, there was no significant difference between the speech identification scores of UMF and FMF and also between the speech identification scores of UHF and FHF within the Group 1 \((p>0.05)\). There was also no statistical significant difference between the speech identification scores of two unfiltered conditions of UMF and UHF and also between the speech identification scores of two filtered conditions of FMF and FHF in both group 1 and 2.

It was observed that there was a significant difference between the speech identification scores of ULF and FLF condition in both Group 1 and Group 2. This was also evident by the increased mean speech identification scores for the filtered condition (Mean: 4.83 and 4.06 for Group 1 and 2 respectively) with the cut-off being 1 kHz as against the unfiltered condition (Mean: 3.75 and 2.62 for Group 1 and 2 respectively). This may be attributed to the fact that the distortion produced due to the off-frequency phenomenon (Patterson & Moore, 1986) may be avoided by filtering the unnecessary frequencies. These effects may reflect cortical plasticity induced changes by the dead regions.

Similar to the 1 kHz edge frequency, results also showed that there was improved performance with filtered speech in individuals with dead region at 2 kHz and 4 kHz edge
frequency. This is also supported by Turner and Brus (2001), which revealed that below 2.8 kHz, amplification provided positive benefit for recognition scores regardless of degree of loss. These results have also been found in the present study, that is, better scores in filtered condition than the unfiltered condition. Similar studies have also been reported in individuals with high frequency DR, where in their performance was better for low pass filtered speech stimulus than wide band speech stimulus (Vickers et al., 2001; Baer et al., 2002).

Results also revealed that there was significant difference in speech identification scores of FMF and FHF in individuals with cochlear dead regions at 2 kHz edge frequency. It was also observed that the mean speech identification scores for FHF was higher (mean = 7.78) as against the mean for speech identification for FMF (mean = 6.85). This can be attributed to the fact that more cues are obtained from the FHF than FMF. FMF has a low pass cut-off of 2 kHz presented to the individuals with edge frequency 2 kHz. It is known that the off-frequency phenomenon is predominant in individuals with DR. This, FMF filtering condition will further create an overload on the mid frequency fibers together with off frequency, which in turn decreases the cues for perception of the stimuli; thus lowering the scores for FMF individuals with 2 kHz DR.

It was also observed that the two unfiltered conditions UMF and UHF were significantly different in individuals without dead regions at corresponding frequency ‘B’ (2 kHz). It was also seen that the mean speech identification score for UHF was higher (Mean = 5.93) than the mean speech identification score for UMF (Mean = 5.30). Higher scores for UHF can be attributed to the fact that the UHF consonants were in the vowel context of /i/ and /e/. This combination will provide more energy than compared to UMF consonants that comprised of /a/ vowel context having relatively lower energy.

Overall, these results support the idea that individuals with dead regions at high frequencies do not make as effective use of audible speech information at high frequencies as individuals without dead regions. Furthermore, the results support the idea that increasing the audibility of speech for frequencies well inside a dead region does not lead to concomitant increases in speech intelligibility.

**Correlation of frequency discrimination scores and speech identification scores in Group 1 and Group 2.**

To establish the relationship between the frequency discrimination scores and speech identification scores in Group 1 and Group 2 Spearman’s correlation was performed. Results revealed that there was a negative correlation between frequency discrimination and the speech identification scores in Group 1, that is, in individuals without DR.

However there was no correlation between frequency discrimination and the speech scores in Group 2, that is in individuals with DR (p>0.05).
The FMDL scores of \( F_F \) and \( F_N \) correlated well with speech identification scores of ULF, UMF and FMF in Group 1. This is also in support with the fact that the speech identification scores of ULF, UMF and FMF have the same frequency composition as that of frequency of \( F_F \) and \( F_N \) which ranged from 500 to 3.8 kHz.

There are several studies correlating the frequency selectivity and speech scores in individuals without DR. Dubno, Dirks and Langhofer (1982) suggested there is one to one correlation between the speech recognition errors and audiogram patterns observed.

However, in individuals without DR, there was absence of any correlation between the frequency discrimination and speech identification scores. Even though the filtered speech scores were significantly higher in individuals with DR as against without DR, there was no correlation seen between the frequency modulation difference limen scores and the speech identification scores. This may be attributed to the mis-match in the frequency place representation due to the presence of off-frequency listening in individuals with DR. Thai-Van et al., (2003) suggested that local improvement in difference limen frequency (DLFs) represents a side effect of neurophysiological mechanisms that have no major perceptual consequences on speech or music perception. This hypothesis of Thai-Van et al., (2003) may be true in individuals with cochlear DR.

**Summary and Conclusions**

Dead region is often described in terms of the edge frequency (\( f_e \)). It is seen from earlier research that the presence of dead region led to improved frequency discrimination near the edge frequency. The present study aimed at analyzing the frequency discrimination across the edge frequencies in individuals with dead regions and start of slope matched individuals without cochlear dead regions. The study also aimed at measuring the speech identification scores under unfiltered and filtered conditions and also to correlate the frequency discrimination scores and the speech identification scores in individuals with and without dead regions.

Analysis revealed that FMDL scores were lower (better) for individuals without dead regions near the edge frequency as against individuals without dead regions. It was also noticed that as the edge frequency was lower, that is at 1 kHz, the FMDL scores were higher (worse) as against 4 kHz in individuals with and without cochlear dead regions. These results also suggest that the enhanced frequency discrimination near the edge frequency in individuals with cochlear dead regions, which was due to cortical re-organization.

The speech identification scores were better for filtered conditions, with cut - off being the frequency of the edge, in individuals with dead regions at edge frequency 1 kHz and 4 kHz. These results again reveal that the individual with dead regions do make use of the full band speech information specially the high frequency information and the identification improves in the filtered conditions with the filter cut- off being the frequency of the edge.
There was some correlation between the frequency discrimination scores and speech identification scores in both filtered and unfiltered conditions in individuals without dead regions as against in individuals with dead regions. This may be due to the mis-match in the frequency-place representation due to the presence of off-frequency listening in individuals with DR.

Implications for future research

- The study can be replicated with different speech filtering conditions and estimating the condition where the individuals with cochlear dead region perform the best and the condition which best correlates with the frequency discrimination.
- Speech material in the form of words and sentences can be taken and filtered sharply without degrading the stimuli and can be used to find the correlation of speech identification scores and frequency discrimination abilities.
- Similar studies can also be carried out with amplification/hearing aids.

References


Utility of the ‘Screening Checklist for Auditory Processing (SCAP)’ in Detecting (C)APD in Children

Muthu Selvi T. & Asha Yathiraj*

Abstract

Chermak and Musiek (1997) reported that 2% to 5% of school-going children have central auditory processing disorder [(C)APD]. Since, the prevalence of (C)APD is high in school-going children, there is a need for an efficient tool to screen and to refer them for further evaluation. The aim of the present study was to use Screening checklist for auditory processing (SCAP) to identify children with symptoms of central auditory processing and find the agreement of the checklist with a battery of diagnostic (C)APD tests. The study also aimed to determine an appropriate cut-off score for the SCAP and check its sensitivity and specificity. A total of 3120 children were screened using the SCAP. Forty-two of them, who had varying score on the SCAP, were evaluated using a test-battery consisting of 5 different diagnostic tests speech-in-noise (SPIN), Gap detection test (GDT), masking level difference (MLD), Dichotic CV (DCV), and Auditory memory and sequencing Test (AMT). These tests were selected to evaluate auditory separation / closure, temporal processing, auditory interaction, auditory integration and auditory memory. The analyses of the data revealed that there was no agreement between a single symptom on the SCAP and the presence of (C)APD. A Kappa measurement of agreement of various cut-off scores of SCAP with the (C)APD diagnostic test findings indicated that a cut-off score of 6 yielded a good agreement with the results of SPIN and AMT as well as with the overall diagnosis of (C)APD. With a cut-off score of 6, the sensitivity of the checklist was 71% and specificity was 68%, the prevalence of suspected (C)APD in school-going children was 3.2%. Among the diagnostic tests used, most of the participant failed in the AMT and DCV tests, followed by SPIN and GDT. Hence, it is important to include these tests in a diagnostic test battery. All the participants who had (C)APD did not demonstrate similar auditory processing difficulties. Thus, a test battery approach should be employed while assessing children with suspected (C)APD. It is evident from study that the SCAP could be used as a simple and practical measure to screen for the presence of (C)APD.

Introduction

Screening to detect the presence or absence of any problem is a necessity. Musiek, Gollegly, Lamb and Lamb (1990) listed several reasons as why screening for (C)APD should be carried out. A major reason was to enable early identification, thus paving the way to plan effective management and educational strategies. They noted that screening also helped in identifying conditions leading to (C)APD that may require medical attention. It was also noted that screening promoted increased awareness about (C)APD among educators and parents. Further, they reported that it helped in easily determining the cause of a particular child’s listening and learning difficulties and hence, minimized the psychological factors like anxiety and stress in the child. Bellis (2003) added that screening for (C)APD could help in

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providing direction to special educators, speech language pathologists, rehabilitative audiologists, and others entrusted in the task of developing remedial programs and hence help in managing the disorders of children more effectively.

Screening for (C)APD has been carried out using checklists and/or tests. Both procedures have been reported to have their own advantages and disadvantages. However, checklists have the advantage of not being affected by a regional language. In a multilingual country like India, it is far easier to just translate a checklist into different languages without influencing the outcome of the findings, instead of developing screening tests in various languages.

Some of the checklists reported in the literature are Children’s Auditory Processing Performance Scale (CHAAPS) developed (Smoski, 1987, cited in Smoski, Brunt and Tannahill, 1992), Screening Checklist for Auditory Processing (SCAP) by Yathiraj and Mascarenhas (2002, 2004) and ‘Fisher’s auditory performance checklist’ (Fisher, 1976, cited in Willeford & Burleigh, 1985). CHAPPS was designed to be administered on parents and teachers to assess the listening ability of a child. It has six listening conditions included perception in quiet, in the presence of noise and multiple inputs as well as auditory memory/sequencing and auditory attention span. Smoski (1990) recommended using CHAPPS as an objective tool to find out the effectiveness of therapy. Purdy and Jonstone (2000) found a significant correlation between the Dichotic digit test and the memory rating with CHAPPS. However, the studies also found that CHAPPS lead to either over or under referral and that it could not be used as an isolated tool for referral (Drake et al., 2006; Cameron, Dillon & Newali, 2005).

In India, the SCAP (Yathiraj & Mascarenhas, 2002, 2004) has been utilized to detect the presence or absence of (C)APD in children effectively (Yathiraj & Mascarenhas, 2003; Priya & Yathiraj, 2007; Devi, Sujitha & Yathiraj, 2008; Maggu & Yathiraj, in press). Yathiraj and Mascarenhas (2003) found no significant difference in the results obtained between SCAP and (C)APD diagnostic tests. The others (Priya & Yathiraj, 2007; Devi & Sujitha & Yathiraj, 2008; Maggu & Yathiraj, in press) also found SCAP to be effective in detecting the presence of (C)APD in children. However, these studies used an arbitrarily cut-off criteria of six to suspect children to have (C)APD. This value was chosen to increase the sensitivity of SCAP. However, it was not confirmed that children who passed the screening checklist did not have (C)APD. Hence, there is a need to confirm whether those children who did not exhibit symptoms of (C)APD on screening checklist, also passed diagnostic tests.

The validity and reliability of a screening procedure needs to be studied to know how effectively it can be used in a clinical set-up. The ASHA task force (2005) recommended that a test battery approach should be used to check for the efficiency of screening checklists and tests. Although, a variety of methods to assess the Central Auditory Nervous System (CANS) are available, behavioural tests have been recommended to be used for the diagnosis of (C)APD in children or adults (Chermak & Musiek, 1992). Chermak and Musiek (1997)
Utility of SCAP in Detecting (C)APD

reported that it is valuable to select tests that assess different processes rather than evaluate the same process to get a better idea of the processing deficits of a client.

There is a need for a tool with fairly high sensitivity and specificity considering the number of children having possible (C)APD. According to Repp and Stockdell (1978), 15% to 20% of a school-age population have some type of language / learning disorder, out of which, 70% have some form of auditory impairment. However, Lewis (1986, cited in Bellis, 1996) estimated that only 3 to 7% of all school-age children exhibit some form of learning disability. Similar to the findings of Lewis, it was found by Cherry (1987) that 6.5% of children in the age range 3 to 17 years have learning disabilities, with a high proposition of these children having (C)APD. In India, it has been found that 3% of school-going children have dyslexia (Rama, 1985). A direct estimate of the number of school aged children with (C)APD was obtained by Chermak and Musiek (1997) who found it to be 2% to 5%.

From the above information, it can be construed that the first stage in identifying the presence of a (C)APD is screening. It is also essential that a screening tool should be efficient with clear cut-off criteria to decide whether an individual should be referred for further evaluation or not. The aim of the present study was to use SCAP to identify children with symptoms of central auditory processing and find the agreement of the checklist with a battery of diagnostic (C)APD tests. The study also aimed to determine an appropriate cut-off score for the SCAP and check its sensitivity and specificity.

Method

The study was carried out in two stages. In the first stage, SCAP was used to detect children with the presence or absence of symptoms of (C)APD. In the second stage, SCAP results were compared with the results of a diagnostic (C)APD test battery. The participants for the second stage of the study were randomly selected from those included in the first stage.

Participants

A total of 3120 children in the age range of 8 to 15 years were screened using the SCAP. These children were selected from four different schools with English as the medium of instruction. They had studied English for at least two years. Among them, 80 children were randomly selected for further diagnostic evaluation, ensuring that they had varying score on the SCAP. Only 42 children could finally be evaluated, since the remaining declined to be evaluated further. The mean age of these 42 children was 10.93 years.

It was ensured that all the children who were selected for suspected to diagnostic evaluation had normal IQ, as determined through Raven’s Progressive coloured/standard Matrices (Raven, 1952). In addition, they had normal hearing. Their pure-tone AC and BC thresholds were less than 15 dB HL in the octave frequencies 250 Hz to 8 kHz and 250 Hz to 4 kHz, respectively. Normal middle ear function was confirmed with the presence of ‘A’ type tympanograms and both ipsilateral and contralateral acoustic reflex being present for the
frequencies 500 Hz, 1 kHz and 2 kHz. In addition, all the participants had a speech identification score that was greater than 85% in quiet, which was determined using the ‘Common Speech Discrimination Test for Indians’ (Mayadevi, 1974). Further, the teacher and the caregivers reported that none of these children had any history of a speech and hearing problem.

**Equipment**

A calibrated dual channel diagnostic audiometer OB 922 (version 2) with AC (TDH-39) and BC (B-71) transducers was used to carry out pure-tone audiometry, speech audiometry and the (C)APD tests. A calibrated immittance meter (GSI Tymstar) was used to ensure the presence of normal middle ear function. The CD version of the test material was played through a Compaq Presario laptop with Intel dual core processor. An Interacoustics AC-40 clinical audiometer was utilized to administer the Masking Level Difference (MLD) test.

**Test Environment**

Part of stage I of the study was carried out in a quiet room, free from distraction. This included administrating the screening checklist and IQ testing. All the audiological tests of stage I and stage II were carried out in a two-room situation with permissible noise limits as per ANSI standards (S3.1-1991).

**Procedure**

**Stage I**

**Procedure for selection of participants**

Screening for the presence of (C)APD was carried out on school-going children from four different schools. Sixty-one teachers who had taught the children for at least one year were asked to identify those with a suspected (C)APD using the SCAP. The checklist was scored on a two point rating scale. Each answer marked ‘Yes’ was scored ‘1’ and each ‘No’ was scored ‘0’.

Eighty children with varying scores on the checklist were randomly selected from four different schools. It was ensured that the score ranged from 0-12. Though, 80 children were selected for further evaluation, only 42 of them reported. Of them, 22 had scores less than 50% and 20 had scores 50% and above. The former group had a mean age of 11.22 years and the latter a mean age of 10.65 years.

It was ensured that all the children met the participant selection criteria which included normal peripheral hearing; normal speech identification in quiet; and normal IQ. Only those participants who met the above criteria were subjected to further (C)APD evaluation in stage II of the study.
Stage II

Procedure for (C)APD evaluation

In stage II, the diagnostic tests were administered. All the participants were evaluated using five different (C)APD tests. The tests included SPIN, Dichotic CV test, Masking Level Difference (MLD), the Gap Detection Test (GDT) and Auditory Memory and Sequencing Test (AMST).

The Speech-in-Noise (SPIN) test was administered using the recorded version of ‘Monosyllabic speech identification test in English for Indian children’ (Rout, 1996) in the presence of speech noise. The signal was presented monaurally to each ear at 0 dB SNR at 40 dB SL (ref. SRT). Verbal responses of the participants were noted. A correct response was given a score of ‘1’ and an incorrect response a score of ‘0’.

The Dichotic CV test was played using the CD version of the test (Yathiraj, 1999) at 40 dB SL (ref. SRT). The participants were asked to repeat the syllables which were heard through headphones. Their double correct responses were noted and compared with norms given by Krishna (2001).

Masking level difference (MLD) was evaluated using a 500 Hz tone at 50 dB HL. The stimuli were presented binaurally through headphones in both homophasic and antiphasic conditions. The noise level was increased until the participants were unable to hear the signal. MLD was calculated by subtracting the $S_{aN_o}$ (antiphasic) threshold from that of the $S_{oN_o}$ (homophasic) threshold. The responses were compared with norms provided by Wilson, Zizz, and Sperry (1994).

Gap detection test (GDT) was obtained with the CD version of the test. The signals were presented monaurally to each ear at 40 dB SL (ref. PTA) through headphones. The participants were required to indicate as to which set of noise bursts in a triad contained a gap. The minimum gap duration which the participants were able to detect was compared with norms given by Chermak and Lee (2005).

The Auditory Memory and Sequencing Test (AMST) developed by Yathiraj and Mascarenhas (2003) was presented using the CD version of the test. The recorded material [at 40 dB SL (ref. SRT)] was routed through an audiometer and was heard through the loudspeaker. The loudspeaker was placed at a 45° azimuth at a distance of one meter from the head of each participant. The participants were asked to repeat the words heard by them. A score of ‘1’ was given for each correctly repeated word to calculate the auditory memory score. The responses were compared with age appropriate norms developed by Devi, Sujitha and Yathiraj (2008).

Test-retest reliability

Test-retest reliability was done for responses got in stage I and stage II. To check for the test-retests reliability of SCAP, the questionnaire was re-administered on 606 children.
(20%) after a gap of three months. This was done by eight teachers who had answered the checklist earlier. Further, in stage II, two of the 42 participants were randomly selected to check for the test-retest reliability of the diagnostic tests after a gap of three months. All five (C)APD tests were re-administered on these two participants. None of the clients who were selected for retesting underwent any remedial help.

**Scoring**

All the tests administered were scored according to the norms provided for each of the tests. The participants were considered to have a problem in a specific process, if his/her score on the particular test were below the age appropriate normative data.

Participants were diagnosed as having an auditory processing disorder if they failed in two or more of the five diagnostic (C)APD tests used in the present study. If they failed only one test, they were considered to have (C)APD if the score on that test was at least three standard deviations below the mean performance of the normative score. This diagnosis was done in keeping with the recommendations of Chermak and Musiek (1997).

**Analyses**

The obtained score were tabulated and analyzed using SPSS (Statistical Package for Social Sciences version 10). Kappa measurement of agreement was used to find the agreement of each question of SCAP with the (C)APD tests findings. To find the correlation of SCAP scores with the (C)APD tests, a Pearson product moment correlation was utilized. Further, the sensitivity and specificity of different SCAP cut-off scores was determined through a decision matrix. Finally, the $\alpha$ tests of reliability was used to find a test-retest reliability of SCAP.

**Results and Discussion**

Initially, the data were analysed to detect children with symptoms of (C)APD as well as identify those with confirmed (C)APD. The former was done using the SCAP findings and the latter was done utilizing a diagnostic test battery.

**Presence of (C)APD symptoms as per the SCAP checklist**

The analysis of the SCAP findings on the 3120 school-going children revealed that 216 (6.9%) of the children had symptoms of (C)APD. The symptoms that occurred most frequently were ‘Requires repeated instruction’ (4.9%) and ‘Short attention span’ (4.2%). The other symptoms that were present fairly frequently were ‘Poor academic performance’ (3.7%), ‘Forgets what is said in a few minutes’(3.6%), ‘Easily distracted by background noise’ (3.4%) and ‘Delayed response to verbal instruction or questions’ (3.1%). The symptoms that occurred the least (0.99%) were questions which dealt with the discrimination of phonemes. It is possible that the teachers did not understand these questions rather than the symptom really not being present. It is suggested that the question should be accompanied with examples, to make the questions clearer.
Symptoms which occurred more frequently could probably act as greater indicators of (C)APD. In the present study, it was found that the occurrence of attention and memory related symptoms were more followed by poor academics. Similar findings were obtained by Smoski, Brunt and Tannahill (1992). They too observed, based on the findings of CHAPPs, that ‘affected memory’ was a common symptoms seen in children with (C)APD. However, a more common symptom noticed by them was ‘difficulty in hearing in the presence of noise’. This was also a common symptom seen in the present study as well as by Musiek, Guerkink, Kietel and Hannover (1982).

In contrast, Sanger, Freed and Decker (1985) reported that the symptoms that were least seen in their group of children with suspected auditory processing disorder was ‘auditory memory’. They noticed this finding using a 23-item informal checklist.

The variation seen across the studies, including the present study could be due to the heterogeneity seen in children with suspected (C)APD. Yet another reason for the variation in the finding may have due to an observer bias. It is possible that teachers varied in terms of the symptoms to which they were more observant. This could have also resulted in the variation seen across the studies.

Presence of (C)APD as per the diagnostic tests

The findings of the diagnostic tests, carried out on 42 of the participants, are provided in Figure 1. The figure provides information regarding the number of children who failed each of the diagnostic tests as well as the number of children diagnosed to have (C)APD, as per the recommendation of Chermak and Musiek (1997).

Among the diagnostic tests, the tests with maximum failure was DCV (38%) followed by AMT (35%), SPIN (average of both ears being 16.5%) and GDT (average of both ear being 15.5%). Only one participant failed the MLD test. Using the criteria suggested by Chermak and Musiek (1997), 40.4 % (17) of the participants were diagnosed to have (C)APD.

![Figure 1: Percentage of children who failed each diagnostic test and those who were diagnosed to have (C)APD.](image)
From the finding it can be construed that children with (C)APD have varied performance on the (C)APD diagnostic tests, with a greater number of them have difficulty in auditory integration and auditory memory. Further, on the SPIN and GDT, a larger number of participants failed when tested in the right ear, when compared to the left ear.

The findings of Musiek et al. (1982) are in consensus with that of the present study. They too noted that their children with (C)APD failed most often on different diagnostic tests, including the presence of an auditory integration problem. However, they too reported of a larger number of their participants having temporal processing problems, as assessed by the frequency pattern test.

Agreement of each question of SCAP with (C)APD

To find out the agreement between the SCAP results and (C)APD findings, further analysis was done. The agreement was checked between each question of the SCAP and the diagnostic tests, as well as between each question with the overall diagnosis of (C)APD. This was analysed using the Kappa measure of agreement.

There was a significant agreement ($p < 0.05$) found between some of the questions of SCAP with the SPIN results of both the ears. However, the agreement between these questions and SPIN results was only moderate. There was no agreement observed for other questions with any of the (C)APD tests. In addition, the results of the Kappa revealed that there was no statistically significant ($p > 0.05$) agreement between any question of SCAP and presence / absence of (C)APD, using the criteria given by Chermak and Musiek (1997)

The above findings substantiates that isolated symptoms cannot be used to suspect the presence / absence of (C)APD and make a judgment as to whether a client is to be referred or not for further evaluation. As the agreement between the each SCAP questions and presence and absence of (C)APD was poor, it was considered better to use groups of questions to suspect the presence / absence of (C)APD, instead of individual questions.

None of the checklists for (C)APD, reported in the literature, have recommended making referrals based on only one symptoms of (C)APD. Smoski et al. (1992) also reported that the symptoms of (C)APD vary from child-to-child as well as situation-to-situation. Due to this heterogeneity, they too recommended that it would be better to use groups of questions to refer a child for further diagnostic assessment. Thus, the findings of present study are in consensus with the recommendation of Smoski et al. (1992).

Further, the correlation between the total score obtained on SCAP with the diagnostic test results was determined. This was done for five different diagnostic tests that had being administered.

**Correlation between overall SCAP scores and each (C)APD diagnostic test**

The correlation between the overall scores obtained on the SCAP checklist with the results of the (C)APD test battery (SPIN, GDT, MLD, DCV, AMT) are depicted in Table 1. This correlation was checked using Pearson moment product correlation.
It is apparent from Table 1 that there was a significant negative correlation between the SCAP scores and the SPIN scores for the right ear ($r = -0.439$, $p < 0.05$), SPIN scores for the left ear ($r = -0.536$, $p < 0.05$), and the auditory memory test ($r = -0.464$, $p < 0.05$). This indicates that as the SCAP score increased the score of these diagnostic tests decreased. However, this correlation was only moderate. There was no correlation between the SCAP scores and any of the other diagnostic tests of (C)APD.

Table 1: Correlation between SCAP scores and each of the (C)APD tests.

<table>
<thead>
<tr>
<th>(C)APD tests</th>
<th>Ear</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPIN</td>
<td>Right ear</td>
<td>-0.439*</td>
</tr>
<tr>
<td></td>
<td>Left ear</td>
<td>-0.536*</td>
</tr>
<tr>
<td>GDT</td>
<td>Right ear</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>Left ear</td>
<td>0.030</td>
</tr>
<tr>
<td>MLD</td>
<td>Both ears</td>
<td>-0.021</td>
</tr>
<tr>
<td>DCV</td>
<td>Both ears</td>
<td>-0.286</td>
</tr>
<tr>
<td>AMT</td>
<td>Both ears</td>
<td>-0.464*</td>
</tr>
</tbody>
</table>

* Significant at $p < 0.05$ level

The findings of the present study are unlike that reported by Purdy and Johnstone (2000). They correlated the subsection of CHAPPS with the Dichotic Digit Test (DDT) and the Frequency Pattern Test (FPT). They found scores obtained from the Dichotic Digit Test correlated significantly with the CHAPPS memory rating but not with the other subsection (attention span, listening in noise etc.). In addition, the authors did not find a correlation between the frequency pattern tests and CHAPPS.

The variation in finding between the present study and that of Purdy and Johnstone (2000) could be due to the differences in the design of the checklists. The CHAPPS used a larger number of questions and a more complex way of scoring when compared to the SCAP. The subtle differences between the questions and the rating used in the CHAPPS could have affected the scores obtained on their checklist. This in turn could have affected the correlation between the checklist and the diagnostic tests used by Purdy and Johnstone (2000). Another reason for the differences in findings across the studies could be due to the heterogenic nature of (C)APD. The variation in the participants could have also resulted in the difference in findings between study by Purdy and Johnstone (2000) and the present study.

**Agreement between various cut-off scores of SCAP and the diagnostic tests**

The agreement between various cut-off scores of SCAP and the diagnosis of the presence of (C)APD was also ascertained using the Kappa measure of agreement. This agreement was done to find which score of SCAP could serve as the best cut-off criteria to indicate the presence / absence of (C)APD. The number of the participants at each cut-off included those with as well as those having scores above the particular cut-off score.
The results revealed that there was a significant moderate agreement for a SCAP cut-off score of five \([k = 0.26 \ (p < 0.05)]\) and six \([k = 0.37 \ (p < 0.05)]\) with the presence/absence of (C)APD. The agreement was slightly greater for the cut-off scores of six. The other cut-off scores demonstrated no such agreement. This finding indicates that the score of six was the best cut-off score to define a pass / refer criteria. Probably when the SCAP cut-off score were set lower than six, the over referral rate was high. On the other hand, with a higher SCAP cut-off score, the under referral rate was high.

Additionally, the agreements between the SCAP findings and each of the (C)APD test results were also carried out using the Kappa measures of agreement. This was done with the SCAP cut-off score of 5 as well as 6. These two cut-off scores were selected since they had a significant agreement with the presence/absence of (C)APD. The results revealed that there was a moderate, yet significant agreement with the SPIN findings for the both ear as well as AMT for the cut-off score of six. However, for the cut-off score of five, there was no such agreement found with any of the (C)APD tests.

Further, the sensitivity and specificity of the SCAP was determined for different cut-off criteria. This was done to confirm the most appropriate cut-off score.

**Sensitivity and specificity of SCAP using different cut-off scores**

The sensitivity and specificity for each cut-off score of SCAP was calculated and tabulated. The number of the true positive [number of participants identified as having (C)APD by SCAP] and number of true negatives [number of participants identified as not having (C)APD by SCAP] were calculated. This was obtained for different cut-off scores of SCAP. Using this information, the sensitivity and specificity was calculated.

It is evident from Figure 2 that as the cut-off score of SCAP increased, the sensitivity decreased and specificity increased. With the cut-off score of six, the sensitivity and specificity values were comparable, and with other cut-off scores either the sensitivity was lower or the specificity was lower. Based on the above finding of the study and the results of
the Kappa measures of agreement, the cut-off score of six for the SCAP is recommended to decide whether a child is suspected to have or not have (C)APD. At this cut-off, the sensitivity was good without compromising on the specificity.

A few studies have provided the sensitivity and specificity of published screening checklists. Drakes et al. (2006) found that the CHAPPS had a sensitivity of 75% but a specificity of just 25%. They observed this finding when using a stringent diagnostic criterion, wherein a child was labeled as having (C)APD if he/she failed in two tests at least in one ear for the same process. However, the authors reported that the findings could have been different if they used a lax criterion, as recommended by Bellis (2003).

Cameron et al. (2005) also noted that CHAPPS results lead to over-referral. Further, they observed that the CHAPPS scores did not shed light on the magnitude of deficits demonstrated in diagnostic tests. However, it provided information in assessing the overall auditory function. It can be seen that though the SCAP had a sensitivity that is comparable to that of CHAPPS, its specificity was far higher. While the specificity of CHAPPS was just 25%, that of SCAP was 68% indicating that the latter checklist was more efficient.

The screening tests reported in the literature have sensitivities and specificities that differ from that of the present study. Domiz and Schow (2000) found the SCAN developed by Keith (1986) to have a sensitivity of only 45% and a specificity of 95%. Thus, this test has considerably poorer sensitivity compare to the SCAP but a much higher specificity. Using the SCAP would result in a lesser chance of under referral, when compared to the SCAN. On the other hand, MAPA developed by Domitz and Schow (2000) has been found to have a high sensitivity and specificity (83% and 85% respectively). Though this screening test would be more efficient in referring / passing children with suspected (C)APD, it would be far more time consuming when compared to SCAP. Schow, Seikal, Brockett and Whitaker (2007) reported that the MAPA took around 21 minutes to administer on a child. In contrast, teachers took approximately 10 minutes to answer the SCAP and provide information about the entire class having a strength of 40 to 50 students.

Thus, it can be inferred that the SCAP is a practical and fairly efficient method to screen school-going child to detect (C)APD. Though, it is not as efficient as some other screening tests, it is far more time and cost effective.

Prevalence of (C)APD in school-going children

From the SCAP scores obtained from the 3120 children, it was found that 216 (6.9%) of them had one or more symptoms of the (C)APD. However, using the cut-off score of 6, only 83 (2.6%) children were suspected to have (C)APD. On the other hand, the remaining 133 (4.2%) of them had some symptoms of (C)APD but they passed as per this cut-off score. Thus, based on the SCAP results, it can be construed that the possible prevalence of (C)APD, in the population studied was just 2.6% without accounting for the false negatives and false positives.
However, the SCAP was noted to have a false negative of 29%. After correcting for the false negatives by subtracting this group, the number of true positive who were referred as per SCAP was 59 (1.9%). Further, SCAP had a false positives of 32% wherein 43 (1.3%) of the children would have been missed. Thus, by adding this group, it can be inferred that the number of children with (C)APD would have been 102 (59 + 43), resulting in 3.2% truly having a suspected (C)APD.

The prevalence observed in present study is in agreement with the findings of Chermak and Musiek (1997). They too observed that 2% to 5% of school-aged children have (C)APD, which is not very different from the average 3.2% found in the present study.

**Profiling of (C)APD Test findings**

The 42 children who were subjected to diagnostic tests, were categorized as pass or refer using their SCAP findings (using a cut-off score of 6). Twenty participants obtained scores of six and greater on the SCAP, while 22 obtained scores below six. The results of each of the diagnostic tests as well as the overall diagnosis of the (C)APD are provided in Figure 3. The diagnostic tests that demarked the two groups (pass, refer) were SPIN, AMT and DCV. However, equal number of participant failed in GDT. Out of the 20 participants who were suspected to have (C)APD and were referred based on the SCAP results, 13 (65%) had (C)APD. On the other hand, five (22%) of the 22 participants, who passed the SCAP checklist, were diagnosed to have (C)APD.

In general, the maximum failure was observed for the DCV and AMT tests, followed by SPIN and GDT. However, only one participant failed the MLD test. Thus, while administering the (C)APD tests, it is necessary to include DCV, AMT, SPIN, and GDT. Higher preference should be given to DCV and AMT during the assessment of (C)APD, as larger number of children failed these tests. It can be deduced from the findings of the study that children generally have greater problems with auditory integration and auditory memory, followed by auditory separation / closure and temporal processing.

![Figure 3](image.png)

**Figure 3**: Percentage of participants who passed / referred based on the SCAP as well as those who failed the diagnostic tests. The numbers provided above each bar indicate the actual number of participants.
Further, it was observed that different children failed different tests indicating that all the children did not exhibit the same kind of auditory processing difficulties. Therefore, it is important to include a battery of tests that assess different auditory processes. It is recommended to profile each client to determine the exact deficit which in-turn would help in better management.

It is difficult to be compared the above finding of the present study with reports in literature. The tests / process that have been assessed in different studies vary. Though there exists variance across studies, a few similarities in choice of tests / process can be observed. Musiek et al. (1982) also observed that their participants had more difficulty in auditory integration and temporal processing similar to that found in the present study.

However, Musiek et al. (1982) rated temporal processing to be the second highest deficits unlike the findings of present study where it was found to be considerably less prevalent. Likewise, the order of processes that were deficient in the present study differs from that reported by Ferry and Wilber (1986). However, they too noted that auditory closure and integration problems were present in their participants. Variation across the studies could be attributed to the variations in the tests administered. Though these studies tap similar process, the actual tests used varied. However, the heterogeneity of the condition could have also contributed to the differences observed across the studies.

**Reliability measures**

In addition to the measures of sensitivity and specificity, the test-retest reliability was checked. It was done separately for the checklist and for the diagnostic tests. While the reliability of SCAP was tested approximately on 20% of the participants, the reliability of the diagnostic tests was done on approximately 5% of the participants.

The reliability of the SCAP was found to be good as per the findings of the alpha reliability co-efficient. The coefficient was greater than 0.6 \( [a = 0.77, (p < 0.05)] \) indicating that the test-retest reliability of SCAP was good.

The reliability of the (C)APD test battery was done on two children showed that the overall diagnosis of the presence / absence of (C)APD and the results of each of the tests of (C)APD remained same. Though there were some differences in the raw scores obtained, the diagnosis continued to be the same.

**Summary and Conclusions**

The present study was undertaken to check the utility of the ‘Screening Checklist for Auditory Processing’ (SCAP) developed by Yathiraj and Mascarenhas (2002) in identifying children with symptoms of (C)APD. The study also aimed at finding the agreement of the SCAP scores with a battery of (C)APD tests. To determine an appropriate cut-off score for SCAP, the sensitivity and specificity of the checklist was studied.
The analysis of the data revealed that a single symptom on the SCAP was not a good indicator of the presence of (C)APD. Hence, the need to use a group of symptoms was felt necessary. It was found that attention span related symptoms were more prevalent in school-going children with suspected (C)APD. This was followed by memory problems and difficulty in hearing in noisy situations.

Further, a comparison of various cut-off scores of SCAP with the (C)APD diagnostic test findings indicated that a SCAP cut-off score of 6 yielded a good correlation with the results of SPIN and AMT as well as with the overall diagnosis of (C)APD. Additionally, the cut-off score of 6 on SCAP resulted in a fairly high sensitivity without compromising on the specificity. A sensitivity of 71% and specificity of 68% was obtained for the SCAP when a cut-off criterion of 6 was used. The sensitivity and specificity of the SCAP was comparable with other checklist / tests reported in the literature (Domitz & Schow, 2000; Drakes et al., 2006; Schow et al., 2007).

Using cut-off criteria of six on the SCAP, the prevalence of suspected (C)APD in school-going children was 3.2%. This value was obtained after making corrections for the false positives and false negatives. The overall results revealed that the SCAP could be used as a simple and practical measure to screen for the presence of (C)APD.

Among the diagnostic tests used, most of the participant failed in the AMT and DCV tests, followed by SPIN and GDT. Hence, it is important to include these tests in a diagnostic test battery. It is more essential to include the first two tests as the participants failed them more frequently. All the participants who had (C)APD did not demonstrate similar auditory processing difficulties. Thus, a test battery approach should be employed while assessing children with suspected (C)APD.

Acknowledgement

Thanks are to the Director AIISH for permitting to carry out the study. Thanks are also due to the HOD Audiology for permitting to use the equipment. We thank all our participants for their co-operation.

References


SPEECH CHARACTERISTICS IN INDIVIDUALS WITH AUDITORY DYS-SYNCHRONY

Pooja Dayal & M. Sandeep*

Abstract

The present study was aimed to examine the effects of longstanding Auditory dys-synchrony (AD) on speech production. Speech production of 12 individuals with acquired long-term AD was characterized and compared against that of 20 age matched individuals with normal hearing sensitivity. It was hypothesized that any difference between the two groups in their speech production will because of long standing perceptual deficits due to AD. Long-term AD was operationally defined as AD for more than 5 years. The study was carried out in 2 phases; Phase 1 included the perceptual analysis of speech of adults with long-term AD, and the phase 2 included acoustic analysis of the same speech samples. Results showed that speech of individual with AD was abnormal on perceptual as well as acoustical analysis. The extent of deficit in speech production correlated well with the speech identification scores. These results highlight the importance of auditory feedback in maintaining the speech production skills. The results show a close relationship between speech perception and production skills in turn supporting the closed loop models of speech production. There was also evidence of compensatory strategies in production that could be associated with the perceptual deficit.

Introduction

Auditory dys-synchrony (AD) is a clinical syndrome in which outer hair cell function is spared, but afferent neural transmission is disordered (Starr, Picton, Sininger, Hood, & Berlin, 1996). A typical person with AN will have elevated pure tone thresholds, very poor speech discrimination for degree of hearing loss, absent acoustic reflex in any configuration for any stimuli, no auditory brainstem response, but presence of robust Otoacoustic emissions. The prevalence of AD is around 1 in 183 (0.54%) among individuals with sensorineural hearing loss (Ajith, 2006).

AD may affect the functioning of inner hair cells, synaptic junctions between the inner hair cells and auditory nerve, or the auditory nerve itself (Starr et al., 1996). These individuals typically have speech recognition deficits that are not in consonance with their pure tone hearing thresholds (Sininger, & Starr, 1999). They usually do not benefit from conventional amplification (Zeng Oba, Garde, Kong, Sininger, & Starr, 1999; Starr, 2004). Poor speech perception abilities in these patients are attributed to abnormal temporal coding and asynchrony (Rance, McKay, & Grayden, 2004).

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Results of psychophysical studies have shown that individuals with AD are proved to have more serious deficits in frequency resolution, temporal resolution and poor gap detection (Zeng, Kong, Michalewski, & Starr, 2005). These deficits further deteriorate in adverse listening conditions (Kraus, Bradlow, Cheatham, Cunningham, King, & Koch, 2000).

Studies have shown that there is a close relationship between speech perception and the development of speech production skills. The relationship between hearing ability and speech intelligibility supports the acoustic theory of speech production (Kuhl, 1981; Stevens, 2002), which claims that the acoustic patterns of a speech signal are processed and organized into an internal map that can be distorted if the acoustic patterns have not been adequately received during the input process. With a compromised input process, such as that associated with a hearing loss, the incorrect mapping will result in distorted or deleted speech sounds in speech production (Stevens, 2002). Dunn and Newton (1986) reported suprasegmental errors in the speech of people with severe to profound hearing impairments.

Ramsden (1981) reported that speech of the adventitiously deaf degenerated systematically over time, indicating that auditory information plays an important role in the maintenance of normal speech. Zimmermann and Retalliata (1981) investigated the systemic longitudinal degeneration of speech in hearing impaired individuals and found that the adventitiously deaf speaker’s speech degenerated slowly due to overlearned motor patterns, and errors made without knowledge. They also reported that it takes many instances of exceeding the normal range of variability to change production. Articulatory movement patterns were less efficiently maintained over time when only non-auditory sensory systems were available. Consequently, auditory information is not used for moment-to-moment monitoring, but periodically to update and calibrate the system. Houde and Jordan (1998) reported that compensatory changes in individual sound production can be induced over time by systematically altering auditory feedback to indicate inaccurate articulation.

Rance, Barker, Sarant, and Ching (2007) reported that school aged children with AD are developing spoken language more slowly than would be expected for children with normal hearing. This is expected as the perceptual deficits occur before the development of the speech and language. However, it was interesting to study perceptual deficits secondary to AD would change the speech production in postlingually acquired AD. There was no such study in AD in the literature. Therefore, the present study was taken up.

The objectives of the present study were:

1. To characterize the speech production of adults with long-term AD through perceptual analysis.
2. To characterize the speech production of adults with long-term AD through acoustic analysis.
Method

Subjects

The study was conducted in 12 individuals (8 females & 4 males) with acquired long-term AD and 20 age matched individuals (10 males & 10 females) with normal hearing sensitivity. Individual with AD were grouped under experimental group while normal hearing individual were grouped under control group. Long-term AD was operationally defined as AD for more than 5 years. The individuals in the AD group had the same diagnosis five years back and they were contacted through mail and recruited. This way, longstanding (at least for 5 years) nature of the disorder was confirmed. Age of the subjects in this group ranged between 17 and 30 years. Subjects in both the groups were native speakers of Kannada and belonged to same geographical location (Mysore city or places within Mysore district). As reported by the parents and also as observed in the informal testing, all the subjects in the present study had normal speech and language development.

Test materials

Two speech samples were collected from all the subjects. The first of these was during reading of a Standardized passage in Kannada on Bengalooru (had total of 39 words containing only voiced sounds) and second was during a description of a standardized picture depicting a picnic situation. The recording of the speech samples was done in sound treated room in ideal recording conditions.

Analysis

Two types of analysis were used in the study: perceptual analysis and acoustic analysis.

Perceptual Analysis

Thirteen sophisticated listeners perceptually rated the parameters (voice, articulation, prosody, rate of speech & overall intelligibility) of speech. They rated the sample as either normal or abnormal. Listeners were blindfolded to the purpose of the study. Also overall intelligibility was rated on speech intelligibility rating scale given by Markides (1986). A score between 1 and 7 was determined for each sample to the following description:

1. Normal
2. Very easy to follow
3. Fairly easy to follow
4. Rather difficult to follow
5. Very difficult to follow
6. Unintelligible
7. Non-existent

Acoustic Analysis

Each sample was acoustically analyzed. Temporal parameters of speech were noted. The parameters analyzed and recorded were word duration, voice onset time, burst duration,
transition duration and speed of transition, preceding vowel duration, & following vowel duration.

**Statistical Analysis**

The perceptual and acoustical data thus obtained were tabulated. Descriptive statistics like mean and standard deviation of the data were obtained for all the parameters analyzed. Independent t test, Mann-Whitney test and Equality of proportion were applied to check whether there were any significant differences between normal and AD group in their speech production.

**Results**

**Perceptual Analysis**

Mean percentage of judgment was calculated for both ‘Normal’ and ‘Abnormal’ judgments using the following formula.

\[
\text{Mean percentage (\%)} = \frac{\text{No. of ‘Normal/ Abnormal’ judgments in each parameter}}{\text{Total no. of judgments}} \times 100
\]

The mean percentages of ‘Normal/ Abnormal’ judgments of the samples were compared among control and experimental groups. Figure 1 showed Mean percentage of ‘Normal’ judgments in each parameter of speech in normal and AD group & Figure 2 showed Mean percentage of ‘Abnormal’ judgment in each parameter of speech in normal and AD group.

Results of the perceptual experiment showed that, majority of speech samples of auditory dys-synchrony (AD) were perceptually abnormal. All the parameters of speech (voice, articulation, prosody, rate of speech & overall naturalness) were rated as abnormal, although prosody was found to be maximally affected.

![Image](image.png)

Figure 1: Mean percentage of ‘Normal’ judgments in each parameter of speech in normal and AD group.
Figure 2: Mean percentage of ‘Abnormal’ judgment in each parameter of speech in normal and AD group.

To verify whether the mean percentage of normal/abnormal judgment was significantly different between control and experimental groups, Equality of proportion was tested and Z scores were calculated. Results of Z scores are given in Table 1. Results showed a significant difference between the 2 groups in all the parameters at 0.05 level of significance.

Table 1: Z scores showing the significance of difference between the mean percentage of ‘Normal/ Abnormal’ judgments in normal and AD group.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Z (Normal judgment)</th>
<th>Z (Abnormal judgment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>10.59*</td>
<td>13.18*</td>
</tr>
<tr>
<td>Articulation</td>
<td>11.90*</td>
<td>11.91*</td>
</tr>
<tr>
<td>Prosody</td>
<td>19.93*</td>
<td>19.93*</td>
</tr>
<tr>
<td>Rate of speech</td>
<td>12.44*</td>
<td>12.83*</td>
</tr>
<tr>
<td>Overall naturalness</td>
<td>16.18*</td>
<td>16.71*</td>
</tr>
</tbody>
</table>

Note: * - p < 0.05

Mean percentage of overall intelligibility was calculated using the following formula.

Mean % percentage of judgments = \( \frac{\text{No. of subjects rated under a particular scale}}{\text{Total no. of judgments}} \times 100 \)

Figure 3 showed Mean percentage of overall intelligibility rating in normal and AD groups. Results showed that AD group had higher rating on the intelligibility scale compared to normal. This means intelligibility of speech of AD was poorer compared to normal. The overall intelligibility ranged from 2-5 in AD group and 1-3 in normal group.
Correlation between Speech Identification Scores and Overall Intelligibility

Speech identification scores and ratings of overall intelligibility were correlated using the data obtained from AD group. Correlation was not carried out for the data from normal group. Correlation was done for the identification scores of the better ear as well as poorer ear. Spearman's rho test was used for the task and the results are as given in Table 2. The correlation coefficient for the better and poorer ear scores are given separately.

Table 2: Results of correlation between overall intelligibility and speech identification scores of better and poorer ear.

<table>
<thead>
<tr>
<th>Ear</th>
<th>N</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results of better ear</td>
<td>12</td>
<td>-0.624*</td>
</tr>
<tr>
<td>Results of poorer ear</td>
<td>12</td>
<td>-0.673*</td>
</tr>
</tbody>
</table>

Note: * - p < 0.05

In individuals with AD, there was a significant high correlation between speech identification scores and, the severity of abnormality in speech intelligibility (p<0.05). Results showed that, as the speech identification scores decreased, overall speech intelligibility reduced.

Acoustic Analysis

The words for this purpose were chosen from speech samples of passage reading as well as picture description task. The words were categorized based on the number syllables. For passage reading, these words were categorized as bisyllabic, trisyllabic, foursyllabic, fivesyllabic and sixsyllabic words. For picture description, these words were categorized as bisyllabic, trisyllabic, and foursyllabic.

Mean and standard deviation of word duration were obtained in different word categories in the two groups (Table 3). In general, the mean word duration was longer in AD group compared to normal group in all the word categories. The AD group had greater
variations in the word duration than that of normal group. To verify whether these differences in word duration were significantly different, the two groups were compared using independent t test.

Table 3: Mean and Standard Deviation (SD) of word duration in different word categories.

<table>
<thead>
<tr>
<th>Word Category</th>
<th>Subject</th>
<th>Passage Reading</th>
<th>Picture Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>Mean (in ms)</td>
</tr>
<tr>
<td>Bisyllabic</td>
<td>Normal</td>
<td>20</td>
<td>290.59</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>348.77</td>
</tr>
<tr>
<td>Trisyllabic</td>
<td>Normal</td>
<td>20</td>
<td>440.67</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>509.71</td>
</tr>
<tr>
<td>Foursyllabic</td>
<td>Normal</td>
<td>20</td>
<td>547.85</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>607.27</td>
</tr>
<tr>
<td>Fivesyllabic</td>
<td>Normal</td>
<td>20</td>
<td>622.92</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>684.54</td>
</tr>
<tr>
<td>Sixsyllabic</td>
<td>Normal</td>
<td>19</td>
<td>774.55</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>862.33</td>
</tr>
</tbody>
</table>

Table 4 gives results of independent t test. Results showed a significant difference in the word duration between the two groups. The mean word duration in AD group was significantly longer compared to normal group. However, this statistical difference (p<0.05) was seen only in bisyllabic and trisyllabic words. There was no difference (p>0.05) in the mean word duration between the two groups in four syllabic, five syllabic and six syllabic words.

Table 4: Results of independent t test in different word categories

<table>
<thead>
<tr>
<th>Word</th>
<th>Passage Reading</th>
<th>Picture Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>df</td>
</tr>
<tr>
<td>Bisyllabic</td>
<td>4.431*</td>
<td>30</td>
</tr>
<tr>
<td>Trisyllabic</td>
<td>3.111*</td>
<td>30</td>
</tr>
<tr>
<td>Foursyllabic</td>
<td>2.014</td>
<td>30</td>
</tr>
<tr>
<td>Fivesyllabic</td>
<td>1.974</td>
<td>30</td>
</tr>
<tr>
<td>Sixsyllabic</td>
<td>1.982</td>
<td>29</td>
</tr>
</tbody>
</table>

Note: * - p < 0.05

In the picture description task, result showed a significant difference (p<0.05) in the word duration between the two groups in bisyllabic words and trisyllabic words. However,
between the groups, there was no significant difference (p>0.05) in the mean word duration of foursyllabic words. Since the data available for foursyllabic words in the clinical group was less, Mann Whitney test was done to cross check the results of Independent t test. Results of Mann-Whitney test is [Z= -0.165, p= 0.869]. Results showed no significant difference between the two groups.

Other Temporal Parameter

The other temporal parameters that analyzed were voice onset time (VOT), burst duration (BD), transition duration (TD) and speed of transition (STD), preceding vowel duration (PVD), following vowel duration (FVD). Mean and standard deviation of data of each temporal parameter are given in Table 5 for the two tasks.

Table 5: Mean and Standard deviation (SD) of data of different temporal parameter in two groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>N</th>
<th>Passage Reading</th>
<th>Picture Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean (in ms)</td>
<td>SD</td>
</tr>
<tr>
<td>VOT</td>
<td>Normal</td>
<td>20</td>
<td>48.15</td>
<td>7.94</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>60.29</td>
<td>7.82</td>
</tr>
<tr>
<td>BD</td>
<td>Normal</td>
<td>20</td>
<td>9.24</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>12.64</td>
<td>1.68</td>
</tr>
<tr>
<td>TD</td>
<td>Normal</td>
<td>20</td>
<td>38.10</td>
<td>6.02</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>26.47</td>
<td>7.48</td>
</tr>
<tr>
<td>STD</td>
<td>Normal</td>
<td>20</td>
<td>8.90</td>
<td>2.91</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>14.01</td>
<td>6.11</td>
</tr>
<tr>
<td>PVD</td>
<td>Normal</td>
<td>20</td>
<td>87.11</td>
<td>18.88</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>109.28</td>
<td>16.49</td>
</tr>
<tr>
<td>PVD</td>
<td>Normal</td>
<td>20</td>
<td>76.88</td>
<td>14.43</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>12</td>
<td>114.37</td>
<td>27.74</td>
</tr>
</tbody>
</table>

For passage reading, in general, the mean VOT, BD, PVD and FVD were longer in AD group compared to normal group. STD was faster in AD groups compared to normal groups. However, the mean TD was shorter in AD group compared to normal group. The AD group had greater variation in all parameters than that of normal group.

To verify whether these differences in all parameters were significantly different, the two groups were compared using independent t test. Table 6 gives results of Independent t-test. Results showed a significant difference (p<0.05) in all the parameters; VOT, BD, TD, STD, PVD and FVD between two groups.
Table 6: Results of Independent t test in different temporal parameter of speech

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Passage Reading</th>
<th>Picture Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>df</td>
</tr>
<tr>
<td>VOT</td>
<td>0.744*</td>
<td>30</td>
</tr>
<tr>
<td>BD</td>
<td>6.381*</td>
<td>30</td>
</tr>
<tr>
<td>TD</td>
<td>4.827*</td>
<td>30</td>
</tr>
<tr>
<td>STD</td>
<td>3.201*</td>
<td>30</td>
</tr>
<tr>
<td>PVD</td>
<td>3.365*</td>
<td>30</td>
</tr>
<tr>
<td>FVD</td>
<td>5.045*</td>
<td>30</td>
</tr>
</tbody>
</table>

Note: * - p < 0.05

In picture description, in general, the mean VOT, BD and TD were longer in AD group compared to normal group. However, the mean STD was faster in AD group compared to normal group. Since the data available in the picture description task in the clinical group was less, Mann Whitney test was done to cross check the results of Independent t test. Table 7 gives results of Mann-Whitney test. Results showed a significant difference (p<0.05) between the two groups in VOT, BD, TD, and STD.

Table 7: Results of Mann-Whitney test for the data from picture description task.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Z</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOT</td>
<td>1.706</td>
<td>0.008*</td>
</tr>
<tr>
<td>BD</td>
<td>2.898</td>
<td>0.004*</td>
</tr>
<tr>
<td>TD</td>
<td>2.154</td>
<td>0.031*</td>
</tr>
<tr>
<td>STD</td>
<td>2.177</td>
<td>0.029*</td>
</tr>
</tbody>
</table>

Note: * - p < 0.05

Discussion

Results of Perceptual Analysis

Speech production was abnormal in individuals with longstanding AD. Perceptually, all the parameters of speech were found to be abnormal. The result of abnormal production is in agreement with earlier studies in individuals with cochlear hearing loss. Houde and Jordan, (1998) reported that compensatory changes in individual sound production can be induced over time by systematically altering auditory feedback to indicate inaccurate articulation. Similar findings have been reported by other investigators (Binnie, Daniloff, & Buckingham, 1982; Cowie, Douglas-Cowie, & Kerr, 1982; Elman, 1981; Kirchner & Suzuki, 1968; Penn, 1955; Ramsden, 1981, Zimmermann & Rettaliata, 1981). Auditory feedback helps in
moment-to-moment monitoring, periodic update and calibration of the system. These results seem to support closed loop models of speech production.

These results further validate the need of auditory feedback in maintaining the speech production skills. In instances of disordered auditory feedback, there is deterioration of speech over time. Also, more speech perception difficulties were found to be associated with more abnormalities in speech production. The results show a close relationship between speech perception and speech production skills in turn supporting the closed loop models of speech production.

Results of the present study showed that the speech produced by individuals with AD was less intelligible compared to normal. Also, there was a significant correlation between speech identification scores and the over intelligibility of speech of AD. That means, ones who had relatively better speech identification, produced more intelligible speech compared to ones who had poorer speech identification. This result again supports the importance of auditory feedback to speech production skills. More the disruption in auditory feedback, more likely of errors in speech production. In contrast, Binnie et al. (1982) and others (Cowie et al., 1982; Plant, 1984) had reported that the changes in speech production observed in deafened adults appear to have little effect on speech intelligibility in cases where onset of deafness occurred in adulthood. The earlier the onset of deafness, the greater the effect of hearing loss on intelligibility.

**Results of Acoustic Analysis**

Earlier studies on speech perception in AD (Ajith, 2006) had shown increased just noticeable differences in the VOT, burst duration and transition duration. Considering these results, it was hypothesized that there shall be changes in the temporal parameters of speech of longstanding AD. Also, results of perceptual analysis in the present seemed to support the closed loop models of speech production. In such a case, the type of errors seen in the speech production in some way related to type of perceptual deficit. That is, if individuals with AD require more temporal and spectral difference to discriminate between phonemes, in their own production they may be using compensatory changes and producing the phonemes accordingly different. This was probed through acoustic analysis of speech of AD. The parameters analyzed were word duration, voice onset time, transition duration, burst duration, speed of duration, preceding vowel duration, and following vowel duration.

Results also showed deviations in speech production in the acoustical analysis. In general, there were lengthened temporal cues of speech. Earlier studies had shown increased JNDs in AD. Hence, lengthened temporal cues could be probably a compensatory strategy used by individuals with AD to facilitate the perception of their own speech.
Summary and Conclusion

Results of the perceptual analysis showed that the speech of auditory dys-synchrony (AD) was perceptually abnormal. All the parameters of speech (voice, articulation, prosody, rate of speech & overall naturalness) showed abnormality, although the prosody was found to be maximally affected. Overall intelligibility of speech of AD was found to be poorer. In individuals with AD, there was a significant high correlation between speech identification scores and, the severity of abnormality in speech intelligibility. Results also showed deviations in speech production on acoustical analysis. In general, there were lengthened temporal parameters of speech in AD.

Overall, there was agreement between the perceptual deficits and the speech production characteristics. This supports the closed loop models of speech production and active theories of speech perception. There was also a good agreement between perceptual deficits in individuals with AD (as reported in studies in the literature) and the characteristics of speech of AD. In general, there were lengthened temporal cues of speech and this could be probably a compensatory strategy used by individuals with AD to facilitate the perception.

References


Relationship between Auditory Long Latency Response and Speech Identification Scores in Individuals with Auditory Neuropathy

Ramesh Chandra Indlamuri & Animesh Barman*

Abstract

The present study aimed at investigating the relationship between speech identification scores and ALLR parameters in quiet and at 0 dB SNR in individuals with auditory neuropathy. In the process, 6 individuals with auditory dys-synchrony and 15 individuals with normal hearing in the age range of 12-40 years participated in the study. Speech identification scores were assessed by bi-syllabic words with and without noise. Cortical auditory evoked potentials were recorded for click and speech stimuli /ba/, /ga/ and /da/. Results revealed that there was no significant correlation between speech identification scores and parameters of ALLR on both normal hearing individuals and individuals with AD. However, the presence of ALLR does correlate with speech identification scores in both the groups in both the conditions. Speech evoked ALLRs had larger amplitude than click evoked in both the groups and conditions (with and without noise). Among the speech stimulus, /da/ elicited more number of ALLR responses in individuals with AD in both the conditions. To conclude, speech evoked ALLR can be recommended for clinical use for both normal hearing individuals and for clinical population (individuals with auditory dys-synchrony). /da/ stimulus could be used to elicit ALLR in individuals with AD.

Introduction

Auditory neuropathy (AN), more recently referred to as auditory dys-synchrony (Berlin, Hood & Rose 2001), is one of the hearing disorders in which cochlear outer hair cell function is spared but neural transmission in afferent pathway is disrupted. The integrity of cochlear function in these individuals is indicated by the presence of evoked otoacoustic emissions and/or cochlear microphonics (CM). The abnormal neural transmission or dys-synchrony in the auditory nerve fibers is indicated by the absence of auditory brainstem responses and acoustic reflexes (Rance et al., 2002).

Audiological and electrophysiological test findings in auditory neuropathy are suggestive of a retro-cochlear pathology, but the exact site of pathology and pathophysiological mechanism leading to auditory neuropathy is not known. Two physiological explanations proposed for the neurophysiological manifestations observed include, dys-synchronized spikes and/or reduced spike of the auditory nerves (Rance et al., 2002).

Some possible sites of lesion that could produce the audiometric and electrophysiological profile of AN include: inner hair cells, synaptic junction between inner hair cell and type I

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afferent nerve fibers, spiral ganglion cells, demyelination of type I auditory nerve fibers and reduce number of type I auditory nerve fibers. Therefore, AN consists of many varieties, depending on the site of lesion (Starr, Picton, Sininger, Hood & Berlin, 1996).

Hearing sensitivity in individuals with auditory neuropathy may range from normal hearing to profound hearing impairment (Rance, Beer & Cone-Wesson, 1999; Starr, Sininger & Pratt, 2000). A majority of the individuals with auditory neuropathy have low frequency hearing loss with wide range of speech identification scores. These individuals typically have speech identification scores that are out of proportion to their degree of hearing impairment and do not benefit from conventional amplification. Poor speech perception abilities in these patients are attributed to abnormal temporal coding and asynchrony (Zeng, Oba, Sininger & Starr, 1999; Kraus et al., 2000; Rance, McKay & Grayden, 2004; Zeng, Kong, Michalewski & Starr, 2004).

**Need for the study**

In auditory neuropathy/dys-synchrony, auditory brainstem responses are severely disrupted. Hence, it might be expected that more central evoked responses such as the middle latency response and cortical auditory evoked potential (CAEP) would be similarly affected. However, CAEPs may be recordable in some cases of auditory neuropathy/dys-synchrony because these potentials are less dependent on synchronous firing of the auditory nerve than auditory brainstem responses. Many individuals with AD had normal CAEP latencies and amplitudes (Starr et al., 1996; Rance et al., 2002). Hence, the current study has been designed to record ALLR in individuals with normal hearing and also with AD.

Infants with auditory neuropathy and possible hearing impairment are being identified at very young ages through the implementation of hearing screening programs. The diagnosis is commonly based on evidence of normal cochlear function but abnormal brainstem function. This lack of normal brainstem function is highly problematic when prescribing amplification in young infants because of lack of thresholds. Cortical auditory evoked potentials may, however, still be evident and reliably recorded to speech stimuli presented at conversational levels. In these clinical populations, it can also be used to evaluate the benefits with rehabilitative measures. Thus, click and speech is used as stimulus to record ALLR.

Since in individuals with AD, the audiometric configuration varies widely, different speech sounds composed of different spectral energy composition would be preferable to obtain ALLR in individuals with AD. This might suggest the processing of different speech signal having different frequency energy concentration. There is a dearth of information in which they correlate whether speech evoked or click evoked ALLR parameters represents the speech perception ability in these individuals. Thus, the present study was undertaken to record ALLR using three different speech stimulus having different spectral energy.
To date, only few studies have investigated the ALLRs using speech stimuli in auditory neuropathy individuals to predict speech identification abilities. However, these studies had a small number of subjects and reported conflicting results. Cortical auditory evoked potentials elicited using speech stimuli were not compared with the speech perception abilities to find which one correlates the best, whether the click or the speech evoked cortical potentials. No study has been done to correlate ALLR in noise and speech identification scores in noise. So research is required to optimize whether click evoked or speech evoked cortical potentials correlates better with speech identification scores in noise in individuals with AD and normal hearing individuals.

**Aims of the study**

Thus the current study was taken up with the aim to:

- know whether the ALLR vary for different speech sounds in quiet and with ipsilateral noise in normal hearing individuals and individuals with AN/AD.
- investigate the relationship between the click evoked ALLR and speech identification scores in quiet and in noise in individuals with normal hearing and with AN/AD.
- investigate the relationship between the speech evoked ALLR and speech identification scores in quiet and in noise in individuals with normal hearing and with AN/AD.
- know whether the non-speech stimulus or speech stimulus is better to elicit ALLR in individuals with AN/AD.
- know which speech sounds is more suitable to elicit ALLR in individuals with auditory dys-synchrony.

**Method**

**Subjects**

The subjects in the present study were in the age range of 12-40 years and were divided into two groups.

- Individuals with normal hearing (control group)
- Individuals with auditory neuropathy (clinical group)

**Control group**

A total of 15 ears from 15 subjects with normal hearing in the age range of 15 to 38 years were evaluated. The criteria considered for the selection of subject were as follows:

Subject selection criteria:

- Pure tone threshold were within 15 dB HL at octave frequencies between 250 to 8000 Hz for air conduction and between 250 to 4000 Hz for bone conduction.
- All the subjects had ‘A’ type tympanogram with normal acoustic reflex thresholds.
• Speech identification scores were greater than 90%.
• Speech identification scores in the presence of noise at 0 dB SNR were assessed and all of them had scores above 60%.
• Good ABR waveform morphology was present for all the individuals at 80 dB nHL for both 11.1 and 90.1/sec repetition rate.
• TEOAE’s were present in all the subjects for both the ears.
• No history of any otological or neurological problems was reported.

Clinical Group

In the clinical group, 25 ears from 16 subjects with auditory neuropathy in the age range of 13 to 40 years were evaluated. The following criteria were considered for the selection of the subject:

• All the subjects had pure tone audiometry thresholds ranging from normal to moderate sensorineural hearing loss.
• Subjects had speech identification scores ranging from 0-100%.
• Speech identification scores in noise at 0 dB SNR were poor.
• All the ears tested had “A” type tympanograms with absent acoustic reflexes.
• TEOAE’s or cochlear microphonics was present in all the ears tested.
• ABR was absent at 80 dB nHL for all the subjects even at 11.1/sec repetition rate.
• No history of any other observable otological or neurological problems was reported.

Stimulus generation

Syllables /ba/ /ga/ and /da/ were spoken by a male speaker and digitally recorded into a computer with the PRAAT software version 4.2.01 with a sampling frequency of 44,000 Hz and 16 bit resolution. These stimuli were edited in such a way that the voice onset time, burst portion and a little portion of the vowel was retained to make the syllable duration approximately 150 ms. The stimuli durations were 147 ms for /ba/, 146 ms for /ga/ and 150 ms for /da/.

Data collection

Speech audiometry

Speech identification scores were assessed with and without noise using speech material developed by Vandana (1998). The stimuli were presented through supra-aural headphones (TDH-39) using calibrated diagnostic audiometer (GSI-61). Speech perception in noise (SPIN) scores was assessed at 0 dB SNR by using SPIN CD developed by Vargesh (2004). SIS and SPIN scores were established at 40 dB above the SRT (speech recognition threshold) level.
Auditory Long Latency Responses (ALLRs) recording

Subjects were instructed to sit comfortably on a reclining chair and relax during the testing and to stay awake during the testing. They were also instructed to ignore the stimulus and restrict the movement of head, neck and eye during testing. Preparation of the subjects and electrode montage used to record ALLR was the same as used for ABR recording. The parameters used to record ALLR are given in Table 2.

Table 2: Parameters used to record ALLR

<table>
<thead>
<tr>
<th>Stimulus parameters</th>
<th>Acquisition parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transducer</td>
<td>Insert ear phones ER-3A</td>
</tr>
<tr>
<td>Type of stimulus</td>
<td>Clicks and speech stimuli /ba/, /ga/, and /da/.</td>
</tr>
<tr>
<td>Duration of the stimulus</td>
<td>Click- 100μsec /ba/- 147 ms, /ga/- 146 ms and /da/- 150 ms</td>
</tr>
<tr>
<td>Intensity</td>
<td>80 dB SPL</td>
</tr>
<tr>
<td>Presentation ear</td>
<td>Monaural</td>
</tr>
<tr>
<td>Stimulus polarity</td>
<td>Alternating</td>
</tr>
<tr>
<td>No of sweeps</td>
<td>300</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1.1/s</td>
</tr>
<tr>
<td>Ipsilateral masking</td>
<td>Without noise With noise at 80 dB SPL (0 dB SNR)</td>
</tr>
</tbody>
</table>

The recording was done twice at each presentation level to check for the reliability. The waveforms elicited in this manner were shown to three experienced audiologists and they were asked to identify N1, P2 waves. They were not told about the condition and the stimulus for which the responses were obtained. The latencies and amplitudes identified in this way were compared across the judges and the waveforms in which the latencies and amplitude marked by at least two judges were similar were taken for analysis.

Results

Cortical auditory evoked potentials were present in all the normal hearing individuals. In some individuals with AD, AEP’s were absent for all the stimuli or certain stimulus.

N1:
The mean value obtained for click evoked N1 latency in quiet condition was shorter for normal hearing individuals than the clinical group as evident from the Table 3. No ALLR could be recorded using click at 0 dB SNR in the clinical group. Though there was difference between N1 latency obtained for different speech stimuli in both the conditions between the groups, no specific pattern could be observed. N1 latency shift observed in the presence of noise in the clinical group was more than that in normals for /ba/ and /da/ stimulus. For /ga/ stimulus the N1 obtained in the presence of noise was less. The N1 latency obtained in both the groups for different stimuli is given in Table 3.

Table 3: Mean, SD for N1 latency and Z-values with significance level obtained for click and different speech stimulus in two conditions between both the groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control group</th>
<th>Clinical group</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 latency (msec)</td>
<td>Mean (N= 15)</td>
<td>Standard deviation</td>
<td>Mean (N= 7)</td>
</tr>
<tr>
<td>Click without noise</td>
<td>118.00</td>
<td>9.01</td>
<td>134.71 (N= 7)</td>
</tr>
<tr>
<td>Click with noise</td>
<td>121.46</td>
<td>6.86</td>
<td>-</td>
</tr>
<tr>
<td>/ba/ without noise</td>
<td>164.33</td>
<td>9.86</td>
<td>156.50 (N= 14)</td>
</tr>
<tr>
<td>/ba/ with noise</td>
<td>171.13</td>
<td>14.12</td>
<td>208.66 (N= 3)</td>
</tr>
<tr>
<td>/ga/ without noise</td>
<td>162.93</td>
<td>10.88</td>
<td>165.41 (N= 12)</td>
</tr>
<tr>
<td>/ga/ with noise</td>
<td>170.46</td>
<td>14.42</td>
<td>165.50 (N= 2)</td>
</tr>
<tr>
<td>/da/ without noise</td>
<td>158.73</td>
<td>9.67</td>
<td>164.38 (N= 18)</td>
</tr>
<tr>
<td>/da/ with noise</td>
<td>172.26</td>
<td>13.11</td>
<td>193.62 (N = 8)</td>
</tr>
</tbody>
</table>

*p< 0.05

For comparison of N1 latency obtained between the groups for each stimulus, Mann Whitney U test was carried out. A statistically significant difference was obtained for N1 latency elicited in quiet only for /ba/ stimulus and not for the other three stimuli (Table 3).

To check for the correlation between speech identification scores and N1 latency, Spearman’s rank correlation was carried out. Both the groups did not show any significant correlation between speech identification scores and N1 latency evoked by all the stimuli in both with and without noise conditions. Both the groups showed a significant reduction in speech identification score in the presence of noise. However, SIS was poor in clinical group than in control group in both the conditions.

P2:

It can be inferred from the Table 4 that the mean P2 latencies elicited by different stimuli in different conditions were longer in clinical group compared to that of the controls. Though there was difference in P2 latency evoked for different speech stimuli in both with and without
noise conditions between the clinical and control groups, no specific trend was observed. P2 latency shift in the presence of noise in clinical group was more than that was observed in normals for /ba/ and /da/ stimulus.

Table 4: Mean, SD and Z-values with significance level for P2 latency for click and different speech stimulus for control and clinical group in both the conditions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control group</th>
<th>Clinical group</th>
<th>Z - value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (N=15)</td>
<td>Mean (N=7)</td>
<td></td>
</tr>
<tr>
<td>P2 latency (msec)</td>
<td>Standard</td>
<td>Standard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>deviation</td>
<td>deviation</td>
<td></td>
</tr>
<tr>
<td>Click without noise</td>
<td>181.71</td>
<td>184.85</td>
<td>1.097</td>
</tr>
<tr>
<td>Click with noise</td>
<td>186.78</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>/ba/ without noise</td>
<td>215.14</td>
<td>219.42</td>
<td>0.000</td>
</tr>
<tr>
<td>/ba/ with noise</td>
<td>225.00</td>
<td>248.00</td>
<td>1.365</td>
</tr>
<tr>
<td>/ga/ without noise</td>
<td>217.78</td>
<td>228.16</td>
<td>1.957*</td>
</tr>
<tr>
<td>/ga/ with noise</td>
<td>226.64</td>
<td>234.00</td>
<td>2.554*</td>
</tr>
<tr>
<td>/da/ without noise</td>
<td>211.35</td>
<td>227.70</td>
<td>2.133*</td>
</tr>
<tr>
<td>/da/ with noise</td>
<td>225.14</td>
<td>253.00</td>
<td></td>
</tr>
</tbody>
</table>

*p< 0.05

The Mann Whitney U test was carried out for the comparison of P2 latency evoked by each of the 4 stimuli and between the groups. There was a significant difference obtained for P2 latency evoked by /da/ and /ga/ in quiet and for /da/ evoked P2 latency at 0 dB SNR. None of the other stimulus condition was significantly different.

Spearman’s rank correlation was carried out to check for relationship between SIS and P2 latency. There was no significant correlation between speech identification scores and P2 latency for both the groups. SIS obtained at 0 dB SNR showed a significant reduction in comparison to SIS obtained without noise in both the clinical and control group. However, the clinical group showed poor SIS than the control group.

N1-P2:

The mean amplitudes obtained from the clinical group were comparatively lesser than the control group in both the conditions. However, the amplitudes elicited in the presence of noise were lesser than amplitudes elicited without noise in both the groups. In both the groups, the amplitudes elicited by speech stimuli were greater than the amplitude evoked by the click stimulus without noise. The mean amplitude can be seen in table 5.
Table 5: Mean, SD along with Z-values with significance level for N1-P2 amplitude elicited by click and speech stimulus in two conditions for both the groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control group</th>
<th>Clinical group</th>
<th>Z</th>
<th>/Z/</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1-P2 click without noise</td>
<td>3.04 (N= 15)</td>
<td>1.76 (N= 7)</td>
<td>0.66</td>
<td>3.034*</td>
</tr>
<tr>
<td>N1-P2 click with noise</td>
<td>1.97 (N= 15)</td>
<td>-</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>/ba/ without noise</td>
<td>3.50 (N=3)</td>
<td>2.71 (N= 14)</td>
<td>1.42</td>
<td>1.811</td>
</tr>
<tr>
<td>/ba/ with noise</td>
<td>2.32 (N=3)</td>
<td>1.92 (N=3)</td>
<td>0.84</td>
<td>0.772</td>
</tr>
<tr>
<td>/ga/ without noise</td>
<td>3.58 (N=12)</td>
<td>2.71 (N= 12)</td>
<td>0.97</td>
<td>2.172*</td>
</tr>
<tr>
<td>/ga/ with noise</td>
<td>2.24 (N=12)</td>
<td>1.45 (N=2)</td>
<td>0.81</td>
<td>0.94</td>
</tr>
<tr>
<td>/da/ without noise</td>
<td>3.56 (N=17)</td>
<td>2.55 (N= 17)</td>
<td>1.08</td>
<td>2.834*</td>
</tr>
<tr>
<td>/da/ with noise</td>
<td>2.41 (N=17)</td>
<td>2.12 (N= 8)</td>
<td>1.18</td>
<td>0.097</td>
</tr>
</tbody>
</table>

*p< 0.05

Comparison of N1-P2 amplitude between control and clinical group for each stimulus was done using Mann Whitney U test. A significant difference was noted between the groups for N1-P2 amplitude evoked by click, /ga/ and /da/ without noise, which can be seen in the Table 5.

On carrying out Spearman’s rank correlation test, it was found that there was no correlation between SIS and N1-P2 amplitude evoked for any of the stimulus. SIS obtained at 0 dB SNR was significantly reduced in both the groups in comparison to SIS obtained without noise. SIS obtained in the clinical group were poor than SIS obtained in control group, in both the conditions.

It can be concluded from the results that there was no correlation between speech identification scores and parameters of ALLR in the clinical group. But in the control group, even though there was a significant correlation found in between SIS and parameters elicited by stimuli in few conditions, definite trend were not observed. Most importantly it could be observed from the data that /da/ stimulus could elicit ALLR from most of the individuals with AD in both the conditions. Click could elicit ALLR from a few individuals with AD in without noise, but failed to record ALLR in the presence of noise.

**Discussion**

The ALLR data obtained from the individuals with normal hearing was statistically analyzed. The results obtained from the statistical analyses are discussed below.
Latency

It has been noticed in the current study that the latencies of N1 and P2 evoked by speech stimuli were longer than those elicited by click in normal hearing individuals. This difference in latencies between click and speech stimulus was statistically significant in normal hearing individuals but not in the clinical group. This difference between the groups could be due to the pathological condition. The prolonged latencies obtained for speech evoked ALLR than click could be because a single mechanism in the auditory cortex might be involved in general temporal processing for speech and non-speech stimuli, but may underlie further processing of verbal stimuli (Liegeois-Chauvel, Graaf, & Laguitton 1999). Another reason could be due to the rise time of the stimulus i.e., click has steeper rise time than speech stimulus which can lead to shorter ALLR latencies (Onishi & Davis 1968).

Most of the individuals with AD had ALLR for speech stimuli than for click. This could be because the click is a short duration signal with steeper rise time and hence it requires high synchronous firing. However, synchrony is affected in individuals with AD, leading to abnormal ALLR. One more reason could be due to impaired detection of short duration signals in individuals with AD (Zeng et al., 2005). As click is a short duration stimulus, ALLR responses might have been severely affected than for speech evoked ALLR.

ALLR recorded for the speech stimulus in the increasing order from the individuals with AD was /ga/, /ba/ and /da/. The presence of ALLR for the speech stimulus dominated by different frequency spectral energy can be explained in terms of spectral and temporal theories. Since in individuals with AD, phase locking is affected leading to dys-synchrony in low frequency auditory nerve fibers (Rance, McKay & Grayden 2004; Zeng et al., 2005) ALLR elicited for /ba/ and /ga/ stimuli were more affected. However, the high frequencies which are represented by the place of excitation on the basilar membrane are unaffected (Starr, Picton & Kim, 2001). As the energy concentration was greater in high frequency for /da/, it might have resulted in the presence of ALLR in most of the individuals with AD.

The mean latency values in the presence of noise were increased when compared to ALLR evoked without noise for all the stimuli in both the groups. The shift in the latencies between conditions was statistically significant in control group but not in clinical group. This difference between the groups could be due to the pathological condition. Since N1 and P2 are obligatory potentials; the presence of noise at 0 dB SNR would have decreased the audibility of the stimulus. Hence, it led to prolongation of latencies in the presence of noise (Martin & Stapells, 2005). In addition to that, in individuals with AD, 0 dB SNR can cause disruption in the synchrony of auditory nerve fibers (Kraus et al., 2000). In most of the individuals with AD, both dys-synchronization and reduced number of fibers often coexists. This produces an average discharge pattern similar to background activity and exaggerates the masking affects seen in
these individuals (Zeng et al., 2005). This over masking affect could have lead to absence of ALLR in the presence of noise along with dys-synchrony in most of the individuals with AD.

The mean latencies of ALLR elicited for all the stimuli in both the conditions were greater for the clinical group than in control group; even though it was not statistically significant. It was also observed that some individuals with auditory neuropathy had normal latencies, whereas some had greater latencies. Large variation in latency was seen in individuals with auditory neuropathy.

The variability in latency across the individuals may be due to degree of dys-synchrony and underlining patho-physiology. In individuals with AN, one of the possible site of lesion is demyelination of auditory nerve fibers. Demyelination results in an increase in membrane capacitance and a decrease in membrane resistance. Thus, it leads to a delay excitation, reduction in the velocity of action potential propagation and an increase in conduction vulnerability (McDonald & Sears, 1970; Rasminsky & Sears, 1972). The repetitive activation of demyelinated fibers results in a progressive increase in conduction time of action potential and may lead to intermittent or total in their propagation (Rasminsky & Sears 1972). Therefore, the latencies of the evoked potentials would lead to prolongation. Another possible site of lesion in these individuals is axonal neuropathy. This axonal neuropathy reduces the number of neural elements but doesn’t directly affect the conduction speed. The refractory periods of these fibers also tend to be normal and are capable of firing at higher rates. Therefore the classic signs of axonal neuropathy are reduction in whole nerve action potential rather than an increase in latency or broadening of potentials (Kuwabara, Nakajima & Hattori 1999). This might have lead to the latency variations observed in the clinical group.

Amplitude

The amplitude of ALLR elicited for all the speech stimuli was greater than click evoked ALLR in both the groups. However, it was not statistically significant. This amplitude of N1-P2 being greater for speech stimulus than click stimulus might be due to the duration of stimulus leading to temporal integration. The longer duration stimulus activated the neurons other than simply onset detectors in generation of ALLR waves (Alain, Woods & Covarrubias 1997) and minimal duration required for the temporal integration to take place is ≥ 30 msec (Forss, Makela, McEvoy & Hari, 1993).

The amplitude of N1-P2 complex also reduced at 0 dB SNR for all the stimuli when compared to without noise in both the groups. This difference in N1-P2 amplitude elicited in both the conditions was statistically significant in control but not in clinical group. Since ALLR is an exogenous potential, the presence of noise reduces the audibility of the stimulus leading to reduction in amplitude of N1-P2 (Martin & Stapells, 2005). Besides this, in individuals with
AD, the reduction in the amplitude of ALLR could be due to disruption of synchrony being more in the presence of noise (Kraus et al., 2000). The reduction in the amplitude was greater for /ba/ and /ga/ when compared to /da/ as phase locking ability is affected in individuals with AD (Zeng, Oba & Garde 2001).

The amplitude of ALLR elicited was greater for control group than clinical group in both with and without noise conditions. However, it was not significant. In clinical group, some individuals had normal N1-P2, whereas some had abnormal amplitude. The reduction in amplitude in the clinical group can be due to the site of the lesion and severity of the pathology (Kumar & Vanaja 2008).

**Relationship between speech identification scores and ALLR**

None of the groups showed significant correlation between SIS and parameters of ALLR in both the conditions. The lack of correlation between speech identification scores and ALLR could be due to the wide variability in ALLR parameters recorded from both the groups especially in individuals with AD. Another reason could be, ALLR is affected by large number of factors like sleep or drowsiness, background EEG etc.

However, the presence of ALLR did correlate with speech identification scores. Individuals who had greater than 60% of speech identification scores showed ALLR for all the stimuli. The reason for correlation between the presence of ALLR and speech identification scores is that the presence of cortical auditory evoked potential reflects some amount of preserved synchrony in central auditory system which contributes to better speech understanding despite the distortion that occurs at 8th nerve and auditory brainstem in these individuals (Kraus et al., 2000 & Rance et al., 2002).

**Conclusions**

It can be concluded from the above results that the speech elicits better ALLR than click. Hence, speech evoked ALLR can be recommended in clinical use for both normal hearing individuals and in clinical population (individuals with auditory dys-synchrony). /da/ stimulus could elicit ALLR from more number of individuals with AD in both the conditions. Hence, it could be a useful stimulus to elicit ALLR in individuals with AD. There was no significant relationship between speech identification scores obtained and parameters of ALLR recorded in both the conditions for both the groups. But there was a good relation between the presence of ALLR for different stimuli and speech identification scores obtained in both the conditions in individuals with AD. It can also be concluded that optimal auditory nerve and auditory brainstem synchrony do not appear to be essential for understanding speech in quiet listening conditions. However, synchrony is critical for understanding speech in the presence of noise.
Clinical implication of the present study

The study can have the following implications:

- It can be used as an electrophysiological tool to evaluate the processing of speech sounds in normal population as well as in the impaired population.
- The present study also suggests the usage of speech stimulus for eliciting ALLR in individuals with auditory neuropathy.
- It also suggests the usage of /da/ stimulus to elicit ALLR response in individuals with AD.
- ALLR can be used to assess the hearing ability in individuals with auditory neuropathy from whom behavioral thresholds cannot be obtained.
- Using different stimuli dominated by different spectral energy helps us in estimating the severity of pathology across speech spectrum.

References


AIDED THRESHOLD EQUALIZING NOISE TEST

Sasmita Behera & S. N. Vinay*

Abstract

The inner hair cells of the cochlea and/or neurons at certain places along the BM may be missing or functioning so poorly that a tone producing peak vibration in that region is detected by off-place (off frequency), those regions are called “dead regions” (DR). The most widely used methods for the detection of the dead region includes psychophysical tuning curve (PTC) and Threshold equalizing noise (TEN) test. But these methods are unable to detect a dead region in individuals with severe to profound sensorineural hearing loss or sloping pattern of audiogram. To detect the dead region in these individuals, an alternative method was devised with the use of hearing aid. This can be termed as Aided TEN (ATEN) test. In the present study 31 participants were tested using the conventional TEN test and the results were compared with that of the thresholds obtained with that of the aided version of the TEN test. Results show the effectiveness of the aided version of TEN test over the conventional method while identifying dead regions in the above mentioned individuals.

Introduction

The role of inner and outer hair cells in the hearing mechanism is well established. In most cochlear hearing losses the hearing loss is associated with the damage to the outer hair cells whereas some of them are due to damage to the inner air cells as well (Engstrom, 1983; Schuknecht, 1993; Borg, Canlon & Engstrom, 1995). When the inner hair cells of the cochlea and/or neurons at certain places along the BM are missing or functioning poorly, then a tone producing peak vibration in that region is detected by off-place (off frequency), those regions are called “dead regions” (DR) (Moore & Glasberg, 1997; Moore, 2001; 2004a).

Moore et al. (2000) developed a more time economical and an effective test called as the Threshold Equalizing Noise (TEN) test. This version of the test is called the TEN (SPL) test. To facilitate the use of the TEN test in clinical assessments, a second version of the TEN test was developed, using a wideband noise with spectral shape designed to give equal masked thresholds for pure tones in dB HL (Moore et al., 2004). The loudness of the TEN (HL) is less than for the original TEN (SPL) because of the reduced bandwidth.

The identification of dead regions is important for people with severe or profound sensorineural hearing loss. Studies have shown that the prevalence of cochlear dead regions is more in subjects with sensorineural hearing loss with greater than moderately severe degree (Preminger, Carpenter & Zeigler, 2005; Markessis, Kapadia, Munro & Moore, 2006; Aazh & Moore, 2007; Vinay & Moore, 2007). However, as with other masking procedures, the detection of a tone in noise is affected by the amount of loudness reaching the cochlea. It is

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well known that subjects with cochlear hearing loss demonstrate the phenomenon of recruitment (Florentine & Houtsma, 1983; Glasberg & Moore, 1986) and also the difficulty of understanding speech in noisy environment (Moore, 1998).

Although the TEN (HL) test is easier to administer and the noise gives rise to less loudness than for the TEN (SPL) test, it is still the case that, when assessing the presence of DRs in subjects with severe and profound hearing loss, the level of the TEN (HL) that can be generated via the audiometer may be insufficient to produce 10 dB of masking, leading to an inconclusive result (Aazh & Moore, 2007; Simpson, McDermott & Dowell, 2005; Vinay & Moore, 2007a). Also some subjects may find the TEN (HL) to be too loud, even if the TEN (HL) level is only slightly above their pure tone threshold at the test frequency. This typically happens when the hearing loss is much greater at some frequencies than at others, the loudness produced by the TEN (HL) in regions of less severe loss makes it difficult to apply the test in regions of more severe loss. For example, a person with near-normal hearing at low frequencies and a person with severe loss at high frequencies might find the TEN (HL) too loud when being assessed for the presence of a DR at high frequencies (Simpson, et al., 2005). The identification of DRs is important for people with severe or profound hearing loss, as the presence of a DR can inform decisions on the likely effectiveness of hearing aid amplification (Baer, Moore & Kluk, 2002; Preminger, Carpenter & Ziegler, 2005; Vickers, Moore & Baer, 2001), and on whether cochlear implantation might be more effective than use of acoustic hearing aids. People with severe or profound hearing loss are usually hearing aid wearers, often with high levels of gain in their hearing aids. The aided version of the TEN (HL) test is referred here as the ATEN test.

Thus, the present study was designed to provide an insight about the benefits of accurate identification of dead region in the individuals with severe to profound sensorineural hearing loss in the aided condition. Apart from this, the study also aims to measure the effectiveness of the ATEN test in terms of the frequency, since most sensorineural hearing loss have a sloping pattern. This may provide sufficient information about the modifications needed for administration of the ATEN test and for programming the hearing aids. The details of the TEN and the ATEN test administration procedure and diagnosis is discussed in detail in the method section. Further rehabilitative approaches can be considered based on the accurate diagnosis of these individuals with sensorineural hearing loss.

Method

In the study, the conventional TEN (HL) test results were obtained and compared with the aided TEN (HL) test results. The unaided TEN (HL) test was administered without the individual wearing the hearing aid (HA). The aided TEN (HL) (ATEN) test was administered with the hearing aids on the participants’ ears. The TEN noise was presented through free field speaker for both the unaided and aided TEN (HL) test conditions.

Participant selection

Thirty one individuals in the age range of 11 to 80 years (mean age = 54.55 years, standard deviation = 18.25) were evaluated in the present study. Out of these participants, 12
were female and 19 were male. Only one ear of each participant was tested. All participants had acquired post-lingual sensorineural hearing loss in at least one ear. The degree of hearing loss ranged from severe to profound for dead region frequencies only. All participants had either flat or high frequency sloping sensorineural hearing loss. In addition to this, all participants had aided pure tone threshold within 45 dB HL. The details of the participants included in the study are provided in Table 1.

Table 1: Audiometric thresholds (in dB HL) for each participant obtained using pure tone presented via headphones

<table>
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<tr>
<th>Subject</th>
<th>Age (Yrs)</th>
<th>Sex</th>
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<th>250</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>6000</th>
<th>8000</th>
<th>PTA (dB)</th>
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</table>

Note: N: No response

**Instrumentation**

- A calibrated double channel, diagnostic audiometer, Madsen Orbiter 922 with Madsen external sound field speakers for obtaining aided & unaided pure tone & TEN thresholds.
- A calibrated middle ear analyzer, (GSI-Tympstar) for tympanometry and reflexometry.
- A digital two channel behind the ear hearing aid for obtaining the aided threshold.
• Hi-Pro (Hearing aid programming interface unit) connected to the personal computer (PC) with NOAH-3 and hearing aid programming software.
• TEN (HL) test Compact Disc (CD), developed by Moore et al. (2004) to detect the presence or absence of cochlear dead regions.
• Fonix 7000 hearing aid analyzer to verify the output of the hearing aid
• The TEN (HL) CD was played from a Philips 729K CD player connected to the calibrated two channel audiometer, Madsen Orbiter 922.
• All the tests were carried out in a two chamber sound treated suite. The noise levels were within permissible levels specified by ANSI (1999).

Procedure
The test procedure consisted of the following steps.

1. Absolute threshold estimation
Air conduction thresholds were estimated using warble tones at frequencies of 250, 500, 750, 1000, 1500, 2000, 3000, 4000 and 8000 Hz using modified Hughson-Westlake procedure developed by Carhart and Jerger (1959). Similar procedure was carried out by using warble tone for estimating bone conduction thresholds (for frequencies 250, 500, 1000, 2000, & 4000 Hz).

2. Hearing aid selection
Two channel digital hearing aids were selected according to the fitting range for the degree of hearing loss of each participant. This hearing aid catered to the amplification needs of the participants who had hearing losses ranging from mild to profound. All the participants in the study had either flat or sloping pattern of hearing loss. For the ease of programming and effectiveness of the gain in low and high frequencies, a double channel hearing aid was suitable. The electro acoustic measurements of the hearing aid were carried out to confirm that the hearing aid’s output was within the comfortable range of the participant. This was done to ensure that during the administration of the aided TEN (HL) test, the test signals were not uncomfortable to the participant.

For verification of the output of the hearing aid, electro acoustic measurements were carried out using Fonix 7000 hearing aid analyzer as per ANSI (2003) standards before testing each participant. The hearing aid was connected to PC through Hi-pro and programmed to full on gain. The hearing aid was placed in the test position in the test chamber. Input (digispeech) was given across frequencies 200 Hz to 8000 Hz at 90 dB SPL. The average SSPL 90 was calculated by taking the average output at 500 Hz, 1000 Hz and 2000 Hz. The maximum output of hearing aid was matched with the obtained uncomfortable level (UCL) of individual participants so that the output does not exceed the uncomfortable level.

Audiometric data of each participant was fed into the NOAH database. The hearing aids were connected to the computer through the Hi-Pro and were programmed to the comfort
level of the participants (with NAOH software) based on the generic NAL-NL1 fitting rationale. Aided free field pure-tone thresholds were established using the OB 922 audiometer for each participant with the programmed hearing aid which he/she wore with an appropriately sized standard ear tip during the test. Aided uncomfortable level (UCL) was also estimated for all the participants.

3. Estimation of TEN Threshold

The TEN (HL) test CD was played via a Philips 729 K CD player connected to Madsen OB922 audiometer equipped with free field speakers. The level of the test signal (warble tone) and the TEN (noise) were controlled using the attenuators in the audiometer. TEN thresholds were estimated in two conditions, unaided and aided. During both the conditions, the non test ear was blocked with broadband noise at 70dB SPL presented through the insert ear phone. For the unaided condition, the TEN level was set at 60 dB/ERBN for participants who had moderate to severe degree of hearing loss and 70 dB/ERBN for participants who had severe to profound degree of hearing loss. For the aided condition, TEN level was set at 50 dB/ERBN for all the participants. The TEN masked thresholds for each participant were measured in dB at 500, 750, 1000, 1500, 2000, 3000 and 4000 Hz using tracks 2-8 of the CD as recommended by Moore et al. (2004). A 2dB ascending and 4dB descending step size was taken to estimate the masked thresholds.

The presence or absence of a dead region at a specific frequency was based on the criteria suggested by Moore et al. (2004). If the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ ERBN, and the TEN (HL) elevated the absolute threshold by 10 dB or more, then the DR was assumed to be present at the signal frequency. If the masked threshold in the TEN (HL) was less than 10 dB above the TEN (HL) level/ ERBN, and the TEN (HL) elevated the absolute threshold by 10 dB or more, then the dead region was assumed to be absent. If the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ ERBN, but the TEN (HL) did not elevate the absolute threshold by 10 dB or more, then the result was considered inconclusive. A “no response (NR)” was recorded when the subject did not indicate hearing the signal at the maximum output level of the audiometer, which was 86 dB HL for the signals derived from the TEN (HL) CD. The unaided and aided TEN (HL) thresholds for all participants at 500 Hz to 4000 Hz were compared and statistically analyzed.

Results & Discussion

The descriptive statistical analysis was carried out for the comparison of both the unaided and aided TEN (HL) [(ATEN)] test conditions, for all the 31 participants. Cross tabulation was also computed across the frequencies i.e., at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz and 4000 Hz for the diagnosis of cochlear dead region. Cross tabulation was expressed as a contingency table to compare the distribution of all the variables simultaneously in a matrix format.
Results of the unaided TEN (HL) and aided TEN (HL) tests

The results of the unaided TEN (HL) test and the ATEN test are given separately for each subject and for each test frequency as shown in Table 3. The results are discussed based on the results of the TEN (HL) test as follows:

1. “P” indicates the presence of dead region in both unaided TEN (HL) test and aided TEN (HL) test condition. In this case, the masked threshold in the TEN (HL) was 10 dB or more above the TEN (HL) level/ERB_N, and the TEN (HL) elevated the absolute threshold by 10 dB or more.

2. “A” indicates the absence of dead region when the TEN (HL) test produced 10 dB or more of the masking, but the masked threshold was less than 10 dB above the TEN levels/ERB_N.

3. “I” indicates inconclusive results when the masked threshold of both unaided and aided TEN (HL) test condition was less than 10 dB above the absolute threshold, leading to an inconclusive result.

The unaided (dark bar) and aided TEN (HL) test conditions (light bars) and their results were present, absent or inconclusive for all the participants across the frequencies (at 500 Hz, 750 Hz, 1000 Hz, 1500 Hz, 2000 Hz, 3000 Hz and 4000 Hz) are shown in Figure 9 to 15.

TEN results for 500 Hz in unaided and aided condition

From Table 4 it was observed that for the test frequency of 500 Hz, three (100%) participants were diagnosed of having DR in both aided and unaided TEN (HL) condition. Out of the 17 participants who were diagnosed as not having DR in the unaided TEN (HL) condition, five (29.4%) were diagnosed as having of DR present and 12 (70.6%) were diagnosed as having absence of DR in ATEN condition. For 11 participants the results were inconclusive in the unaided TEN (HL) test. However, the aided TEN (HL) test showed six (54.5%) of these participants had the presence of dead region and five (45.5%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

Table 2: Cross tabulation comparison data at the TEN test frequency of 500 Hz in both aided and unaided condition.

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<tr>
<td></td>
<td>% within Unaided</td>
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<td>0%</td>
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<td>Count</td>
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</tr>
<tr>
<td></td>
<td>% within Unaided</td>
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<td>70.6%</td>
</tr>
<tr>
<td>Inconclusive</td>
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<td>5</td>
</tr>
<tr>
<td></td>
<td>% within Unaided</td>
<td>54.5%</td>
<td>45.5%</td>
</tr>
<tr>
<td>Total</td>
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<td>17</td>
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<tr>
<td></td>
<td>% within Unaided</td>
<td>45.2%</td>
<td>54.8%</td>
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</table>
At 500 Hz, as shown in figure 1, out of 31 participants, 14 participants were diagnosed as presence of DR in ATEN condition and in unaided TEN (HL) test condition, three participants were diagnosed as presence of dead region. Seventeen participants were diagnosed as absence of DR in both unaided and ATEN test condition whereas for 11 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed for 500 Hz frequency.

![Figure 1: The number of participants for the results of aided & unaided TEN test at 500 Hz.](image)

Thus, from the results obtained, 11 participants had inconclusive results in the unaided TEN (HL) test where as the ATEN test showed six (54.5%) participants as having presence of DR and five participants had no DR. Out of 17 participants, who were diagnosed as absence DR in the unaided TEN (HL) condition, 12 were diagnosed as DR absent and five (29.4%) were diagnosed as DR present in the ATEN condition. Three participants were diagnosed of having DR in both unaided and ATEN test condition. Similar results were reported by Marriage, Moore and Stone (2008) regarding the efficacy of ATEN test. They found that for one subject at 500 Hz, the criteria for DR were not met for the TEN (HL) test, but were met for the ATEN test.

**TEN results for 750 Hz in unaided and aided condition**

From Table 3, it was observed that for the test frequency of 750 Hz, seven (100%) participants were diagnosed of having DR in unaided TEN (HL) condition. Out of these seven (100%) participants, five (71.4%) were diagnosed as having of DR present and two (28.6%) participants were diagnosed as having absence of DR in ATEN condition. Fourteen (100%) participants were diagnosed as having absence of DR in both unaided and ATEN test condition. For 10 participants the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed three (30%) participants had presence of DR and seven (70%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

At 750 Hz, as shown in figure 2, out of 31 participants, eight participants were diagnosed as presence of DR in ATEN condition and seven participants were diagnosed as presence of DR in unaided TEN (HL) test condition. Twenty-three participants were
diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 14 participants diagnosed as absence of DR whereas for 10 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 750 Hz frequency.

<table>
<thead>
<tr>
<th></th>
<th>Aided</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Unaided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>Count</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>% within Unaided</td>
<td>71.4%</td>
<td>28.6%</td>
<td>100%</td>
</tr>
<tr>
<td>Absent</td>
<td>Count</td>
<td>0</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>% within Unaided</td>
<td>0%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>Count</td>
<td>3</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>% within Unaided</td>
<td>30%</td>
<td>70%</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>8</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>% within Unaided</td>
<td>25.8%</td>
<td>74.2%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3: Cross tabulation comparison data at the TEN test frequency of 750 Hz in both aided and unaided condition.

![Figure 2](image)

Figure 2: The number of participants for the results of aided & unaided TEN test at 750 Hz.

**TEN results for 1000 Hz in unaided and aided condition**

From the table 4, it was observed that for the test frequency of 1000 Hz, five (100%) participants were diagnosed of having DR in unaided TEN (HL) condition. Out of five (100%) participants, two (40%) were diagnosed as having of DR present and three (60%) were diagnosed as having absence of DR in ATEN test condition. Out of 10 participants who were diagnosed as not having DR in unaided TEN (HL) test condition, one (10%) was diagnosed as having of DR present and nine (90%) were diagnosed as having absence of DR in ATEN test condition. For 16 (100%) participants the results were inconclusive in the unaided TEN (HL) test. However, the ATEN test showed seven (43.8%) had presence of DR and nine (56.2%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.
Table 4: Cross tabulation comparison data at the TEN test frequency of 1000 Hz in both aided and unaided condition.

At 1000 Hz, for eight participants the outcome of the TEN (HL) test was inconclusive whereas with the ATEN test they were diagnosed as absence of DR. Similar kinds of findings were reported by Marriage et al (2008). In their study, for one participant, the outcome of the TEN (HL) test was inconclusive whereas ATEN test showed the absence of DR.

Figure 3: The number of participants for results of aided & unaided TEN test at 1000 Hz.

At 1000 Hz, as shown in figure 3, out of 31 participants, 10 participants were diagnosed presence of DR in ATEN condition and five participants were diagnosed as having DR present in unaided TEN (HL) test condition. Twenty-one participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 10 participants were diagnosed as absence of DR whereas for 16 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 1000 Hz frequency.

TEN results for 1500 Hz in unaided and aided condition

From the table below it was observed that for the test frequency of 1500 Hz, three participants were diagnosed of having DR in unaided TEN (HL) test condition. Out of these three, two (67.7%) were diagnosed of having DR and one (33.3%) was diagnosed as having absence of DR in the ATEN test condition. six (100%) participants who were diagnosed as not having DR in the unaided TEN (HL) condition, one (16.7%) was diagnosed as having of
DR present and five (83.3%) were diagnosed as having absence of DR in ATEN test condition. For 22 participants the results were inconclusive in unaided TEN (HL) test condition. However, the ATEN test showed 17 (77.3%) had presence of DR and five (22.7%) had no of DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

<table>
<thead>
<tr>
<th></th>
<th>Aided</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>1500 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unaided</td>
<td>Count</td>
<td>% within Unaided</td>
<td>Count</td>
<td>% within Unaided</td>
</tr>
<tr>
<td>Present</td>
<td>2</td>
<td>66.7%</td>
<td>2</td>
<td>66.7%</td>
</tr>
<tr>
<td>Absent</td>
<td>1</td>
<td>33.3%</td>
<td>1</td>
<td>33.3%</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>17</td>
<td>77.3%</td>
<td>5</td>
<td>83.3%</td>
</tr>
</tbody>
</table>

Table 5: Cross tabulation comparison data at the TEN test frequency of 1500 Hz in both aided and unaided condition.

At 1500 Hz, as shown in figure 4, out of 31 participants, 20 participants were diagnosed presence of DR in ATEN test condition and three were diagnosed as having DR present in unaided TEN (HL) test condition. Eleven participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition six participants were diagnosed as absence of DR whereas for 22 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 1500 Hz frequency.

**TEN results for 2000 Hz in unaided and aided condition**

From Table 6, it was observed that for the test frequency of 2000 Hz, 10 (100%) participants were diagnosed as not having DR in unaided TEN (HL) condition, and out of 10 (100%), one (10%) was diagnosed as having of DR present and nine (90%) were diagnosed as having absence of DR in ATEN test condition. For 21 participants the results were inconclusive in the unaided TEN (HL) test condition. However, ATEN test showed 10
(47.6%) participants had presence of DR and 11 (52.4%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, whereas the unaided TEN (HL) test results showed a greater degree of inconclusive results.

<table>
<thead>
<tr>
<th></th>
<th>2000 Hz</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aided</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Unaided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>Count</td>
<td>1</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>% within Unaided</td>
<td></td>
<td>10.0%</td>
<td>90.0%</td>
<td>100%</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>Count</td>
<td>10</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>% within Unaided</td>
<td></td>
<td>47.6%</td>
<td>52.4%</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>11</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>% within Unaided</td>
<td></td>
<td>35.5%</td>
<td>64.5%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 6: Cross tabulation comparison data at the TEN test frequency of 2000 Hz in both aided and unaided condition.

At 2000 Hz, as shown in figure 5, out of 31 participants, 11 participants were diagnosed presence of DR in ATEN test condition and no participants were diagnosed as having DR present in unaided TEN (HL) test condition. Twenty participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition 10 were diagnosed as absence of DR whereas for 21 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 2000 Hz frequency.

There were cases whose results indicated that absence of DR in unaided TEN (HL) test condition whereas the ATEN test condition indicated that dead region was present. Similar findings obtained in Marriage et al (2008).

**TEN results for 3000 Hz in unaided and aided condition**

From the table below it was observed that for the test frequency of 3000 Hz frequency, one participant was diagnosed of having DR in both unaided and ATEN condition. Out of the five (100%) participants who were diagnosed as not having DR in the unaided TEN (HL) condition, two (40.0%) were diagnosed as having of DR present and three (60.0%) were diagnosed as having absence of DR in ATEN test condition. For 25 participants
the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed 18 (72.0%) participants out of these 25 (100%) had the presence of DR and seven (28.0%) had no DR. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, where as the unaided TEN (HL) test results showed a greater degree of inconclusive results.

Table 7: Cross tabulation comparison data at the TEN test frequency of 3000 Hz in both aided and unaided condition.

<table>
<thead>
<tr>
<th></th>
<th>Aided</th>
<th>Total</th>
<th>Unaided</th>
<th>% within Unaided</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>100.0%</td>
</tr>
<tr>
<td>Absent</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>40.0%</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>18</td>
<td>7</td>
<td>25</td>
<td>72.0%</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>10</td>
<td>31</td>
<td>67.7%</td>
</tr>
</tbody>
</table>

At 3000 Hz, as shown in figure 6, out of 31 participants, 21 participants were diagnosed presence of DR in ATEN test condition and one was diagnosed as having DR present in unaided TEN (HL) test condition. Ten participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition five participants were diagnosed as absence of DR whereas for 25 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition no inconclusive results observed at 3000 Hz frequency.

Moore et al., 2007 affirmed that due to severity of hearing impairment, the results were inconclusive at some frequencies as the unaided TEN (HL) test could not be made intense enough to produce sufficient masking, or because absolute or masked thresholds exceeded the maximum output of the audiometer.
TEN results for 4000 Hz in unaided and aided condition

From Table 8, it was observed that for the test frequency of 4000 Hz, three (100%) participants were diagnosed as absence of DR in both unaided and ATEN test condition. For 28 participants the results were inconclusive in the unaided TEN (HL) test condition. However, the ATEN test showed 23 (82.1%) participants out of these 28 (100%) had presence of DR and three (10.7%) had no DR and two (7.1%) had inconclusive results. This indicated that ATEN test showed conclusive results of either having presence or absence of a DR, whereas the unaided TEN (HL) test results showed a greater degree of inconclusive results.

Table 8: Cross tabulation comparison data at the TEN test frequency of 4000 Hz in both aided and unaided condition.

<table>
<thead>
<tr>
<th>4000 Hz</th>
<th>Aided</th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Present</td>
<td>Absent</td>
<td>Inconclusive</td>
<td></td>
</tr>
<tr>
<td>Unaided</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>% within Unaided</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>23</td>
<td>3</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>% within Unaided</td>
<td>82.1%</td>
<td>10.7%</td>
<td>7.1%</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>6</td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td>% within Unaided</td>
<td>74.2%</td>
<td>19.4%</td>
<td>6.5%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Figure 7: The number of participants for results of aided & unaided TEN test at 4000 Hz.

At 4000 Hz, as shown in figure 7, out of 31 participants, 23 participants were diagnosed presence of DR in ATEN test condition and no participants were diagnosed as presence of DR in unaided TEN (HL) test condition. Six participants were diagnosed as absence of DR in ATEN test condition and in unaided TEN (HL) test condition three participants were diagnosed as absence of DR whereas for 28 participants, the results were inconclusive in unaided TEN (HL) test condition but in ATEN test condition, the results were inconclusive for two participants at 4000 Hz frequency.

When the hearing loss was greater than 70 dB (HL), there was a relatively high incidence of inconclusive results for the TEN (HL) test and only 2 participants at 4000 Hz has inconclusive results in ATEN test condition. There are many cases where the results were inconclusive for the TEN (HL) test while there were less cases for the ATEN test, which is
consistent with our expectation that the gain provided by the participant’s hearing aids would reduce the incidence of inconclusive results. Similar results were reported in Marriage et al. (2008).

Clinical Implications of Aided Threshold Equalizing Noise (ATEN) Test

The results of the aided Threshold Equalizing Noise (ATEN) test have important implications for identification and rehabilitation of individuals with cochlear dead regions (Vickers et al. 2001; Vinay & Moore, 2007). The implications are discussed separately for identification and rehabilitation of individuals with cochlear dead regions.

Implications of aided Threshold Equalizing Noise (ATEN) test for identification of cochlear dead regions:

While the results support our expectation that the ATEN test would lead to a lower incidence of inconclusive results than the TEN (HL) test, the results also reveal some modifications required with the ATEN test. In particular, for most subjects the inconclusive results in the unaided condition lead to a clear diagnosis (DR either present or not), in the aided condition. One another finding was a relatively high incidence of cases for which the TEN (HL) test indicated that no DR was present, but the ATEN test indicated that a DR was present. This can be explained by the fact that some of the hearing aids reduced the level of the tone relative to the noise. Therefore, for the tone to be heard, its level had to be raised relative to the noise, and this caused the tone level at threshold to be 10 dB or more above the “nominal” TEN level/ERB

Table 9: Tabulation of unaided and aided TEN (HL) test results.

<table>
<thead>
<tr>
<th>Freq (Hz)</th>
<th>No. of subjects</th>
<th>Unaided TEN (HL) test</th>
<th>Aided TEN (HL) test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence</td>
<td>Absence</td>
<td>Inconclusive</td>
</tr>
<tr>
<td>500</td>
<td>3</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>750</td>
<td>3</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>1000</td>
<td>3</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>1500</td>
<td>3</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>2000</td>
<td>3</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>3000</td>
<td>3</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>4000</td>
<td>3</td>
<td>3</td>
<td>28</td>
</tr>
</tbody>
</table>

However, some of the findings of this study that require careful interpretation of the results is connected with the fact most hearing aids incorporate some form of automatic gain control. This meant that, for the ATEN test, the gain applied when absolute thresholds were being measured alone would have been greater than when the masked thresholds were being measured. This change in gain would have increased the likelihood of achieving the required threshold shift to meet the criteria for a DR (masked threshold 10 dB or more above absolute

215
threshold). It may be mentioned here that further studies are definitely required in order to validate the results of the ATEN test.

*Implications of aided Threshold Equalizing Noise (ATEN) test for rehabilitation of individuals with cochlear dead regions*

For individuals with high frequency dead regions, amplification of the high frequencies may not be beneficial because of the amount of gain that is provided from the hearing aid resulting in distortion and the inability of the neurones in those frequency regions to transmit the signals to the higher centres. Hence, before deciding what form of amplification should be provided for a patient with high-frequency hearing loss, it is important to determine whether the individual has a high-frequency dead region. It is in this case that the ATEN test is recommended for this purpose.

**References**


Multifrequency, Multi-Component Tympanometry: Normative in Kindergarten and Preschool Children (3-6 Years)

Sharath Kumar K.S. & Vijayalakshmi Basavaraj*

Abstract

The aim of the present was to provide a normative for $RF$ at $\Delta B \approx 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° for children from 3-6 years of age and to study the effect of age, ear and gender effects on RF at $\Delta B \approx 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45°. A sweep frequency method was used which involves the probe tone frequency to be swept twice from 250 Hz to 2000 Hz at two different pressure i.e., +200 daPa and peak pressure and the F45° value which needs to be calculated manually using the B and G values in the GSI tympstar immittance meter. The mean of RF for 3+ to 4 years was 1087.83 Hz, 4+ to 5 years with a mean of 1059.33 Hz and for 5+ to 6 years with a mean of 1049.50 Hz. The mean of compensated admittance ($\Delta Y$) for 3+ to 4yrs was 1.29 mmho, 4+ to 5yrs with a mean of 1.49 mmho and 5+ to 6yrs with a mean of 1.41 mmho. The mean of compensated conductance ($\Delta G$) for 3+ to 4yrs was 2.12 mmho, 4+ to 5yrs with a mean of 2.64 mmho and 5+ to 6yrs with a mean of 2.72 mmho. The mean of phase angle ($\Delta \theta$) for 3+ to 4yrs was -26.36°, 4+ to 5yrs with a mean of -25.13° and 5+ to 6yrs with a mean of -31.13°. The mean of frequency at 45° (F45°) for 3+ to 4 years was 494.16 Hz, 4+ to 5 years with a mean of 497.50 Hz and for 5+ to 6 years with a mean of 465 Hz. The normative provided by this study can aid in assessing the middle ear functioning in clinical population and also to see the developmental trend of the middle ear across the age groups.

Key words: Multifrequency- multicomponent tympanometry, Kindergarten.

Introduction

Tympanometry is one of easy, safe and quick method for assessing middle ear function. From the pioneering work of Terkildsen and Thomson (1959), tympanometry performed using a low probe tone frequency, has proven its validity in identifying a variety of middle ear disorders (Lilly, 1984). However, it has been reported that standard low frequency tympanometry often fails to distinguish normal middle ears from some middle ear pathologies which affect middle ear sound transmission (Colletti, 1976, 1977; Hunter & Margolis, 1992; Lilly, 1984). It is possible that low frequency tympanometry may fail to reveal distinct patterns for many middle ear pathologies, because the status of the tympanic membrane dominates the tympanograms and thus effectively overshadows conditions affecting more medial structures.

Multifrequency tympanometry (MFT) records changes in the middle ear after acute otitis media, that 226 Hz tympanometry is unable to detect, implying persistence of pathology. It has also been concluded by the authors that more extended research will

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illuminate the clinical value of this method in the follow-up of acute otitis media (Ferekidis et al., 1999). The MFT is a better tool in the diagnosis of otitis media with effusion and adhesive otitis media and has better performance in reflecting middle ear pathology with an efficacy of 100% in the diagnosis of otitis media with effusion and 70% in the diagnosis of adhesive otitis media (Abou-Elhamd, Abd-Ellatif, & Sultan, 2006).

According to Shahnaz and Polka (1997), the admittance phase angle corresponds to 45° at frequency where $\Delta B = \Delta G$ or $B = G$. It was noted that phasor angle admittance at 45° was significantly affected in otosclerotic ears. However application of F45° in other pathologies is not mentioned in literature and there are very few studies regarding $\Delta Y$ (peak to tail difference in acoustic admittance) at resonant frequency (RF) in normal and pathological middle ears. Parameters $\Delta Y$, $\Delta G$ (peak to tail difference in acoustic conductance), $\Delta \theta$ (peak to tail difference in phase angle) at RF, and RF at $\Delta B = 0$ ($\Delta B$ is the peak to tail difference in acoustic susceptance) are important in differentiating, describing, studying the mechano-acoustical transformation of middle ear system.

Multifrequency tympanometry (MFT) records changes in the middle ear after acute otitis media, that 226 Hz tympanometry is unable to detect, implying persistence of pathology. The MFT is a better tool in the diagnosis of otitis media with effusion and adhesive otitis media and has better performance in reflecting middle ear pathology with an efficacy of 100% in the diagnosis of otitis media with effusion and 70% in the diagnosis of adhesive otitis media (Abou-Elhamd, Abd-Ellatif, & Sultan, 2006).

MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry. Moreover, it has been shown that conventional 226 Hz tympanometry is unable to detect sequelae and subtle changes in middle-ear mechanics following OM; however, MFT appears to be sensitive to these changes (Hanks & Rose, 1993; Margolis, Hunter, & Giebnik, 1994; Vlachou, Ferekidis, Tsakanikos, Apostolopoulos, & Adamopoulos, 1999; Vlachou, Tsakanikos, Douniadakis, & Adamopoulos, 2001). Harris, Hutchinson and Moravec (2005) evaluated the effectiveness of conventional 226 Hz and MFT tympanograms in detecting middle ear effusion in 21 children prior to myringotomy and concluded that MFT detects some middle ear pathologies that are not detected by conventional 226 Hz tympanometry.

Several studies noted the importance of resonant frequency (RF) on identifying middle ear pathologies like ossicular fixation, AOM in children as well as adults (Funasaka & Kumakawa, 1988; Shahnaz & Polka, 1997). Colletti (1975) has stated that multi frequency tympanometry could be useful in differential diagnosis of middle ear pathologies with normal otoscopic findings. Literature review shows that the RF and $\Delta G$ have clinical significance in differentiating a normal ear from otosclerotic ear in adults and $\Delta G$ also has a high correlation with the RF i.e., higher RF values corresponded to lower G values (Miani et al., 2000).
Need for the study

Even though the prevalence of ME pathologies like Acute Otitis Media (AOM) is very high in children between the age groups of 2-5 years and 6-11 years, in most of the audiology clinics acoustic immittance measures are done with standard 226Hz probe tone (Martin & Sides, 1985). The information on the usefulness of the high probe tone frequencies, multifrequency, multi-component tympanometry in infants and preschool age children for differential diagnosis of ME pathology is not adequate. Studies have also shown that there is statistically significant decrease in both RF values and change in phase angle in ears with OME compared to normal ears (Kontrogianni et al., 1996).

However, normative data for RF at $\Delta B \sim 0$, $\Delta Y$, $\Delta G, \Delta \theta$ at RF and F45°, which could be of diagnostic significance, are not available for population between the age group of 3-6 years. Wong, Lena, Joyce, and Wan (2008) reported significant difference in Chinese children aged between 6 and 15 yrs from that of white children in four tympanometric variables [peak, compensated static acoustic admittance (peak Ytm); equivalent ear canal volume ($V_{ec}$); tympanometric width (TW) and tympanometric peak pressure]. Since the normative value may vary from race to race, there is a need to establish a separate normative for, RF at $\Delta B \sim 0$, $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° for Indian population. Present data can be used in checking incidence, prevalence and also in identifying and ME pathologies which affects ossicular chain like otosclerosis and ossicular chain discontinuity in children between age group of 3-6 years, as multifrequency is a better indicator for these pathologies. Thus normative needs to be obtained in order to use it for clinical population.

Objectives

- To provide normative data for, RF at $\Delta B \sim 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° for children from 3-6 years of age.
- To study the RF at $\Delta B \sim 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° across the age groups from 3-6 years.
- To study the ear differences for RF at $\Delta B \sim 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° across 3-6 years of age.
- To study the gender differences for RF at $\Delta B \sim 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° across 3-6 years of age.

Method

To arrive at the normative data for RF at $\Delta B \sim 0$; $\Delta Y$, $\Delta G$, $\Delta \theta$ at RF and F45° for children from 3-6 years of age, the following method was employed.

Participants

Ninety participants in the age group of 3-6 years were enrolled for the study.

Participants were divided into three age groups. The mean age for each group with the age range is shown in Table 1.
Table 1: Mean and age range for the three age groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gender</th>
<th>Mean age (in years)</th>
<th>Range (in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A: 3+ to 4 years</td>
<td>Male</td>
<td>3.65</td>
<td>3.2 to 3.7</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>3.48</td>
<td>3.3 to 3.6</td>
</tr>
<tr>
<td>Group B: 4+ to 5 years</td>
<td>Male</td>
<td>4.53</td>
<td>4.3 to 4.6</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>4.26</td>
<td>4.4 to 4.8</td>
</tr>
<tr>
<td>Group C: 5+ to 6 years</td>
<td>Male</td>
<td>5.42</td>
<td>5.0 to 5.7</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>5.34</td>
<td>5.2 to 5.6</td>
</tr>
</tbody>
</table>

Thirty participants were taken in each group. The 10% of subjects from each group were retested to check the reliability of the obtained data within two months from the first testing.

**Participant selection criteria**

- A questionnaire consisting of questions which would rule out high risk factors as well as prior history of any middle ear disorder was prepared.
- Participants without any past history of middle ear disorders/problems were selected based on the data collected on this questionnaire.
- Pure tone audiometric thresholds of all participants for air conduction (AC) from 500 to 4000 Hz frequency range were ≤ 15 dB HL.
- Subjects who have normal acoustic reflex thresholds ≤ 100 dB HL (Wiley, Oviatt & Block, 1987) at frequencies 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz ipsilaterally were taken for study.

**Instrumentation**

- Calibrated two channel diagnostic OB 922 diagnostic audiometer with TDH 39 headphones with MX 14AR cushion.
- Calibrated GSI Tympstar middle ear analyzer version 2.0

**Test environment**

Both pure tone audiometry and tympanometric measurements were done in sound treated room with permissible noise levels (ANSI, 1991).

**Procedure**

1. Puretone thresholds for air conduction were obtained at octave intervals from 500 Hz to 4000 Hz.
2. Immittance audiometry with a probe tone frequency of 226 Hz was carried out. Ipsilateral acoustic reflexes thresholds were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at the peak pressure.
3. The procedure described by Funasaka, Funai and Kumakawa (1984) i.e., the sweep frequency method of multifrequency tympanometry was used in the current study to obtain the following data (1) RF at $\Delta B \sim 0$; (2) $\Delta Y, \Delta G, \Delta \theta$ at RF and (3) F45°.

According to the sweep frequency procedure the frequency is swept twice from 250 to 2000 Hz at two different pressure i.e., +200 daPa and peak pressure.

- At +200daPa, the vectors are measured as $Y_{+200}, B_{+200}, G_{+200}$ with respect to selection of delta plots $Y, B$ and $G$ respectively.
- At peak pressure, the vectors are measured as $Y_{\text{peak}}, B_{\text{peak}}, G_{\text{peak}}$ with respect to selection of delta plots $Y, B$ and $G$ respectively.

The differences of the two vectors $Y_{+200}, B_{+200}, G_{+200}$ and $Y_{\text{peak}}, B_{\text{peak}}, G_{\text{peak}}$ are calculated by the middle ear analyzer as a function of frequency in step size of 10Hz. The admittance, susceptance, conductance parameters are represented as $\Delta Y$ (the peak to tail difference in acoustic admittance), $\Delta B$ (the peak to tail difference in acoustic susceptance), $\Delta G$ (the peak to tail difference in acoustic conductance) are calculated as function of frequency, Similarly $\Delta \theta$ (phase angle difference between the admittance vectors at peak pressure and at +200daPa) is calculated simultaneously as function of frequency, where $\theta$ is angle between susceptance and conductance.

The $\Delta Y, \Delta B, \Delta G$ and $\Delta \theta$ values are given by the automated subtraction of corresponding values at each frequency between first and second frequency sweep and graph of $\Delta Y, \Delta B, \Delta G$ and $\Delta \theta$ are displayed across frequency. From these displays, RF was identified as the frequency where the value of $\Delta B$ reaches 0mmhos. The values of $\Delta Y, \Delta G, \Delta \theta$ were taken at the resonant frequency.

*Frequency at admittance phase angle of 45° (F 45°)*

Estimate of frequency corresponding to 45° phase angle is taken as the lowest frequency at which compensated conductance first becomes equal or larger than compensated peak suspetance i.e. where $\Delta B \leq \Delta G$. This was accomplished by comparing the delta plot values of susceptance and conductance at each frequency from 250-2000 Hz in 50 Hz step.

Analysis of the obtained data was done to calculate the mean and standard deviation for resonant frequency, $\Delta Y, \Delta G, \Delta \theta$ and frequency at 45°. Analysis was also done to study the age, ear, and gender differences. Correlation was done to check the reliability of the data. All the statistical analyses were done using SPSS 15 software.

**Results and Discussion**

The present study was conducted with an aim of establishing a normative data for resonant frequency (RF), compensated admittance ($\Delta Y$), compensated susceptance ($\Delta G$), phase angle ($\Delta \theta$) and frequency at 45° (F45°) across the three age groups of 3+ to 4 yrs, 4+ to 5 yrs and 5+ to 6 yrs. The present study also aimed at studying the age, ear, and gender differences in the three age groups.
Mean and standard deviation for different multifrequency parameters

The mean and standard deviation (SD) for RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups from 3+ to 4 yrs, 4+ to 5 yrs and 5+ to 6 yrs, with 30 subjects in each group (60 ears, N=60) is shown in Table 2.

Table 2: Mean and SD for RF, ΔY, ΔG, Δθ and frequency at 45° across three age groups

<table>
<thead>
<tr>
<th>Age groups (years)</th>
<th>RF (Hz)</th>
<th>ΔY (mmho)</th>
<th>ΔG (mmho)</th>
<th>Δθ (degree)</th>
<th>F45° (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>3+ to 4</td>
<td>1087.83</td>
<td>177.25</td>
<td>1.29</td>
<td>0.86</td>
<td>2.12</td>
</tr>
<tr>
<td>4+ to 5</td>
<td>1059.33</td>
<td>158.41</td>
<td>1.49</td>
<td>0.77</td>
<td>2.64</td>
</tr>
<tr>
<td>5+ to 6</td>
<td>1049.50</td>
<td>110.82</td>
<td>1.41</td>
<td>0.54</td>
<td>2.72</td>
</tr>
</tbody>
</table>

Note. RF- Resonant frequency; ΔY- compensated admittance; ΔG- compensated conductance; Δθ- phase angle; F45°- frequency at 45°.

From Table 2 it can be seen that the multifrequency parameters vary across the 3 age groups. The mean and SD for resonant frequency decreases across the three age groups. The range of RF for 3+ to 4 years was 620 to 1390 Hz with a mean of 1087.83 Hz, which was less than the RF range of 4+ to 5 years (650 to 1400 Hz with a mean of 1059.33 Hz); this was further less than the range of 5+ to 6 years, that is, 790 to 1260 Hz, with a mean value of 1049.50 Hz. This implies that the RF values decrease as the age increases from 3 to 6 years of age.

The range of compensated admittance (ΔY) for 3+ to 4yrs group was 0.21 to 3.65 mmho, with a mean of 1.29 mmho. This was less compared to that of 4+ to 5yrs and 5+ to 6yrs with range of 0.21 to 3.73 mmho (mean = 1.49 mmho) and 0.34 to 2.78 mmho (mean = 1.41 mmho) respectively. But there was no difference in mean values between 4+ to 5yrs and 5+ to 6yrs of age. The SD for ΔY decreased across the age groups, implying decreased variation in compensated admittance measures of children with in an age group, as they grew older.

The range of compensated conductance (ΔG) for 3+ to 4yrs group was 0.72 to 5.48 mmho with a mean of 2.12 mmho. This was less compared to that of 4+ to 5yrs and 5+ to 6yrs with range of 0.51 to 6.60 mmho (mean = 2.64) and 0.79 to 3.97 mmho (mean = 2.72) respectively. But there was little difference in mean values between 4+ to 5yrs and 5+ to 6yrs of age. The SD for ΔG decreased across the age group implying decreased variation in compensated conductance measures of children with in an age group, as they grew older.

The range of phase angle (Δθ) for the 3+ to 4yrs was -60° to -10° with a mean of -26.36° and for 4+ to 5yrs was -38° to -10° with a mean of -25.13°. These values were almost comparable. The range for 5+ to 6 yrs group was -39° to -22° with a mean of -31.13°, which
was much lower than that of 3+ to 4yrs and 4+ to 5yrs of age. The mean SD of phase angle decreased across the age groups implying decreased variation in compensated phase angle measures of children with in an age group, as they grew older.

The range for frequency at 45° (F45°) for 3+ to 4yrs was 350 to 750 Hz with a mean of 494.16 Hz and 4+ to 5yrs 350 to 700 Hz with a mean of 497.50 Hz, which were almost comparable. The range for 5+ to 6 yrs was 350 to 700 Hz with a mean of 465 Hz which was much lower than that of 3+ to 4yrs and 4+ to 5yrs of age. The mean SD of F45° decreased across the age groups, implying decreased variation in F45° measures of children with in an age group, as they grew older.

Comparison of multifrequency parameters across groups

Multiple analysis of variance (MANOVA) was done to compare the multifrequency parameters RF, ΔY, ΔG, Δθ and frequency at 45° across the age groups. The results showed that there was a significant difference in compensated conductance (ΔG) [F (2, 180) = 5.60, p<0.05] and phase angle (Δθ) [F (2, 180) = 10.21, p<0.05] across age groups. However RF, ΔY and F45° did not show any significant difference across the age groups.

The parameters which showed significant difference (ΔG and Δθ) were further analysed for pair wise comparison using the Bonferroni post hoc analysis test. The results of Bonferroni post hoc test revealed that there is significant difference in compensated conductance (ΔG) between the pairs 3+ to 4 years and 4+ to 5 years age groups (p<0.05) and also between 3+ to 4 years and 5+ to 6 years age groups (p<0.05).

Hanks and Rose (1993) reported that the mean value of RF as 1003 Hz with SD 216 in children from 6 years to 15 years which is consistent with the results of the present study. Margolis & Goycoolea (1993) reported mean RF of 1135 Hz in adults and similar results have also been found by Kumar and Adithya (2007) with a mean RF of 1051.53 Hz in adults. Megha and Kumar (2008) studied multifrequency parameters in neonates and reported the mean RF as 261.85 Hz. Thus it can be seen that there is an increase of RF from birth to childhood. However there is no change of RF in 3-6 years and is comparable to that of adults. This indicates that RF reaches adult like values by the age of 3-6 years of age.

Manuel (2004) reported that mean compensated admittance values in neonates as 0.74 mmho with standard deviation (SD) 0.26, which is lower than the obtained values for 3-6 years of age in the present study. Calandruccio et al., (2006) reported that admittance of the middle ear in 2 years at 1 kHz probe tone to be 2.46 mmho (median value) with range from 1.11 to 4.07 mmho and in adults 2.76 mmho (median) with range from 0.86 to 4.69 mmho which was not significantly different from that of 2 year old group. In the present study, the median values were 1.075, 1.46 and 1.25 in 3+ to 4 years, 4+ to 5 years and 5+ to 6 years respectively. However, these values were taken at the RF, and show no statistical significance across the age groups. Even though, there is a trend of successive increase of compensated admittance from birth to childhood, there is no change of compensated admittance in 3-6
years and is comparable to that of adults. This indicates that compensated admittance reaches adult like values by the age of 3-6 years of age.

Sabitha (1994) studied conductance at 1000 Hz across the age groups 8-12 years of age. The mean conductance value was 3.67, 3.99 and 3.74 mmho respectively for the three age groups. These results are similar to that of the adults. Kumar and Adithya (2007) reported mean ΔG of 3.58 mmho in adults and similar results have been found by Miani et al., (2000). Megha and Kumar (2008) reported mean ΔG for neonates to be 0.38 mmho. In this present study, the mean ΔG was 2.49 mmho for 3 years to 6 years old children. This was higher than the neonatal age group and lower than the adult age group. Thus it can be seen that there is a trend of successive increase of ΔG from neonate to childhood and reaches adult like value by 8 years of age.

The phase angle (Δθ) was significantly different between the age groups 3+ to 4 years and 5+ to 6 years age groups (p<0.05) and also between the age groups 4+ to 5 years and 5+ to 6 years (p<0.05). In adults the mean Δθ as reported by Kumar and Adithya (2007) was -26.77°, which was taken at RF, where the reported mean RF value was 1051.53 Hz. Similarly, Megha and Kumar (2008) reported a mean of -35.73° for Δθ in neonates at RF, where the reported mean RF value was 261.85 Hz. Hence Δθ value for both adults and neonates was taken at RF, and thus it can be compared. It can be seen that the Δθ value for a neonatal middle ear was low with a mean of -35.73° (Megha & Kumar, 2008) which was less than the adult mean values which was -26.77° (Kumar & Adithya, 2007). The present study showed significant difference in Δθ values between the age groups 3+ to 4 years and 5+ to 6 years and also between the pairs 4+ to 5 years and 5+ to 6 years age groups. Thus, these results show the developmental changes in the Δθ values.

Shahnaz and Polka (1997) studied F45° in adults and reported that the mean F45° to be 615 Hz (SD 148). In the present study, the mean F45° value for 3+ 4 years group to 5+ to 6 years group was 485.55 Hz. This is lower than the mean reported by Shahnaz and Polka (1997). In the present study, there was no significant difference across age groups for F45°. Even after taking into cognizance, Shahnaz and Polka (1997) used Virtual digital immittance instrument (model 310) where the values of F45° are calculated automatically by the instrument and in the present study used GSI Tympstar immittance meter where the experimenter has to manually calculate the F45° values by considering the point where B and G values are equal and they reported for the western population. It appears that the F45° increases from childhood to adulthood, but may not be significantly increasing from 3-6 years of age. In the absence of studies of F45° values on younger children, it is difficult to remark on variation of F45° from birth to childhood.

The significant changes only in ΔG and Δθ may indicate that these parameters change with maturational changes in the middle ear. Eby and Nadol (1986) indicate that the formation of the middle ear is complete by 5 years. Lilly (1973) demonstrated that the first component of impedance to be affected by otosclerosis, in a subclinical stage is resistance.
(Conductance in case of admittance measures). More the increase in resistance, more the decrease in conductance. This is again shown in the recent years that $\Delta G$ and $\Delta \theta$ are more sensitive in detecting the subtle middle ear pathologies, which may go undiagnosed by the normal 226 Hz tympanometry (Kumar & Adithya, 2007). These findings are also in support with respect to the anatomical changes in the external ear and middle ear and also occurrence of tympanic membrane changes among school aged children (Haapaniemi, Suonpää, & Virolainen, 1995; Haapaniemi, Suonpää, Salmivalli, & Tuominen, 1995). Petrak (2002) reported that there are changes in the size of the external and middle ear cavity, orientation of tympanic membrane and tightening of the ossicular joints from birth to childhood till 2 years of age. Thus, this indicates that $\Delta G$ and $\Delta \theta$ are more sensitive in indicating the subtle age related changes in the middle ear.

Comparison of multifrequency parameters between the ears across age groups

Comparison of multifrequency parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° were done to see the differences between the ears across the three age groups (N=90). The mean and standard deviation for right and left ears across the age are as tabulated in Table 3.

The mean values of multifrequency parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° were comparable for both right and left ears across the three age groups. Paired sample t-test was done to compare the right and left ear values for multifrequency parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° across the three age groups (N=90).

Results of paired sample t-test showed no significant difference between the right and left ears for multifrequency parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° across the three age groups. This is in consistent with the results found by Hanks and Rose (1993) in 6-15 years group and Haapaniemi (1996) in adults. Thus confirming that there is similar middle ear mechanics taking place in both the ears.

Table 3: Mean and standard deviation for RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° for right and left ear across the three age groups.

<table>
<thead>
<tr>
<th>Age groups (years)</th>
<th>RF (Hz)</th>
<th>$\Delta Y$ (mmho)</th>
<th>$\Delta G$ (mmho)</th>
<th>$\Delta \theta$ (degree)</th>
<th>F45° (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>3+ to 4</td>
<td>R</td>
<td>1089.66</td>
<td>184.43</td>
<td>1.29</td>
<td>2.11</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>1086.00</td>
<td>172.91</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>4+ to 5</td>
<td>R</td>
<td>1071.00</td>
<td>156.71</td>
<td>1.52</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>1047.66</td>
<td>161.90</td>
<td>1.46</td>
<td>2.55</td>
</tr>
<tr>
<td>5+ to 6</td>
<td>R</td>
<td>1059.66</td>
<td>112.11</td>
<td>1.40</td>
<td>2.69</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>1039.33</td>
<td>110.48</td>
<td>1.42</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Table 3: Mean and standard deviation for RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° for right and left ear across the three age groups.
Comparison of multifrequency parameters $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ for boys and girls across the age groups

The mean and standard deviation for multifrequency parameters $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ across the three age groups for boys and girls are shown in Table 4.

From Table 4 it can be seen that the mean values for both boys and girls were similar for all the multifrequency parameters $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ across the three age groups.

Table 4: Mean and standard deviation for boys and girls for $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ across the age groups.

<table>
<thead>
<tr>
<th>Age groups (years)</th>
<th>RF (Hz) Mean/SD</th>
<th>$\Delta Y$ (mmho) Mean/SD</th>
<th>$\Delta G$ (mmho) Mean/SD</th>
<th>$\Delta \theta$ (degree) Mean/SD</th>
<th>$F45^\circ$ (Hz) Mean/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+ to 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys (N= 20)</td>
<td>1087.0/229.4</td>
<td>1.37/0.92</td>
<td>2.19/1.12</td>
<td>-25.10/8.24</td>
<td>492.50/93.57</td>
</tr>
<tr>
<td>Girls (N= 40)</td>
<td>1088.25/147.95</td>
<td>1.26/0.84</td>
<td>2.08/1.17</td>
<td>-27.00/10.6</td>
<td>495.00/106.6</td>
</tr>
<tr>
<td>4+ to 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys (N= 22)</td>
<td>1027.72/156.14</td>
<td>1.30/0.75</td>
<td>2.32/1.20</td>
<td>-23.18/6.22</td>
<td>470.45/89.52</td>
</tr>
<tr>
<td>Girls (N= 38)</td>
<td>1077.63/158.87</td>
<td>1.60/0.76</td>
<td>2.83/1.20</td>
<td>-26.36/6.34</td>
<td>492.10/67.30</td>
</tr>
<tr>
<td>5+ to 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys (N= 28)</td>
<td>1037.50/108.17</td>
<td>1.37/0.50</td>
<td>2.76/0.63</td>
<td>-23.18/6.22</td>
<td>470.45/89.52</td>
</tr>
<tr>
<td>Girls (N= 32)</td>
<td>1053.12/111.77</td>
<td>1.43/0.58</td>
<td>2.70/0.82</td>
<td>-31.87/3.35</td>
<td>465.62/49.89</td>
</tr>
</tbody>
</table>

Mann-Whitney test was done to compare the boy and girl differences for multifrequency parameters $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ across the three age groups. Results of Mann-Whitney test showed no significant difference between boys and girls for multifrequency parameters $RF$, $\Delta Y$, $\Delta G$, $\Delta \theta$ and $F45^\circ$ across the three age groups. This is also consistent with the results by Hanks and Rose (1993) and Li (2006) who state that there are no gender differences in both sweep frequency tympanometry and normal 226 Hz tympanometry. This shows that the middle ear mechanism (stiffness and mass component) are same irrespective of the gender.

Reliability check

Reliability check was performed on 10% of the obtained data. The correlation analysis was done to check the reliability of the data. The results of Pearson’s rank correlation are as shown in the following Table 5.
Table 5: Results of Correlation analysis for RF, ΔY, ΔG, Δθ and F45°

<table>
<thead>
<tr>
<th>Parameters</th>
<th>N</th>
<th>R</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency</td>
<td>20</td>
<td>0.95 ***</td>
<td>0.00 (0.001 level)</td>
</tr>
<tr>
<td>ΔY</td>
<td>20</td>
<td>0.90 ***</td>
<td>0.00 (0.001 level)</td>
</tr>
<tr>
<td>ΔG</td>
<td>20</td>
<td>0.97 ***</td>
<td>0.00 (0.001 level)</td>
</tr>
<tr>
<td>Δθ</td>
<td>20</td>
<td>0.48 *</td>
<td>0.03 (0.05 level)</td>
</tr>
<tr>
<td>F45°</td>
<td>20</td>
<td>0.57 **</td>
<td>0.00 (0.001 level)</td>
</tr>
</tbody>
</table>

Note. *** indicates high correlation, ** indicates positive correlation at 0.001 significance level, * indicates positive correlation at 0.05 significance.

Pearson’s rank correlation results from the Table 9 indicate that there is correlation for RF, ΔY, ΔG, Δθ and F45° between the two measurements. Thus this shows that RF, ΔY, ΔG, Δθ and F45° measurements were reliable.

Thus, a normative data has been established for multifrequency parameters RF, ΔY, ΔG, Δθ and F45° in 3 to 6 years of age. RF, ΔY, and F45° showed no significant differences across the age from 3 to 6 years. However, ΔG and Δθ showed variations across 3 to 6 years of age. There were no ear and gender effects seen in the groups for all the multifrequency parameters.

Summary and Conclusions

The study aimed at providing the normative data for multifrequency tympanometry parameters RF, ΔY, ΔG, Δθ and F45° using the sweep frequency method for the age range of 3-6 years. The sweep frequency method involves the probe tone frequency to be swept twice from 250 Hz to 2000 Hz at two different pressure i.e., +200 daPa and peak pressure and the F45° value needs to be calculated manually using the B and G values in the GSI tympstar immittance meter. Results were analysed using appropriate statistical tools like descriptive statistics, MANOVA, paired sample t-test, Mann Whitney test and correlational analysis. Results are summarized in Table 6.

Table 6: Summary of mean values for RF, ΔY, ΔG, Δθ and F45° across the three age groups

<table>
<thead>
<tr>
<th>Age groups (years)</th>
<th>RF (Hz)</th>
<th>ΔY (mmho)</th>
<th>ΔG (mmho)</th>
<th>Δθ (degree)</th>
<th>F45° (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+ to 4</td>
<td>1087.83</td>
<td>1.29</td>
<td>2.12</td>
<td>-26.36°</td>
<td>494.16</td>
</tr>
<tr>
<td>4+ to 5</td>
<td>1059.33</td>
<td>1.49</td>
<td>2.64</td>
<td>-25.13°</td>
<td>497.50</td>
</tr>
<tr>
<td>5+ to 6</td>
<td>1049.50</td>
<td>1.41</td>
<td>2.72</td>
<td>-31.13°</td>
<td>465.0</td>
</tr>
</tbody>
</table>

- ANOVA and Bonferroni post Hoc tests revealed that there is significant increase in the values of compensated conductance (ΔG) between the pairs 3+ to 4 years and 4+ to 5 years age groups (p<0.05) and also between 3+ to 4 years and 5+ to 6 years age groups (p<0.05) and the phase angle (Δθ) significantly increase between the pairs 3+ to 4 years
Multifrequency & Multi-component Tympanometry in Children

and 5+ to 6 years age groups (p<0.05); also between the pairs 4+ to 5 years and 5+ to 6 years age groups (p<0.05). This can be due to the developmental changes in external and middle ear resulting in differences in $\Delta G$ and $\Delta \theta$ and indicate the maturational changes that is taking place in the middle ear across 3-6 years of age.

- However other multifrequency parameters like RF, $\Delta Y$ and F45° did not show any change across the age groups indicating that they may be stabilized by 3-6 years of age.
- There was no effect of gender and ear differences in the age range of 3-6 years on the parameters studied.

Thus, the normative provided by this study can aid in assessing the middle ear functioning in clinical population and also to see the developmental trend of the middle ear across the age groups. However, further research can be conducted by comparing the obtained normative with the clinical population to establish the efficacy of these multifrequency tympanometric parameters in the age range of 3-6 years.

Future research and directions

Sensitivity and specificity of multifrequency tympanometry parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45° should be established by comparing the obtained normative with the data obtained from clinical population.

- Incidence and prevalence of middle ear disorders can be established using of multifrequency tympanometry parameters RF, $\Delta Y$, $\Delta G$, $\Delta \theta$ and F45°.

References


Relationship between Speech Identification Scores and Auditory Evoked Potentials in Children with Learning Disability

Shuchi Garg & Animesh Barman*

Abstract

The main aim of the study was to correlate the SIS scores with the AEPs recorded from children with and without learning disabilities having normal hearing. A comparison was also made between the AEPs recorded using different stimulus in three different stimulus conditions. In the process two groups of subjects were taken, 10 children with learning problem and 10 children without learning problem. Routine audiometric tests such as pure tone audiometry, speech audiometry and immittance testing was carried out to rule out the presence of hearing loss in children from both the groups. ABR and LLR were recorded for the speech stimulus /da/ in three different conditions (quiet, 0 dB SNR and +3 dB SNR). ABR wave V latency was and N1, P2 latency and the amplitude of the N1-P2 complex of ALLR were noted for the analysis. The results showed that wave V latency was prolonged for both the groups in the presence of ipsilateral noise. Within the two signal to noise ratio conditions no significant difference was noted. Group wise comparison revealed no significance difference for all the conditions although; the clinical group had longer wave V latency in all the conditions. No significant difference was observed in the N1 and P2 latency across the three conditions in both the groups. Comparison between the groups revealed that there was a significant difference in the N1 latency for all the three stimulus conditions, and P2 latency for 0 and +3 dB SNR conditions. The clinical group had prolonged latency of N1 and P2 in all the conditions. The amplitude of the N1-P2 complex in the two groups was different across the three stimulus conditions, but failed to reach a significant level. The presence of noise reduced the SIS scores for both the groups and the effect was more for the clinical group. However, there was no one-to-one correlation could be obtained between the SIS and AEP recordings. In conclusion, AEPs are sensitive to differentiate between children with learning problem from those without learning problem, especially in conditions with background noise. Although, the ABR wave V latency is not a sensitive measure, the latency of N1 and P2 of ALLR may be a sensitive measures to identify a with learning problem.

Introduction

The role of an audiologist is to identify and rehabilitate individuals with hearing problem. Some of these problems may be very obvious and easy to identify such as a severe-to-profound hearing loss, or the presence of a conductive hearing loss. The major challenge is faced when one has to identify hearing problem which are subtle in nature such as the presence of central auditory processing disorder (C) APD, or auditory neuropathy.

There are various behavioral tests which have been developed to identify different auditory processes like gap detection test which assesses the temporal integrity and dichotic CV test which assesses the binaural integration deficits are few to name. There is a surfeit of literature available to prove the sensitivity and specificity of these tests. Most of these tests are time consuming, during which there is high possibility for the child to get distracted or

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lose his attention. It is also possible that some children may not understand the complex instructions in which case the testing would be difficult. In Indian context, where many languages are spoken it is difficult to develop a test in each language. Also, for children less than 7 years of age there is lack of normative data available. In case the normative data is available, a wide range of scores makes it difficult to identify a child with auditory processing disorder.

The prevalence of central auditory processing deficit is more in children with learning disability. The National Joint Committee on Learning Disabilities (NJCLD, 1990) defines the term learning disability as: “a heterogeneous group of disorders manifested by significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning or mathematical abilities. These disorders are intrinsic to the individual and presumed to be due to the Central Nervous System Dysfunction” (NJCLD, 1990).

There have been many studies done to evaluate the usefulness of auditory evoked potentials (AEPs) in discriminating children having learning problem with those having no learning problem. Majority of these studies have recorded AEPs using speech as a stimulus as it represents the signals encountered in daily living situation. The studies have shown that in the auditory brainstem responses the latency of wave V, and the wave V slope latency and amplitude are sensitive measures to differentiate between children having learning problem from those having no learning problem (Wible, Nicol, & Kraus, 2005; Cunningham, Nicol, Zecker, & Kraus, 2001). In the auditory late latency responses it is the amplitude of the N1-P2 complex, which is sensitive to identify children with learning problem (Putter-Katz et al, 2005; Purdy, Kelly, & Davies, 2002; & Cunningham et al, 2001).

Behavioral measures of speech intelligibility show that children with learning problem have poorer speech perception ability than the children without learning problem. This difference in the perception is enhanced in stressful environmental conditions like listening in the presence of background noise, degrading the perception abilities of children with learning problem even more (Wible, Nicol, & Kraus, 2005; Cunningham et al, 2001). Various studies have been done using AEPs to tap the exact nature of deficit responsible for degrading speech perception in children with learning problem. None of the study has been able to identify the exact deficit (Song, Banai, & Kraus, 2008; Russo, Nicol, Musacchia, & Kraus, 2004; & Cunningham et al, 2001).

Need for the study

Learning disability (LD) is a very heterogeneous group; it has many subgroups. Some children having LD may exhibit auditory processing deficits, while some may not exhibit auditory processing. There are various tests which enable us to differentiate the kind of deficit the child has. Most of these tests are subjective in nature and require complete attention and concentration of the child. The results of the tests would be invariably affected by the variables such as the attention span of the child, his/her willingness to co-operate in
the testing. The child might be wrongly diagnosed as having LD based purely on these subjective tests if the above mentioned variables are not controlled. Hence, there is a need for an objective test which will help us in accurately diagnosing these children.

In literature there are many studies done to find the neurophysiological responses i.e., auditory evoked potentials (AEPs), in children without a learning problem and in children with learning disability. Majority of these studies have been done under quite background conditions and not in adverse listening conditions (Wible, Nicol, & Kraus, 2005). The learning disabled population performs well in quite situations; whereas the major problem faced by them is in adverse listening situations (Russo et al, 2004; Cunningham et al, 2001). Hence these study over estimate their performance. AEPs for speech stimuli in adverse conditions could be sensitive in identifying auditory processing deficits, as most often this population does not exhibit abnormality in quite conditions.

As both the speech perception abilities and the AEPs are affected in the learning disabled group to a larger degree than compared to normals there is a need to relate the both.

**Aim of the study is to:**

1) Know whether the latency of ABR wave V vary in different stimulus conditions and also between the two groups.
2) Know whether the latency of N1 and P2 waves vary in different stimulus conditions and also between the two groups.
3) Also to know whether the amplitude of the N1-P2 complex differ in different conditions and also between the two groups.
4) Find a relationship between the latency of the ABR wave V, ALLR waves N1 and P2 latency with the SIS scores obtained in different conditions independently for both the groups.
5) Find a relationship between the amplitude of N1-P2 complex with the SIS scores obtained in different conditions independently for both the groups.

**Method**

**Subjects**

A total of 20 subjects were taken for the study. They were divided into two groups. Group I consists of children with learning disability who served as the clinical group; and group II consists of children with no learning disability who served as the control group.

**Clinical Group:** A total of 20 ears from ‘10’ children in the age range of 7 to 15 years, who were diagnosed as having learning disability by an experienced speech language pathologist; and psychologist was taken. All the children had normal hearing sensitivity.

**Selection criteria:** Subjects who met the following criteria were taken:
- All the subjects had pure tone thresholds within 15 dB HL at octave frequencies from 250 Hz to 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction.
- All the subjects had good Speech Identification Scores (above 90%) in quiet.
- All of them had ‘A’ type tympanogram with acoustic reflex threshold within normal limits, indicating a normal middle ear function.
- No relevant otologic history was reported by the subjects.
- No history of any observable medical or neurological impairment.
- All the subjects were diagnosed as having learning disability by an experienced speech and language pathologist and or psychologist, based on the Early Reading Skills test results (Loomba, 1995).

Control Group: A total of 10 ears from ‘10’ children in the age range of 7 to 15 years, whose language skill was adequate to their age were taken. All of them had normal hearing sensitivity.

Selection Criteria
- All the subjects had pure tone thresholds within 15 dB HL at octave frequencies from 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction.
- All the subjects had Speech in noise (SPIN) scores 70% and above at 0 dB SNR.
- ‘A’ type tympanogram with acoustic reflex threshold within normal limits was obtained from all the subjects, indicating a normal middle ear function.
- No relevant otologic history was reported by the subjects.
- No history of any observable medical or neurological impairment was noticed.
- A checklist developed by WHO (1999, cited in Singhi, Kumar, Malhi, & Kumar, 2007) was administered on all the children to rule out the presence of any learning impairment.

Speech in noise scores (SPIN)
SPIN test was done in two different conditions having speech stimulus at 40 dB above the SRT level. The type of noise used was the speech noise. A standardized word list developed by Vandana (1998) was used as the stimulus.

The conditions in which SPIN scores obtained were:
- SIS at 0 dB SNR
- SIS at +3 dB SNR

AEP recording
All the subjects participated in the study were made to sit comfortably on an arm chair. They were asked not to move their head or blink their eyes while AEP recording to avoid muscle artifacts. They were also instructed to be awake throughout the AEP recording.
as it might affect ALLR recording. All the three electrode sites were cleaned and the intra electrode impedance of 5 kΩ and inter electrode impedance of 3 kΩ was maintain.

### Table 1: Parameters used to record ABR

<table>
<thead>
<tr>
<th>STIMULUS PARAMETERS</th>
<th>ACQUISITION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stimulus type</strong></td>
<td>Speech stimulus (/da/)</td>
</tr>
<tr>
<td><strong>Stimulus duration</strong></td>
<td>40 msec</td>
</tr>
<tr>
<td><strong>Stimulus rate</strong></td>
<td>9.1/sec</td>
</tr>
<tr>
<td><strong>Polarity</strong></td>
<td>Alternating</td>
</tr>
<tr>
<td><strong>Number of Sweeps</strong></td>
<td>1500</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>65 dB SPL for both the subject groups</td>
</tr>
<tr>
<td><strong>Transducer</strong></td>
<td>ER-3A insert receiver</td>
</tr>
<tr>
<td><strong>Ipsilateral masking</strong></td>
<td>i) without noise ii) with 65 dB SPL WBN (0 dB SNR) iii) with 62 dB SPL WBN (+3 dB SNR)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Mode</strong></th>
<th>Monaural stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrode type</strong></td>
<td>Disc electrode</td>
</tr>
<tr>
<td><strong>No of channels</strong></td>
<td>Single channel</td>
</tr>
<tr>
<td><strong>Analysis window</strong></td>
<td>60 ms</td>
</tr>
<tr>
<td><strong>Filter settings</strong></td>
<td>100 Hz – 3000 Hz</td>
</tr>
<tr>
<td><strong>Notch Filter</strong></td>
<td>On</td>
</tr>
<tr>
<td><strong>Replicability</strong></td>
<td>Twice for all the 3 conditions</td>
</tr>
<tr>
<td><strong>Electrode montage</strong></td>
<td>Ground: non test ear mastoid (M₁) Inverting: test ear mastoid (M₂) Non inverting: forehead (Fpz)</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>1,000,000 times</td>
</tr>
<tr>
<td><strong>Artifact rejection</strong></td>
<td>40 µV</td>
</tr>
</tbody>
</table>

### Table 2: Parameters used to record ALLR

<table>
<thead>
<tr>
<th>STIMULUS PARAMETERS</th>
<th>ACQUISITION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stimulus type</strong></td>
<td>Speech stimulus (/da/)</td>
</tr>
<tr>
<td><strong>Stimulus duration</strong></td>
<td>40 msec</td>
</tr>
<tr>
<td><strong>Stimulus rate</strong></td>
<td>Speech: 1.1/sec</td>
</tr>
<tr>
<td><strong>Polarity</strong></td>
<td>Alternating</td>
</tr>
<tr>
<td><strong>Number of Sweeps</strong></td>
<td>300</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>65 dB SPL for both the subject groups</td>
</tr>
<tr>
<td><strong>Transducer</strong></td>
<td>ER-3A insert receiver</td>
</tr>
<tr>
<td><strong>Ipsilateral masking</strong></td>
<td>i) without noise ii) with 65 dB SPL WBN (0 dB SNR) iii) with 62 dB SPL WBN (+3 dB SNR)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Mode</strong></th>
<th>Monaural stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrode type</strong></td>
<td>Disc electrode</td>
</tr>
<tr>
<td><strong>No of channels</strong></td>
<td>Single channel</td>
</tr>
<tr>
<td><strong>Analysis window</strong></td>
<td>500 ms with pre stimulus recording of 50 ms</td>
</tr>
<tr>
<td><strong>Filter settings</strong></td>
<td>1 Hz – 30 Hz</td>
</tr>
<tr>
<td><strong>Notch Filter</strong></td>
<td>Off</td>
</tr>
<tr>
<td><strong>Replicability</strong></td>
<td>Twice at all the 3 conditions</td>
</tr>
<tr>
<td><strong>Electrode montage</strong></td>
<td>Ground: non test ear mastoid (M₁) Inverting: test ear mastoid (M₂) Non inverting: forehead (Fpz)</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>50,000 times</td>
</tr>
<tr>
<td><strong>Artifact rejection</strong></td>
<td>80 µV</td>
</tr>
</tbody>
</table>
ABR and LLR were recorded at 65 dB SPL. This level was chosen because according to Olsen, (1998) normal conversational level is between 55-65 dB SPL. For ABR the Wave V latency was noted. For the LLR the N1, P2 latency and N1-P2 complex’ amplitude were identified and marked. More emphasis was given on these two components of the LLR waveform as the N1 amplitude was found to be more affected by noise (Putter-Katz et.al, 2005).

Waveform Analysis

Both the ABR and LLR waveforms were stored for further analysis. Later the waveforms were recalled and analyzed. The waveforms were shown to three experienced audiologists. Their task was to identify the presence or absence of a response for both ABR and LLR for all the stimuli conditions. When there was an agreement regarding presence of response between the three audiologists the latencies of Wave V of ABR, N1, P2 of LLR and the amplitude of N1-P2 complex for LLR were noted. The prominent peaks of the response were then correlated to the behavioral SPIN results in both the groups.

Results

The SIS scores and the AEP data obtained for the different conditions and from both the control (children with no learning problem) and the clinical (children having learning disability) groups were tabulated. They were then compared to check if there was any statistically significant difference in the data obtained between the two groups. The data was also analyzed to compare the differences amongst the three stimulus conditions in each group separately. The final part of the analysis was to correlate the SIS scores with the AEP results obtained from each of the three conditions separately. The details of the mean and standard deviation of different AEP parameters are shown in table 3 and table 4.

Auditory brainstem Responses

Wave V latency was shorter for control group than the clinical group for all the conditions. However, they have failed to reach a statistically significant level. The amount of Wave V latency shift is same for both the groups in all the three conditions. Maximum shift however occurred at 0 dB SNR (table 3).

Table 3: Mean and SD for Wave V latency for both the groups obtained at three conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Group</th>
<th>Mean (in msec)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABR without noise</td>
<td>Normals</td>
<td>6.81 (N=7)</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td>LD</td>
<td>7.07 (N=11)</td>
<td>.44</td>
</tr>
<tr>
<td>ABR at 0 dB SNR</td>
<td>Normals</td>
<td>7.58 (N=7)</td>
<td>.92</td>
</tr>
<tr>
<td></td>
<td>LD</td>
<td>7.33 (N=11)</td>
<td>.67</td>
</tr>
<tr>
<td>ABR at 3 dB SNR</td>
<td>Normals</td>
<td>7.27 (N=7)</td>
<td>.70</td>
</tr>
<tr>
<td></td>
<td>LD</td>
<td>7.57 (N=11)</td>
<td>.45</td>
</tr>
</tbody>
</table>
A Mixed ANOVA’s (condition 3 x groups 2) were done to examine the significant interaction of ABR wave V latency. The result revealed that there was a significant difference in the Wave V latency across the three conditions [F (2, 32) = 21.605, p<0.001]. Further analysis was done using Bonferroni’s Post Hoc Test which revealed that there was a significant difference in the latency in the without noise condition with that of 0 and +3 dB SNR. Within the 0 and + 3 dB SNR condition there was no significant difference. No significant difference between the groups [F (1, 16) = 1.155, p>0.05] was seen. It also did not reveal any significant interaction between the group and within the condition on the wave V latency [F (2, 32) = 0.27, p>0.05].

Auditory Brainstem Response in the control group and the clinical group

The latencies were compared across the stimulus conditions using Friedman’s test for the control group and using repeated measure ANOVA for the clinical group. Both the tests revealed a significant difference in the latency across the three stimulus conditions [χ² (2) = 10.571, p<0.005]. For pair wise difference Wilcoxon’s test (for control group) and Bonferroni’s post hoc test (for clinical group) was done which revealed that there was a statistically significant difference in the wave V latency in the condition with no noise as compared to the conditions with noise (both 0 and 3 dB SNR). The comparison of the latencies in the two conditions with noise revealed no significant difference.

Auditory Late Latency Responses

Significant difference in the N1 latency between the groups in the three stimulus conditions was present, whereas for P2 latency no significant difference was seen in presence of noise at both 0 and +3 dB SNR. However, the amplitude of N1-P2 complex did not differ statistically between the groups in anyone of the stimulus conditions.

Table 4: Mean and SD values for N1, P2 latency and N1-P2 amplitude of ALLR obtained in both the groups at different stimulus conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control Group</th>
<th></th>
<th></th>
<th></th>
<th>Clinical Group</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without noise</td>
<td>0 dB SNR</td>
<td>+ 3 dB SNR</td>
<td>Without noise</td>
<td>0 dB SNR</td>
<td>+ 3 dB SNR</td>
<td></td>
</tr>
<tr>
<td>N1 Latency</td>
<td>Mean</td>
<td>153.85</td>
<td>145.71</td>
<td>152.57</td>
<td>191.12</td>
<td>204.43</td>
<td>195.75</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>39.50</td>
<td>35.10</td>
<td>28.48</td>
<td>35.51</td>
<td>35.94</td>
<td>29.17</td>
</tr>
<tr>
<td>P2 Latency</td>
<td>Mean</td>
<td>233.33</td>
<td>236.33</td>
<td>215.66</td>
<td>266.57</td>
<td>279.42</td>
<td>276.85</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>42.95</td>
<td>52.72</td>
<td>37.16</td>
<td>43.89</td>
<td>34.92</td>
<td>42.96</td>
</tr>
<tr>
<td>N1-P2 Amplitude</td>
<td>Mean</td>
<td>7.265</td>
<td>6.00</td>
<td>4.90</td>
<td>5.60</td>
<td>5.48</td>
<td>2.23</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.38</td>
<td>2.62</td>
<td>6.01</td>
<td>3.23</td>
<td>1.68</td>
<td>3.95</td>
</tr>
</tbody>
</table>

A Mixed ANOVA’s (condition 3 x groups 2) were done for each of the ALLR components to check for the main effect across the three stimuli conditions, and between the groups. The results indicated that there was a significant difference in the latencies of both N1 and P2 between the two groups [F (1, 21) = 13.077, p<0.05] and [F (1, 18) = 7.723, p<0.05] respectively. There was no significant difference in the latencies of N1 and P2 across
the three stimulus conditions [F (2, 42) = 0.063, p>0.05] and [F (2, 36) = 0.642, p>0.05] respectively. Also there was no interaction between the groups and the conditions for both N1 and P2 latency [F (2, 42) = 1.131, p>0.05] and [F (2, 36) = 0.915, p>0.05] respectively. For N1-P2 amplitude there was no significant difference between the groups [F (1, 19) = 0.148, p>0.05], or across the three stimulus conditions [F (2, 38) = 0.575, p>0.05]. Along with this interaction effect was also absent between groups and stimulus condition [F (2, 38) = 1.112, p>0.05].

Late Latency Response in the control group

The N1 and P2 latency was almost similar in all the three stimulus conditions. The amplitude however was maximum in the condition without any noise and minimum for 3 dB SNR condition. Friedman’s test was done to check for significance difference, if any, in the latencies of N1, P2 and the N1-P2 amplitude of ALLR across the three different stimulus conditions. No statistically significant difference in the N1 and P2 latency was seen across the stimulus conditions. A similar result was also observed for the N1-P2 amplitude across the three conditions.

Late Latency Response in the clinical group

Slight differences were observed in the latency of N1 and P2 across the three conditions. The latency is least in the condition with no noise and is maximum for the 0 dB SNR condition. The amplitude of the N1-P2 complex was maximum in the absence of noise and least at 3 dB SNR. The results of the repeated measure ANOVA showed that there is no significant effect in the N1 [F (2, 30 = 1.153, p>0.05], P2 [F (2, 26 = 0.582, p>0.05] latency and N1-P2 [F (2, 28 = 0.135, p>0.05] amplitude across the three stimulus condition. Thus the presence or absence of noise had no significant effect on any one of the ALLR components.

Speech Identification Scores (SIS)

The SIS obtained without ipsilateral noise is 100% in the control group. The clinical group had 99.5 % scores in the absence of ipsilateral noise. In the presence of noise the SIS deteriorated for both the groups. However, SIS obtained in the clinical group was more severely affected than the control group.

Mixed ANOVA (condition3 x groups 2) was done to check for the main effect of the stimulus conditions and also between the two groups. The mixed ANOVA results revealed a significant difference [F (2, 56) = 63.867, p<0.001] in the SIS scores across the three conditions. Bonferroni’s test was carried out further for pair wise comparison between the conditions. The results showed that the SIS obtained in all the stimulus conditions was significantly different from each other. There was a significant difference in the SIS scores between the two groups [F (1, 28) = 16.421, p<0.001], where the scores were higher for the control group than the clinical group. An interaction effect was also found between the SIS obtained in three stimulus conditions and, the two groups, which was statistically significant [F (2, 56) = 9.474, p<0.001].
**Correlation of Auditory Brainstem Response and Late Latency Response to SIS scores**

All the subjects in the control group had 100% speech perception scores without ipsilateral noise, because of which it was not possible to do a statistical test to find the correlation between AEP parameters and the SIS scores. For the clinical group Spearman’s correlation test was done which showed that no particular trend was followed by the AEP parameters and the SIS scores in different condition. No significance correlation between the AEP parameters and the SIS scores across the stimulus conditions in the clinical group were obtained.

**Discussion**

**Auditory brainstem Responses (ABR)**

The wave V latency was prolonged for the control group in the condition with ipsilateral noise. Within the two conditions of noise however there was no significant difference. Similar results have been quoted by Cunningham et al. (2001), who found that in the presence of background noise the latency of wave V increases for children with no learning problem. Russo et al. (2004) found that in the presence of background noise, brainstem encoding of speech is disrupted. In particular, noise interferes with the onset response. In the majority of normal subjects they evaluated the onset response was severely degraded, while in 40% of subjects it was completely abolished. They concluded that the onset portion of the response is more susceptible to degradation in the presence of noise rather than the sustained portion.

The results obtained in the present study add on to the existing studies which reveal that in the presence of noise the ABR wave V latency is affected. The lack of difference in the wave V latency between the two condition of noise; 0 and +3 dB SNR; can be attributed to the fact that the noise degrade the onset response hence resulting in almost equal shift in wave V latency.

The clinical group also had significant difference in the latency in the presence and absence of ipsilateral noise. Within the two noise conditions (0 and +3 dB SNR) however, no significant difference was observed. Johnson, Nicol, and Kraus, (2005) also reported similar findings. They found that the children with learning problem exhibited delayed peak latency of the wave V indicating poor synchrony to transient events. They also report that environmental stresses such as noise and rapidly presented stimuli further negatively influence the neural encoding of linguistic information in children with learning problem. Wible, Nicol, & Kraus, (2004) reported that the brainstem processing of speech sound rather than being completely different for children with a learning problem, is to some extent similar in both children with and without a learning problem.

The possible reason for the deficits observed for the clinical group in the current study cannot be attributed to an overall deficit in neural synchrony. The prolongation of the wave V latency seen for the clinical group is comparable, although to a higher degree, to what has been observed for the control group under stressful situations. Hence, it can be said that the deficits which are seen for the clinical group can also be observed in the control group under stressful environmental conditions such as in the presence of background noise. Based on this
it can be concluded that the children with learning disability rather than having a deficit in neural synchrony have abnormal representation of specific neural activity (Johnson, Nicol, Zecker, & Kraus, 2007).

**Group wise comparison revealed no significance difference in the wave V latency for both the groups for all the conditions although; the clinical group had longer wave V latency in all the conditions.**

The trend followed by both the groups were similar having shortest latency for the condition without ipsilateral noise and longest for condition with 0 dB SNR. These results are in support of the previous studies done (Johnson, Nicol, & Kraus, 2005; Johnson et al. 2007), which also reported that although the wave V latency is prolonged in children with learning disability as compared to children with no learning problem, the difference is not statistically significant. The lack of any statistical difference between the two groups can be because of a smaller number of samples collected. Another reason can be the heterogeneity of the LD group. Thus, it can be concluded that ABR for speech stimulus, with or without noise ipsilaterally, may not be efficient to identify abnormal auditory processing in individuals with learning disability.

**Auditory Late Latency Responses (ALLR)**

There was no significant difference in the N1 and P2 latency across the three stimulus conditions in the control group. The results are similar to those stated by Cunningham et al. (2001); Wible, Nicol, and Kraus, 2002; and Wible, Nicol, and Kraus, (2004). They reported that in the presence of noise there is no change in the latency of the ALLR peaks in children having no learning problem. However, the SNRs used in the studies were different where the Cunningham et al. (2001) and Wible, Nicol, & Kraus, (2004) used 0 dB SNR, while Wible, Nicol, & Kraus, (2002) used +15 dB SNR.

Contradictory studies have also been reported in the literatures. It has been reported that with the addition of noise there is an increase in the latency of the ALLR components (Whiting, Martin, & Stapells, 1998; Martin, Kurtzberg, & Stapells, 1999).

It is possible that the noise does not affect the firing of the neurons in the cortex to the extent it effects the firing of neurons at the level of brainstem. Another reason can be the fact that the cortical response requires lesser degree of synchronous firing than the brainstem response, and the presence of background noise does not compromise the synchronous firing to that great an extent (Cunningham et al, 2001).

In the clinical group no significant difference was observed in the N1 and P2 latency across the three stimulus conditions. These results are similar to those stated by Cunningham et al. (2001); Wible, Nicol, & Kraus, (2002, 2004) who report that in the presence of noise there is no change in the latency of the ALLR peaks in children with learning problem. The reason for the insignificant difference in the latencies could be the same as that mentioned for the control group.

Comparison between the two groups revealed that there was a significant difference in the N1 latency for all the three stimulus conditions, and P2 latency for the condition with 0
and +3 dB SNR noises. The clinical group had prolonged latency of N1 and P2 for all the conditions. The results of the present study are in contradiction to those done by Cunningham et al, in 2001, who reported no difference in the latency of any of the ALLR components for the two groups in the presence and absence of noise. The reason for the differences in the findings of the present study with that of the previous authors can be because of the fact that the learning disabled group is a heterogeneous one (Cunningham et al, 2001; Wible, Nicol, & Kraus, 2002, 2004). Some of them show results which are similar to those observed in children with no learning problem whereas, the others show a significance deviance. It is possible that the children taken for the present study might have been fallen under the second category thereby varying the latency significantly.

The amplitude of the N1-P2 complex in the control group was different across the three stimulus conditions, but failed to reach a significant level. Similar results were showed by Cunningham et al. (2001) and Wible, Nicol, and Kraus, (2004) who found that there is a reduction in the amplitude at 0dB SNR compared to no noise condition for children having no learning problem. However, Wible, Nicol, and Kraus, (2002) found a significant reduction in the amplitude at +15dB SNR compared to no noise condition for children having no learning problem.

In the present study no significant difference in the amplitude of N1-P2 complex was found although there was a reduction in the response amplitude in the conditions with ipsilateral noise. The lack of significance can be because of a smaller sample size. Another reason can be the way in which the amplitude was measured. The above reported studies all measure the RMS amplitude of the cortical response, whereas in the present study the peak-to-trough amplitude of the N1-P2 complex was taken.

In the clinical group there was a reduction in the amplitude of the N1-P2 complex in the conditions with ipsilateral noise (0 and +3dB SNR). However, it failed to reach a significant level. Cunningham et al. (2001); and Wible, Nicol, and Kraus, (2002, 2004) have also shown similar results for children with learning problem. They found a reduction in the amplitude of the N1-P2 complex in condition with ipsilateral noise when compared to no noise condition. The possible reason for the reduction in the amplitude of the N1-P2 complex can be attributed to asynchronous firing of the neurons responsible for the generation of cortical responses in stressful conditions such as presence of background noise (Wible, Nicol, & Kraus, (2004).

The amplitude of the N1-P2 complex showed no significant difference between the two groups across either of the three stimulus conditions. This is in consonance with the previous findings of (Wible, Nicol, & Kraus, (2004). They found that the introduction of background noise had a similar effect of reduction in the response amplitude for children with and without a learning problem. It can be suggested that in the children with a learning problem, the poor cortical representation of speech sounds in the presence of noise cannot be attributed to an abnormal decrease in overall response activity. Rather, it is possible that the activity associated with the neural encoding of speech sounds is being distributed differently over
time across the responses recorded in noise in the children with learning problem (Wible, Nicol, & Kraus, 2004).

It can be concluded from the above discussion that the N1, P2 latency of ALLR can be used to identify auditory processing disorder in children with learning disability. However, amplitude is not a sensitive parameter for both with and without ipsilateral noise to identify an auditory processing disorder.

**Speech Identification Scores (SIS)**

The control group had 100% scores in quiet. The control group had hearing sensitivity within normal limits and did not have any other abnormality, which resulted in good SIS in quiet.

*The presence of noise reduced the SIS scores for the control groups. Within the two conditions of noise, 0 and +3 dB SNR, the scores were more severely degraded at 0 dB SNR condition.* This supports the literature that in adverse listening situations even children with normal language skills perform poorly (Elliot, 1979). Bradlow, Kraus, & Hayes, (2003) stated that as the listening condition becomes more adverse (from -4 to -8 dB SNR) the speech perception deteriorates even further. The reason for reduction in SIS scores in 0dB condition than +3 dB can be because the poor SNR affects the speech processing to a greater extent than at higher SNR.

*In the condition with no ipsilateral noise the clinical group also had higher SIS scores than in the conditions with noise. The scores were significantly poorer in the condition with ipsilateral noise (0 and +3 dB SNR).* This is consistent with the previous studies which report that children with learning disability have poorer speech perception abilities (Chermak, Vonhof, & Bendel, 1989). The poorer performance for the clinical group in the conditions with ipsilateral noise as compared to no noise condition can be because of a similar phenomenon as that seen for the control group.

*On comparing the performance between the two groups it was found that the control group had significantly higher scores in all the conditions as compared to the clinical group.* In the presence of noise the SIS scores reduced significantly more for the clinical group. Within the two conditions of noise, 0 and +3 dB SNR, the scores were more severely degraded in the 0 dB SNR condition for both the groups. Similar results have been quoted by Bradlow, Kraus, & Hayes, (2003). There is considerable literature reporting that children with learning disability perform poorer than the children with no learning problem in the presence of background noise (Chermak, Vonhof, & Bendel, 1989; Bradlow, Kraus, & Hayes, 2003) and the findings of the present study are in analogous to them.

Cunningham et al. (2001) and Johnson, Nicol, & Kraus, (2005) have shown that in quiet there is no significant difference in the speech perception of children with and without a learning disability. The reason they report is that the quiet condition is an ideal listening situation which does not strain the auditory system. Hence, it is not possible to detect the subtle auditory deficits present in the children with learning disability in quiet conditions.
**Correlation between the AEPs and Speech Identification Scores (SIS)**

In order to categorize the cause of the learning disability an attempt was made to correlate the AEPs measured in the present study with the SIS scores obtained in each condition. **No correlation was found between the ABR wave V latency and the SIS scores in one any of the condition for both the groups.** There is dearth of information regarding the correlation between the SIS scores with that of wave V latency. The reason could be that the wave V is not very sensitive to the differences in the processing of speech sounds in the control and the clinical group. Another reason can be that the synthetic speech stimulus might not accurately represent the brainstem processing for speech.

**The clinical group showed no correlation between the ALLR response parameters and the SIS scores for the three conditions.** Very less information is available to support or contradict the current findings. However, literature is available measuring the JNDs (Cunningham et al, 2001) and its correlation with the cortical responses. They found that children with poorer JND had more reduction in the RMS amplitude of the response as compared to children with better JNDs. It is also possible that the brief duration of the stimulus (40 msec /da/) used here is not sufficient to assess the cortical response adequately.

**Conclusion**

It can be concluded from the present study that AEPs are sensitive measure to differentiate between children with a learning problem from those without a learning problem, especially in conditions with background noise. Although, the ABR wave V latency is not a sensitive measure, the latency of N1 and P2 of ALLR are sensitive measures. Hence, the N1 and P2 latencies are useful in identifying auditory processing deficits in children with learning disability. These parameters are sensitive to auditory processing disorders in both conditions with and without background noise. Also, when testing in adverse listening situations both 0 and +3 dB SNR are equally sensitive in identifying an auditory processing disorder. The results of the study also suggest that there is need not be a one-to-one relation between the AEP findings and SIS at different SNRs.

**References**


HIGH FREQUENCY SPEECH IDENTIFICATION TEST IN TAMIL

Sinthiya K. & M. Sandeep*

Abstract

The present study aimed at developing and standardising a high frequency speech identification test in Tamil. The study was carried out in two phases. Phase 1 involved the development of High frequency word lists while in phase 2 these words were standardised on 100 normal hearing individuals. Two lists of bisyllabic high frequency words and one list of trisyllabic high frequency words were developed. The mean speech identification scores for all the three lists were above 99%. Comparison across the 3 lists showed that any of the 3 lists can be used to obtain high frequency speech identification scores and can also be used in providing amplification for individuals with high frequency hearing loss.

Introduction

Speech communication is so important that it is rightly considered to be the most characteristic feature of the human race (Plomp, 2002). The two components, speech perception and production are closely related and have been studied extensively for decades. The acoustic information carried by speech is quite complex and has many dynamic variations. Sounds are by their nature dynamic, changing over time in terms of level and spectral content. In general, consonants contribute primarily to speech intelligibility while vowels contribute to the power of speech (Niemeyer, 1967). Hence, it is important that one identifies consonants properly if have to understand speech better. This requires the identification of place as well as manner of articulation which in turn are cued by dynamic filter cues like closure duration, burst and transition (Dorman, Studdert-Kennedy & Rapheal, 1977). The spectral cues for place and manner of articulation of different speech sounds are given in Table 1.

Table 1: The spectral energy and the major cues for perception of consonants.

<table>
<thead>
<tr>
<th>Phonemes</th>
<th>Energy spectrum</th>
<th>Place cue</th>
<th>Manner cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>/s/</td>
<td>2000-4000 Hz</td>
<td>Spectral properties – F2 transition, noise duration and amplitude (overall and relative amplitude)</td>
<td>Duration of frication noise, amplitude of noise component and fundamental frequency at vowel onset</td>
</tr>
<tr>
<td>/ʃ/</td>
<td>3500 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/l/</td>
<td>6800-8400 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/k/</td>
<td>1500 – 4000 Hz</td>
<td>Frequency position of burst, F2 transition, spectral pattern, voice onset time</td>
<td>Stop gap, silence, closure duration, duration of preceding vowel, F1 cutback</td>
</tr>
<tr>
<td>/t̪/</td>
<td>Above 4000 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/dʒ/</td>
<td>2500 Hz</td>
<td>Duration of noise segment</td>
<td>Frication duration, closure duration.</td>
</tr>
</tbody>
</table>
The above table represents the spectral energy of the consonants and the major cues for the perception given by Hughes and Halle (1956).

Evaluating a person’s ability to understand conversational speech is a difficult task because conversational speech sounds are strung together in a variety of ways. For this reason audiologists traditionally limit their tests to two important measures, which are the speech recognition threshold and speech identification scores. Most of the speech identification tests use phonetically balanced word list that are standardized on individuals having flat audiometric configuration. The performance on these tests may overestimate speech perception in individuals with sloping high frequency hearing loss as the spectral information in the frequency (below 2 kHz) regions where the hearing is normal could help in perception. Furthermore, the speech perception in noise particularly becomes more difficult for these individuals, in the background noise conditions as background noise masks the low frequencies information that was otherwise available in facilitating perception.

Hence there was a need to develop High frequency Speech Identification Test. The first high frequency word list was developed by Gardner (1971). Gardner developed a word list that contained consonants of high frequency spectral energy and used it for testing speech discrimination in cases of high frequency hearing loss. Though it was specifically designed for application of hearing aid selection it was reported to be useful for auditory training as well.

Maroonroge and Diefendorf (1974) administered 3 words lists: North-western Auditory Test No. 6, the California Consonant Test, and Pascoe’s High-Frequency Test, in two groups of individuals. Group 1 consisted of individuals with normal hearing up to 2 kHz accompanied by a high-frequency loss, while individuals in Group 2 had normal hearing even between 2 and 8 kHz. Results of the study showed that individuals in the Group 1 scored near normal scores on NU 6 test while scores were significantly lesser than that of normals on Pascoe’s high frequency word list. The comparison between the 2 tests showed greater sensitivity of Pascoe’s high frequency word list in determining the communicative handicap in the individuals with high frequency hearing loss.

Furthermore, an individual’s perception of speech is reported to be influenced by his mother tongue (Singh & Black, 1966). De (1973) found that people consistently had better and optimum discrimination scores in their mother tongue as compared to other languages. On account of this, administering the test in a subject’s native language is considered ideal. Since India is a multilingual country, there is a need to develop the tests in each of the languages. Although phonetically balanced speech identification tests have been developed in more than 7 Indian languages, there is a lack of High frequency word lists in all these languages. High frequency speech identification tests are developed only in Kannada (Kavitha, 2002), Hindi (Ramachandra, 2001) and English (Sudiptha, 2006). Speech identification scores obtained for High frequency word list is a better estimate for such individuals. Because such a list is not available in Tamil language the study is attempting to develop the test material.
Objectives

1) To develop high frequency word list in Tamil to determine speech identification scores in individuals with predominantly high frequency hearing loss.

2) Establish a normative for the newly developed material on normal hearing adults, who are native speakers of Tamil.

Method

The study was conducted in the following two phases.

Phase 1: The development of high frequency word list.

Phase 2: Standardization of the test material.

Phase 1: The Development of High Frequency Word List

Selection of the Words and Familiarization

Only the bisyllabic and trisyllabic words were considered to develop the test list as they were the smallest meaningful units and also would provide optimum redundant cues for the identification. The words were selected from different sources like newspapers, books, and magazines. Totally 355 words were collected for the purpose. Words with phonemes /k/, /tʰ/, /s/, /d̪/, /r/, /d̪/ and /l/ were preferred as these phonemes have spectral energy predominantly distributed in the frequencies above 1 kHz (Hughes & Halle, 1956). These words were tested for familiarity. Thirty adults who were native speakers of Tamil were involved for this task. They were instructed to rate the words according to the frequency of occurrence on a three point scale of familiarity; most familiar, familiar and unfamiliar. Only the words that were most familiar to all of the subjects were selected for the construction of the test list. There were 111 such words out of the 355 selected words.

LTASS on the familiar words

LTASS was done to determine if the most familiar words had spectral information predominantly in the higher frequencies. This was necessary as the spectral information of the phonemes, /k/, /tʰ/, /s/, /d̪/, /r/, /d̪/ and /l/ could differ depending on the context, and hence the so called high frequency word may not be having high frequency spectral information. LTASS was derived using CSL 4500 (as shown in figure1) and the spectral information was determined manually. The peak frequency of the spectra was taken as the target parameter. Peak frequency was defined as the frequency having highest energy concentration. Peak frequency in LTASS was also determined for the words in the phonetically balanced speech identification test (Prakash, 1998). This was required for the comparison of the spectra between the two. A total of 75 words had spectral information at significantly higher frequencies compared to the phonetically balanced words.
Construction of Word Subtest

The 75 words that were available for the construction of high frequency test were further categorised into a bisyllabic and a trisyllabic list. There were 50 words in the bisyllabic list and 25 words in the trisyllabic list. The 50 bisyllabic words were further divided into 2 half lists. The frequency of occurrence of high frequency sounds was maintained same between the two half lists with bisyllabic words.

Recording of the Test Material

The recording was done in a sound treated room where the noise levels were as per the ANSI guidelines (1991). Test words spoken by 4 adult females and 4 adult males, who were native speakers of Tamil were recorded into a computer using Adobe Audition (version 1.0) software. These recorded materials were then perceptually rated and the speaker who spoke with the best clarity was chosen for the audio recording of final test list. The signal was digitized at a sampling rate of 16 kHz using 12 bit analog to digital and digital to analog converter housed within a computer. Each word was saved as a separate file. The recorded material was then edited to carry out noise and hiss reduction. The inter stimulus interval between the two words was set to 5 seconds.

Phase 2: Standardization of the Test Material

The developed test material was standardized by obtaining speech identification scores in 100 native speakers of Tamil. The participants were in the age range of 19-25 years and, had normal hearing sensitivity (< 15 dB HL) in the octave frequencies between 250 Hz and 8 kHz. There was no relevant past or present history of otological dysfunctioning. The information about the past history was collected through case history and results of pure tone audiometry and immittance was used to interpret the current status.

Test Procedure

After estimation of pure tone thresholds, the speech recognition threshold (SRT) was estimated through bracketing method using standardized Tamil words and the high frequency word identification lists developed in the phase I was played (through Philips CD player) at 40 dB SL (ref: SRT). All the participants were tested monaurally with all the three lists. Stimuli were presented through head phones and the order of the list was randomised.
Scoring

The responses were marked either 0 or 1. Each correct response was given a score of 1 and an incorrect response was given a score of 0.

The raw score was then converted to percentage as below

\[ \text{Total score (\%)} = \frac{\text{Total number of correct responses} \times 100}{\text{Total number of words presented}} \]

Statistical analysis

Statistical Package for the Social Sciences (version 10) software was used to carry out the statistical analysis. Descriptive statistics, Independent \( t \) test, One-way ANOVA and repeated measures ANOVA were the statistical tests used.

Results and Discussion

Development of the High Frequency Word List/s

Selection of the words and their familiarity

Initially a total 355 words were collected for the development of the high frequency speech identification test. These were bisyllabic and trisyllabic words. The words were then rated for their familiarity. The outcome was, of the 355 selected words, 111 words were rated as most familiar. Only those were considered for the development of the final list.

Results of LTASS of Target Words

LTASS of the target words was obtained to validate the spectral information of the words, to be included in the final test list. LTASS was done on 111 words that were reported as most familiar by the representative population. In each word, data of LTASS revealed the frequency range with predominant energy concentration. The spectral parameter that was noted down from the LTASS was peak frequency of the spectrum. The 111 most familiar words were categorized based on their peak frequency (Hz) as given in Table 2. The cut off peak frequencies considered were 1, 1.5, 2, 2.5 and 3 kHz.

Table 2: Mean and standard deviation (SD) of peak frequency in words above different cut off frequencies.

<table>
<thead>
<tr>
<th>Cut off Frequency (Hz)</th>
<th>Number of words</th>
<th>Mean (Hz)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>111</td>
<td>1960</td>
<td>864</td>
</tr>
<tr>
<td>1.5</td>
<td>108</td>
<td>1964</td>
<td>860</td>
</tr>
<tr>
<td>2.0</td>
<td>75</td>
<td>2396</td>
<td>803</td>
</tr>
<tr>
<td>2.5</td>
<td>54</td>
<td>2790</td>
<td>599</td>
</tr>
<tr>
<td>3.0</td>
<td>19</td>
<td>3684</td>
<td>401</td>
</tr>
</tbody>
</table>

From the data given in Table 2, it can be inferred that, all the 111 most familiar words had predominant spectral information above 1 kHz. As the cut off frequency increased, the number words decreased.
LTASS was also administered on phonetically balanced word list in Tamil, developed by Prakash (1998). There were 50 words in the list. The mean peak frequency was 1278 Hz with standard deviation of 880 Hz.

To verify whether the spectral information of the most familiar words of the present study is significantly different from that of phonetically balanced list, the data were statistically compared. The mean peak frequency of phonetically balanced words was compared with that of the most familiar words. This was done separately for the words with spectral information above 1, 1.5, 2 and 2.5 kHz. Because the words with spectral information above 3 kHz were only 19 in number, they were not considered for the comparison.

The results of independent $t$ test are given in Table 3. Results show a significant difference (p<0.01) between mean peak frequency of phonetically balanced words and mean peak frequency of the most familiar words of the present study. The result was same at all cut off frequencies. Thus, the information in the words of the present study is at significantly higher frequencies compared to that of phonetically balanced list and in turn supports the use of these words for the construction of a high frequency word list.

Table 3: Results of independent t test showing the significance of difference between most familiar words and the phonetically balanced words

<table>
<thead>
<tr>
<th>Cut-off Frequency</th>
<th>$t$</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 kHz</td>
<td>4.4*</td>
<td>159</td>
</tr>
<tr>
<td>1.5 kHz</td>
<td>4.6*</td>
<td>156</td>
</tr>
<tr>
<td>2.0 kHz</td>
<td>7.3*</td>
<td>123</td>
</tr>
<tr>
<td>2.5 kHz</td>
<td>10.2*</td>
<td>102</td>
</tr>
</tbody>
</table>

* - p < 0.01

The results showed that there is a significant difference in peak frequency between the phonetically balanced Tamil list and the high frequency list developed at each cut off frequencies. This could be because, standardised phonetically balanced speech identification test has words with phonemes like /m/, /p/, /l/ and /d/ which have energy predominantly at low frequencies while the high frequency word list has phonemes /s/, /t/, /t/ and /k/ which have energy predominantly at high frequencies.

Although all the 111 words showed a significant difference in the spectral information, inspection of the $t$ values shows that the difference was more as the cut off frequency was higher. Hence, it can be inferred that words with predominant spectral information above 2 kHz are more sensitive in detecting speech perception deficits in individuals with high frequency hearing loss, compared to words with energy above 1 kHz. Considering this, in the present study it was decided to use words with peak frequency above 2 kHz. There were 75 words with peak frequency above 2 kHz, of which 25 were trisyllabic and 50 were bisyllabic words.
Construction of the word subtests

Two separate lists were prepared based on the number of syllables. List 1 had 50 bisyllabic words while the list 2 had 25 trisyllabic words. This was done because the redundancy in trisyllabic words could be more than that in a bisyllabic words and hence may lead to different identification scores (Hirsh, Silverman, Reynolds, Eldert, & Benson 1952). It was presumed that in terms of difficulty these two lists could differ and a normative developed combining these two words within the same list may be erroneous. The list of 50 bisyllabic words was further divided into two half list with 25 words each. This was done to provide a shorter version of the test which could be useful when the complete list cannot be used due to time constraints. While dividing the list, the attempt was made to keep the frequency of high frequency sounds same in the two half lists.

Development of the normative for the high frequency word list in Tamil

Normative was developed on 100 normal hearing individuals who were native speakers of Tamil. Mean and standard deviation of speech identification scores obtained for the two half lists with bisyllabic words and one list in trisyllabic words are given in Table 4.

Table 4: Mean and standard deviation (SD) of high frequency speech identification scores in normals.

<table>
<thead>
<tr>
<th>Lists</th>
<th>Ears</th>
<th>Mean (%)</th>
<th>Range</th>
<th>1 SD</th>
<th>2 SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisyllabic word-</td>
<td>Right</td>
<td>99.7</td>
<td>100-96</td>
<td>1.0</td>
<td>2.00</td>
</tr>
<tr>
<td>Half list 1</td>
<td>Left</td>
<td>99.8</td>
<td>100-96</td>
<td>0.787</td>
<td>1.57</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>99.7</td>
<td>200-192</td>
<td>0.914</td>
<td>1.83</td>
</tr>
<tr>
<td>Bisyllabic word-</td>
<td>Right</td>
<td>99.5</td>
<td>100-96</td>
<td>1.25</td>
<td>2.50</td>
</tr>
<tr>
<td>Half list 2</td>
<td>Left</td>
<td>99.7</td>
<td>100-92</td>
<td>1.11</td>
<td>2.22</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>99.6</td>
<td>200-188</td>
<td>1.19</td>
<td>2.38</td>
</tr>
<tr>
<td>Trisyllabic words</td>
<td>Right</td>
<td>99.9</td>
<td>100-96</td>
<td>0.40</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>99.9</td>
<td>100-96</td>
<td>0.562</td>
<td>1.12</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>99.9</td>
<td>200-192</td>
<td>0.487</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Majority of the normal hearing individuals obtained almost 100% speech identification scores in left as well as right ear. The speech identification scores were first compared between right and left ears separately in the three lists. One way ANOVA (Table 5) was done for this purpose. Results of one way ANOVA showed no significant difference between the identification scores obtained in the two ears. Hence, the data from left and right ear were combined for further statistical analysis.

Table 5: One way ANOVA results across lists

<table>
<thead>
<tr>
<th>List</th>
<th>F</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisyllabic word-</td>
<td>0.861</td>
<td>198(1)</td>
<td>0.355</td>
</tr>
<tr>
<td>Half list 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bisyllabic word-</td>
<td>1.420</td>
<td>198(1)</td>
<td>0.235</td>
</tr>
<tr>
<td>Half list 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trisyllabic list</td>
<td>0.336</td>
<td>198(1)</td>
<td>0.536</td>
</tr>
</tbody>
</table>

252
The present result of almost 100% identification of high frequency words in normal hearing individuals is in agreement with earlier studies (Schwartz & Surr, 1979; Mascarenhas, 2002; Sudipta, 2006). The lowest score obtained among the 100 subjects was 92%. Thus, it can be inferred that the specificity of the high frequency speech identification test in Tamil is good. The earlier studies (Schwartz & Surr, 1979; Mascarenhas, 2002; Sudipta, 2006) have checked for the sensitivity of the respective tests in identifying perceptual deficits in individuals with high frequency sensorineural hearing loss. However, that was not among the objectives of the present study.

Comparison across the Word Subtests

To verify whether there is a significant difference in the identification scores across the three lists, repeated measures ANOVA was done. The results of repeated measure ANOVA \( [F (2,398) = 5.402, p < 0.01] \) showed a significant main effect of word list on speech identification scores. To obtain the pair wise comparisons, Bonferroni post hoc test was carried out. Results of post hoc test are depicted in Table 6. Results showed no significant difference between the 2 bisyllabic word half lists. This means, either of the lists can be used to test high frequency speech identification. Also, there was no significant difference \( (p>0.05) \) between bisyllabic word half list 1 and the trisyllabic word list in terms of speech identification scores. This goes to prove that there is not much difference in the redundancy present in the two lists.

Table 6: Results of Bonferroni post hoc test showing the pair wise comparison across the word subtests.

<table>
<thead>
<tr>
<th>Lists</th>
<th>Bisyllabic word-Half list 1</th>
<th>Bisyllabic word-Half list 2</th>
<th>Trisyllabic word list</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisyllabic word-Half list 1</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Bisyllabic word-Half list 2</td>
<td>NS</td>
<td>NS</td>
<td>S</td>
</tr>
<tr>
<td>Trisyllabic word list</td>
<td>NS</td>
<td>S</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: \( S - p<0.05, \) \( NS - p>0.05 \)

However, Bonferroni test showed a significant difference between bisyllabic word half list 2 and the trisyllabic word list. Inspection of the mean speech identification scores obtained for the bisyllabic word half list 2 and the trisyllabic word list reveal that, both are above 99%. Therefore, though there is a statistical difference, the magnitude of the mean difference is small and will not have any clinical importance. Hence, it can be concluded that any of the 3 word subtests can be used to assess the high frequency speech identification.
Conclusions

The high frequency speech identification test developed will be useful to identify the speech perceptual deficits in individuals with high frequency hearing loss. This shall give a better estimate of the communicative handicap that these individuals possess compared to phonetically balanced word test. This could also be useful in the selection of amplification devices for individuals with HFHL and auditory training of high frequency words.

References


**APPENDIX**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Bisyllabic word Half List 1</th>
<th>Bisyllabic word Half List 2</th>
<th>Trisyllabic List</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>கிளிப்பர்</td>
<td>கிளிப்பர்</td>
<td>கிளிப்பர்</td>
</tr>
<tr>
<td>2</td>
<td>மரம்</td>
<td>மரம்</td>
<td>மரம்</td>
</tr>
<tr>
<td>3</td>
<td>பண்பு</td>
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</tr>
<tr>
<td>4</td>
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<td>பிள்ளை</td>
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</tr>
<tr>
<td>9</td>
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</tbody>
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EFFICACY OF NON-LINEAR FREQUENCY COMPRESSION IN INDIVIDUALS WITH AND WITHOUT COCHLEAR DEAD REGIONS

Sruthy Hrishikesan & P. Manjula*

Abstract

There have been reports about different frequency lowering strategies like Non-linear Frequency Compression (NLFC) in individuals with a sloping hearing loss (Simpson, Hersbach, and McDermott, 2005, 2006). The present study investigated the usefulness of NLFC in individuals with and without cochlear dead regions. Two groups (Group I without cochlear dead region and Group II with cochlear dead region) formed the basis of the study. The hearing aid testing was done for three aided conditions - without NLFC, with NLFC initial fit settings and with NLFC fine-tuned settings. The parameters assessed were speech identification scores, Ling’s six sound identification and quality judgment. The results revealed that there was a significant difference in the mean SIS scores for words only for the pair without NLFC and NLFC fine-tuned settings for Group I with no significant difference in Group II for any pair. The performance was similar for all the aided conditions for SIS for sentences in both the groups. Ling’s six sound identification revealed a slight improvement in fricative identification among participants in Group I with no improvement in the Group II. The results of quality ratings showed that the mean ratings of quality were higher for the Group I compared to Group II and there was a significant difference in the quality rating between both the groups. In conclusion, the amplification needs of individuals with and without cochlear dead region are different and frequency lowering strategies like NLC may be of limited usefulness to individuals with cochlear dead region.

Key Words: Speech Identification Scores, Ling six Sound identification, quality judgment.

Introduction

The most prevalent audiometric configuration among adults with hearing loss is the sloping type which is around 50% (Pittman & Stelmachowicz, 2003). The primary goal of current hearing aid fitting strategies is to make the speech signal audible in those regions where the sensitivity is reduced, and in the case of high-frequency hearing loss this means providing high-frequency amplification. The American Speech-Language Hearing association (1998) asserts that amplification should provide audibility and comfort for soft and average input levels, and tolerance for high input levels.

It is important to point out that providing audibility of high-frequency information to listeners with severe to profound hearing impairment remains a controversial topic (Ching, Dillon, & Byrne, 1998; Ching, Dillon, Katsch, & Byrne, 2001; Hogan & Turner, 1998; Plyler & Fleck, 2006; Turner & Henry, 2002). Large variability in aided listening performance is thought to be due to both the level of high-frequency audibility the listener is receiving as well as the listener’s ability to extract useful information from the audible signals.

There have been equivocal findings in the area of high frequency amplification for sloping hearing loss. Some investigators report that significant improvements in speech

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understanding, especially in noisy environments, occur when listeners with sloping sensorineural hearing loss are provided with high-frequency information (Plyler & Fleck, 2006; Turner & Henry, 2002). On the other hand, listeners who are provided with audibility at frequencies where hearing levels are severe and/or sloping did not show speech recognition benefit (Ching, Dillon, & Byrne, 1998; Ching, Dillon, Katsch, & Byrne, 2001; Hogan & Turner, 1998). This is thought to be due to a limited ability to use the amplified signal in that frequency region. Other investigators have reported that, listeners with suspected dead regions in the high-frequencies perform similar to normals on speech recognition tasks when broadband amplification is used in a quiet listening environment (Mackersie, Crocker, & Davis, 2004). The listeners without dead regions are better able to make use of high-frequency cues (Moore, 2004). Thus, different outcomes may be due to factors such as the inner hair cell (IHC) loss which can be referred to as dead regions, congenital versus acquired hearing loss, and wide band versus frequency lowering technology. The results of these studies have important implications for clinical practice. If amplifying speech to audible levels in the high frequencies does not improve speech recognition, then attempts to provide gain may not be necessary or desirable in certain cases.

Various signal processing strategies have emerged to allow high-frequency information to be moved to a lower-frequency region so it can be more easily accessed by the listener. Frequency transposition or shifting and frequency compression technology are the two main types of frequency-lowering technology available even today. Frequency transposition or shifting refers to shifting each frequency component in the sound by a constant factor. This is specifically related to lower the signal by a fixed frequency value. A possible advantage of this form of transposition is that ratios among the frequency components of the signal are not changed by the processing. This may be beneficial for speech perception because frequency ratios convey important information. On the other hand, a possible disadvantage is that overall pitch of the speech signal is also lowered. Another problem with shifting is that it does not reduce the bandwidth. It only shifts the signal down. This creates very strong distortions when the shifting frequency is greater than the signal frequency.

The frequency compression technology compresses the output bandwidth of the signal by a specified ratio. Also frequency compression reduces both the frequency and the bandwidth by a preset compression ratio or factor (for instance, anywhere from 1.5 to 5.0 in steps of 0.25). Because the spectrum is “squeezed” with frequency compression, operating in real-time requires a complex algorithm that maintains the critical information. This action takes place extremely rapidly, in the order of two to four milliseconds. When the next sound comes along, usually a vowel in the normal syllabic sequence, the aid reverts to its normal amplification pattern. The voiced sounds are simply passed through and processed as determined during the initial programming. When the next voiceless sound is detected, the frequency compression circuit is again activated. For setting the parameters of frequency compression, both the hearing levels at specific frequencies and the slope of the audiogram across frequencies are taken into account. For calculation of the cut-off frequency, relatively high frequencies are selected, if the hearing impairment is mild or the audiogram is flat. Lower cut-off frequencies are selected for more severe levels of impairment or for
audiograms with relatively steep slopes. The frequency compression ratio is then derived from the cut-off frequency. The compression ratio effectively determines the strength of the frequency compression processing above the cut-off frequency (Ross, 2000).

Some listeners have obtained speech perception benefits when listening to proportional frequency compression (Turner & Hurtig, 1999). This method of frequency compression preserved the ratios between the frequencies of the components of natural speech, as well as the temporal envelope of the unprocessed speech stimuli. Both frequency-compressed speech and the control condition of unprocessed speech were presented with high-pass amplification. An advantage of this method is that frequency ratios are preserved. In other words, the relationship between the frequencies of different formant peaks in speech remains constant. These ratios may be particularly important cues for the recognition of vowels in speech (Neary, 1989). Frequency compression is of two types, linear compression and non-linear frequency compression.

Simpson, Hersbach, and McDermott (2005) evaluated the performance of an experimental frequency compression hearing device using tests of speech understanding and results showed that eight showed a significant improvement in score, eight participants did not show any change in the score whereas, one participant showed a significant decrease in score.

A similar study was done by the same investigators Simpson, Hersbach, and McDermott (2006) who examined speech perception in seven individuals with steeply sloping hearing loss. No significant differences in group mean scores were found between the frequency-compression device and a conventional hearing instrument for understanding speech in quiet and subjective comparisons between conventional hearing aids and the frequency compression scheme revealed that the majority of listeners preferred conventional amplification (Cox & Alexander, 1995). The authors concluded that frequency compression provided limited benefit to individuals with steeply sloping sensorineural hearing loss with suspected dead regions.

Thus, the studies on frequency lowering technologies have led to equivocal results which indicate the need for more research in the field. There is a dearth of information regarding the benefits of the non-linear compression in hearing aids among individuals with hearing impairment.

The aim of the present study was to evaluate the effect of non-linear frequency compression (NLFC) in hearing aids on the speech identification performance and also on the perceived quality of speech using NLFC in individuals having sloping sensorineural hearing loss

1. With cochlear dead region and
2. Without cochlear dead region.

Method

Twenty-four individuals with bilateral sensorineural hearing loss were selected for the study. The participants were divided into two groups. Group I, which included 13 participants
(N=15 ears) having sloping sensorineural hearing loss without any cochlear dead region. The slope of the hearing loss in the test ear was 10-15 dB threshold increase per octave. The participants were in the age range from 32 to 72 years (mean: 57.61 years; SD: 8.78 years). Group II which consisted of 11 participants (N=14 ears) having sloping sensorineural hearing loss with the presence of cochlear dead region. The slope of the hearing loss in the test ear was 15-30 dB/octave. The participants were in the age range of 35 years to 76 years (mean: 49.81 years; SD: 13.98 years). All the participants were native speakers of Kannada language and were naïve hearing aid users.

High frequency word lists and sentence material developed by Mascarenhas (2001) were used. The test material consists of three lists each with twenty five words and three lists of nine sentences each. The word lists and sentence lists were recorded using Adobe Audition software (version 1.0) spoken by a native female speaker of Kannada with normal vocal effort with the microphone kept at a distance of 5-6 inches from the mouth of the speaker. The testing was done in a sound treated single/double room, with ambient noise levels within permissible limits.

**Procedure**

The testing was done in three phases

*Phase I*: Categorization of participants into those having cochlear dead region and without cochlear dead region

*Phase II*: Hearing Aid Fitting without and with non-linear frequency compression (NLFC)

*Phase III*: Evaluating the efficacy of frequency compression through

3.1. Speech Identification Score

3.2. Ling six sound identification

3.3. Quality judgment

**Phase I**

Step 1: Routine audiological testing including pure tone audiometry, speech audiometry, and immittance evaluation were carried out for each participant. Later the TEN (HL) test was administered to categorize the participants with and without cochlear dead regions. The steps followed to select high frequency sloping sensorineural hearing loss were:

1. Pure tone audiometry was done for all the participants. Air conduction thresholds were estimated between 250 Hz to 8000 Hz at audiometric frequencies under TDH-39 headphones encased in MX-41 AR ear cushion. The bone conduction thresholds were estimated between 250 Hz to 4000 Hz using B-71 bone vibrator. Modified Hughson Westlake method (Carhart & Jerger, 1959) was used to estimate the threshold.

2. Speech audiometry was administered for all the participants in which Speech Recognition Threshold (SRT), Speech Identification Scores (SIS) and Uncomfortable Loudness Level (UCL) for speech were measured.
3. Tympanometry with a 226 Hz probe tone was carried out for all the participants. Reflexometry was carried out in which the ipsilateral and contralateral thresholds were estimated for all the participants at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

After the initial diagnosis of sloping sensorineural hearing loss, the participants were administered the TEN(HL) test (Moore, Glasberg, & Stone; 2004) for the identification of dead region in the cochlea.

The Threshold Equalizing Noise (Hearing Level) or TEN(HL) CD was played using a laptop computer and the stimuli were presented via the Madsen OB-922 (Version 2.0) through TDH-39 ear phones. Test frequencies were 0.5, 0.75, 1, 1.5, 2, 3, and 4 kHz. The TEN (HL) level is specified as the level of a one-ERB\textsubscript{N} wide centered at 1 kHz. ERB\textsubscript{N} stands for Equivalent Rectangular Bandwidth Noise of the auditory filter determined by using young individuals with normal hearing at moderate sound levels (Glasberg & Moore, 1990). Levels of the TEN noise were 50 and 70 dB/ERB\textsubscript{N} (50, 70 dB SPL) for all participants. A TEN level of 70 dB HL / ERB\textsubscript{N} was used for most of the frequencies and a lower level of 50 dB HL/ ERB\textsubscript{N} was used for frequencies with lesser degree of (< 50 dB HL) hearing loss.

The level of the signal and the TEN was controlled using the attenuators in the audiometer. The TEN(HL) test was carried out as described by Moore, Glasberg, and Stone (2004), using a procedure similar to manual audiometry, that is modified Hughson-Westlake procedure (Carhart & Jerger, 1959), except that masked thresholds were measured using a 2-dB final step-size as recommended by Moore, Glasberg, and Stone (2004).

The TEN noise and pure tones were played in same channels of the audiometer. Prior to testing, calibration was done in which an individual with normal hearing was supposed to detect the tone in the presence of noise at 50 dB HL. The noise level was kept constant at 50 dB HL. The level of tone was adjusted using the level adjustment knob of the audiometer. The individual with normal hearing was asked to indicate whether he / she heard the tone in the presence of TEN which was presented continuously at a fixed level of 50 dB HL and the intensity of the tone was varied, for equal loudness. The level adjustment knob for the tone was decreased if the participant was able to hear the tone and the level adjustment knob was increased if the participant was not able to hear the tone. An up and down procedure for changing the level adjustment knob of the audiometer was done until the participant was able to detect the tone in the presence of TEN when both the tone and TEN were presented at 50 dB HL. TEN was presented ipsilaterally and the masked thresholds were obtained for each test frequency. Once the calibration was performed, the masked thresholds were compared to ascertain the presence of cochlear dead regions. The presence or absence of a cochlear dead region was based on the criteria suggested by Moore, Glasberg, and Stone (2004). The criteria to signify a dead cochlear region were:
1. If the masked threshold in the TEN was 10 dB or more than the TEN level/ERB_N and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was assumed to be present at that frequency.

2. If the masked threshold in the TEN was less than 10 dB above the TEN level/ERB_N, and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was assumed to be absent.

3. In case the TEN(HL) level could not be made high enough to elevate the absolute threshold by 10 dB or more, then the results were considered inconclusive. This would happen because the noise that would have been required was judged as too loud or because the maximum output of the audiometer was reached. A “no response (NR)” was recorded when the participant did not indicate hearing at the maximum output level of the audiometer. Participants with inconclusive results were not included in the study.

This test was administered for all participants and they were assigned to either the group without cochlear dead region (Group I) or with cochlear dead region (Group II) depending on the presence or absence of a cochlear dead region. The edge frequency, that is, the frequency from which a cochlear dead region starts, was noted down for all the participants in Group II.

Phase II

A. Hearing Aid Fitting

Two digital BTE hearing aids of the same model with NLFC feature were used for the study. The hearing aids were programmed in three conditions

1. Without the NLFC being activated as program 1(P1) of the first hearing aid.

2. The default settings for the gain and cut-off frequency and compression ratio of non-linear frequency compression as determined by the software were saved as the program 2 (P2) of the first hearing aid.

3. The fine tuning of NLFC in the hearing aid was done by manipulating two adjustable parameters of frequency compression from the ‘sound recover’ feature in the software. In this feature, the Cut-off Frequency and the frequency Compression Ratio of the NLFC were adjustable.

To ‘fine tune’ or optimize the frequency compression parameter, the cut-off frequency (range being 1.5 kHz to 6 kHz), and the ratio of frequency compression (range being 1.5:1 to 4:1) were manipulated in such a way that the participant was able to perform better on a identification task for /s/ and /ʃ/.

The fine tuning of the ratio of frequency compression parameter was done by the following steps:
1. If the participant was able to identify both the phonemes /s/ and /ʃ/ with the initial fit setting of the frequency compression, the parameter was adjusted to weaker settings step-by-step. In other words, the cut-off frequency was increased, i.e., the strength of frequency compression was decreased when the participant was able to identify the phonemes at the default cut-off frequency till he/she was able to identify both the phonemes presented at normal conversational levels.

2. If the participant was not able to identify one or both the phonemes correctly, the frequency compression parameter was made stronger step-by-step. In other words, the cut-off frequency was decreased, i.e., the strength of frequency compression was increased when the participant was not able to identify the two phonemes. An up and down procedure was used until consistent correct responses were obtained from the participants when the phonemes were presented randomly. This was done each time by testing the identification ability for /s/ and /ʃ/. The frequency compression ratio at which he/she was able to identify correctly at least for 50% of the time being presented was used. If the client was not able to identify the phonemes through auditory mode alone, then training was given for a brief period of about ten minutes along with the visual modality. Later, the fine tuning was continued with the auditory modality alone. If any participants were not able to identify the two phonemes even after fine tuning of the cut-off frequency and compression ratio, the cut-off frequency at which the maximum number of times the participant identified the phonemes were finalized as the cut-off frequency and compression ratio of the participant. This fine tuned cut-off frequency and frequency compression ratio of the NLFC was stored in as Program 1 (P1) of the second hearing aid. After programming the hearing aid, Speech Identification Score and Quality Judgment were evaluated.

For each participant, if the non-test ear was the poorer ear, then the testing was done without masking. However, if the non-test ear was the better ear, then the better ear was masked with speech noise at 65 dB using ER-3A insert ear phone fitted with an appropriate ear tip. This was done to avoid the participation of the non-test ear in the test.

**Phase III: Hearing Aid Verification**

**A. Measurement of Speech Identification Score (SIS)**

The participants were made to sit comfortably on a chair in the test room at a distance of one meter from the loud speaker of the audiometer at 45° A on the aided ear side. The recorded word list was presented through a computer routed through the Madsen OB-922 (Version 2.0) audiometer. The presentation level was set at 40 dB HL. Level adjustment was done for the calibration tone so that the VU-meter deflections averaged ‘0’. The SIS was obtained in quiet condition.

The order of testing the participants was unaided testing followed by aided testing in which the enabling and disabling of the Non-Linear Frequency Compression feature, was randomized across and within the participants to avoid any order or learning effect. The SIS was measured in unaided and three aided conditions.
1. **SIS in unaided condition**
   This was done without a hearing aid being worn by each of the participant.

2. **SIS in aided condition**
   Three aided conditions were evaluated for each participant from both the groups.
   1. With Non-Linear Frequency Compression disabled
   2. With Non-Linear Frequency Compression enabled - Initial Fit setting
   3. With Non-Linear Frequency Compression enabled - Fine Tuned setting

As there were three lists of words and sentences, none of the words or sentences list was repeated for any participant during the data collection. The participants were instructed to repeat the recorded words that he/she heard which were presented through a computer and routed through the auxiliary input of the audiometer. The responses were noted down in the International Phonetic Alphabet by the tester. The total number of correct responses was noted down for each test condition for each participant.

For the purpose of the study, scoring for words and sentences were done. For word identification, the response was considered incorrect if he/she failed to repeat or if it was repeated incorrectly. For sentences, it was taken as a correct response only if the participant repeated the entire sentence verbatim. The response was considered as incorrect if any word was missed or reworded or any phoneme in a word being replaced by another phoneme. Each correct response was given a score of ‘one’. The total number of correct responses was calculated after testing in each condition, for a maximum score of 25 for words and 9 for sentences.

Further, the ability of the participant to identify the Ling six speech sounds (/a/, /i/, /u/, /s/, /∫/, /m/) was done for each condition at 40 dB HL and the sounds which were not identified by the participant were noted down. The sounds were presented in random order. This was done using monitored live voice through the audiometer. For each correct identification, a score of ‘one’ was given and ‘zero’ for each incorrect identification. All the sounds were presented once and the responses were noted down. If any client found difficulty in identifying the phonemes, then the sounds were presented once more. After the presentation, the identification scores were converted to percentage scores.

**B. Quality Judgment**

The participants were asked to rate the hearing aid in terms of its quality of speech output in all the four conditions tested. For this, the recorded Kannada passage was routed through the audiometer at 40 dB HL. The participants were instructed to rate on six parameters of quality. The instructions were made simple in Kannada and it was explained to the participant.
The parameters and the rating scale for evaluating the quality judgment were loudness, clearness, sharpness, fullness, naturalness, overall impression. Each parameter was rated on a 10 point scale. That is 0 for very poor, 2 for poor, 4 for fair, 6 for good, 8 for very good, 10 for excellent. The participants were asked to rate the odd numbers if they found the quality to be intermediate between two points.

**Results and Discussion**

The data for the above parameters were analyzed using Statistical Package for the Social Sciences (SPSS for windows, Version 16) software. The mean and standard deviation of performance for words and sentences in terms of SIS was obtained for unaided condition (UA), without NLFC (WNFC), with NLFC-initial fit settings (NFCIF), and with NLFC- fine tuned (NFCFT) settings across the two groups. The mean and standard deviation of Group I (N=15 ears without DR) and Group II (N=14 ears with DR) for the SIS in the four test conditions have been tabulated.

Table 1: Mean and standard deviation (SD) of groups with cochlear dead regions (Group I) and without cochlear dead regions (Group II) in the four different conditions for words and sentences

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Unaided</th>
<th>Without NLFC</th>
<th>With NLFC-initial fit settings</th>
<th>With NLFC-fine tuned settings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Words</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Score = 25</td>
<td>Group I</td>
<td>Mean 3.53</td>
<td>14.47</td>
<td>15.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD 5.12</td>
<td>2.97</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>Mean 6.00</td>
<td>11.50</td>
<td>11.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD 6.52</td>
<td>6.25</td>
<td>5.86</td>
</tr>
<tr>
<td><strong>Sentences</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Score = 9</td>
<td>Group I</td>
<td>Mean 2.0667</td>
<td>6.27</td>
<td>7.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD 2.46</td>
<td>1.91</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>Mean 3.57</td>
<td>5.79</td>
<td>5.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD 3.82</td>
<td>2.97</td>
<td>3.21</td>
</tr>
</tbody>
</table>

For Group I, among the aided conditions, the performance for words was best with NLFC- fine tuned settings followed by NLFC-initial fit settings, compared to that without NLFC. However for the Group II, the mean SIS values revealed that the performance improved in the aided condition, but remained similar in all the three aided conditions for words. For sentences, the performance in the aided condition improved when compared to that in the unaided condition with no difference between the three aided conditions in both the groups. In order to find out if the slight differences in the mean scores of the performances were significantly different, mixed ANOVA was performed. It showed that among the aided conditions, a significant difference was found between with NLFC-fine tuned settings and without NLFC. Whereas, there was no significant difference between the pairs with NLFC-initial fit settings and with NLFC- fine tuned settings for both words and sentences. The NLFC-initial fit settings and without NLFC conditions were not statistically significant even at 5% level of significance.
Figure 1 depicts the mean scores for all the four conditions for words and sentences as stimuli. It can be seen that the mean scores were higher for Group I (without DR) than Group II (with DR) in all the three aided conditions.

![Graphical representation of mean SIS for words and sentences for both groups.](image)

Figure 1: The graphical representation of the mean SIS for words and sentences for both the groups.

Independent samples t-test for SIS for words was done to check the group differences within each condition. The results showed a significant difference between the NLFC-initial fit settings \(t (27) = 2.826, p < 0.05\) and fine tuned settings \(t (27) = 3.376, p < 0.05\) across the two groups at 5% level of significance while no significant difference for other pairs. But for sentences, no significant difference was seen for any pair. One way repeated measures ANOVA was done to compare the SIS between the unaided condition and the three aided conditions in both the groups. Results of the analysis showed that for Group I, significant difference was found only for the NLFC fine tuned settings and without NLFC at 5% level of significance for words and sentences and no significant difference for any other pairs for Group I. No significant difference for Group II for both words and sentences even at 5% level of significance was noted.

The results support the findings of the studies on speech perception through non-linear frequency compression by Simpson, Hersbach, and McDermott (2005, 2006). In their study, it was reported that a significant improvement for individuals with gradually sloping hearing loss but no improvement for individuals with steeply sloping hearing loss was reported. They attributed the cause for lesser improvement in steeply sloping hearing loss to the presence of a “cochlear dead region”. An improvement might have been present if the amplification was given within half to one octave above the estimated edge frequency (Vickers, Moore & Baer., 2001).

There are studies which show that reduction of hearing aid gain in the frequency range of dead regions may be desirable in some listeners who have them (Preminger, 2004). Probably in the present study, an improvement in performance of Group II might have been noticed if amplification was restricted to within half to one octave above the estimated edge frequency, as reported by Vickers, Moore, and Baer (2001). Kluk (2005) concluded that if for subjects with DRs, a larger than normal region of the auditory cortex is devoted to the analysis of frequencies just below \(f_e\), then it is possible that this auditory cortex reorganization makes subjects with DRs more effective at extracting “useful” information from lower frequencies in the speech. The frequency lowering strategies like non-linear frequency compression shifts the inaudible high frequency information to the lower frequencies where there is more useful hearing. So, it may be possible that the individual with a cochlear dead
region may benefit better if the higher frequencies are shifted to the frequencies around the edge frequencies where it is more effective in extracting the information.

Table 2: The identification of Ling’s six sounds in four test conditions

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Group</th>
<th>/a/</th>
<th>/i/</th>
<th>/u/</th>
<th>/s/</th>
<th>/∫/</th>
<th>/m/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unaided</td>
<td>Group I</td>
<td>100%</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>6.7%</td>
<td>86.7%</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>100%</td>
<td>0%</td>
<td>71.4%</td>
<td>0%</td>
<td>0%</td>
<td>85.7%</td>
</tr>
<tr>
<td>Without NLFC</td>
<td>Group I</td>
<td>100%</td>
<td>73.3%</td>
<td>100%</td>
<td>33.3%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>100%</td>
<td>35.7%</td>
<td>92.9%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>With NLFC-initial fit settings</td>
<td>Group I</td>
<td>100%</td>
<td>73.3%</td>
<td>100%</td>
<td>33.3%</td>
<td>53.3%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>100%</td>
<td>35.7%</td>
<td>92.9%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>With NLFC- fine tuned settings</td>
<td>Group I</td>
<td>100%</td>
<td>80%</td>
<td>100%</td>
<td>33.3%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Group II</td>
<td>100%</td>
<td>35.7%</td>
<td>92.9%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The Figure 2 is the line graph depicting the percentage scores of identification of scores for both the groups.

The NLFC slightly improved the identification of fricatives in Group I comprising of participants without a cochlear dead region. The high frequency amplification did benefit the Group I having participants without a cochlear dead region. However, the NLFC did not aid in the identification of fricatives in the Group II with participants having a cochlear dead region. This may be due to the non-functioning or absent inner hair cells in the Group II because of which the benefit from high frequency amplification is less. This finding supports that in the literature which reports of limited benefit for individuals with high frequency amplification in individuals with a cochlear dead region (Gordo & Iorio, 2007; Baer, Moore, & Kluk, 2002; Mackersie, Tracy, & Davis, 2004; Vickers, Moore, & Baer, 2001) while improvement in performance for individuals without a cochlear dead region (Gordo & Iorio, 2007). This may be due to the fact that at frequencies where dead region is present, those
individuals will not receive usable speech cues despite “sufficient” aided gain (Preminger, Carpenter, & Ziegler, 2005).

**Quality Judgements**

The Figure 3 depicts the mean ratings for all parameters of quality across all the three aided conditions. It shows that the maximum score or rating obtained for any parameter is ‘6’.

![Figure 3: The mean ratings of the subjective quality across the aided conditions for six parameters for both the groups, UA - Unaided, WNFC - Without NLFC, NFCIF - With NLFC Initial Fit settings, NFCFT - With NLFC Fine Tuned settings.](image)

These results reveal that mean scores of subjective quality rating was higher for the Group I - without cochlear dead region, when compared to Group II - with cochlear dead region. This finding supports that reported by Preminger, Carpenter, and Ziegler, (2005) which showed that the performance of participants with no dead region was similar to the normative group in APHAB sub-scales, whereas, the subjects with dead region scored poorer. In other words, the group that closely resembled the “successful” hearing aid users in subjective hearing aid performance was the group without a cochlear dead region.

Mann-Whitney U test was done to investigate the significant difference between the quality ratings by participants in the two groups across the three aided conditions for each of the six parameters of quality. The results of Mann-Whitney U test showed significant difference across the three aided conditions for all the six parameters of quality between the two groups with the Group I (without a cochlear dead region) performing better than the Group II (having a cochlear dead region).

From the present study, it can be concluded that high frequency amplification does help individuals with sloping hearing loss without a cochlear dead region. Also, frequency lowering strategies like NLFC, with the compression ratio optimized can be of help in speech understanding in individuals with sloping sensorineural hearing loss without a cochlear dead region. The implication of the present study is that unlike the individuals without cochlear dead region, individuals with cochlear dead region did not seem to benefit either with any high frequency amplification or NLFC. Thus, prescription of such technology should be done with caution for individuals with a sloping hearing loss. However further research is
required to validate the benefits of NLFC in individuals without cochlear dead region. The study throws light on the limited benefit from amplification for individuals with sloping hearing loss with cochlear dead region. Their amplification needs are different from those with sloping hearing loss without dead regions.

References


BINAURAL FUSION TEST IN KANNADA FOR CHILDREN

Tamanna Khurana & Vijayalakshmi Basavaraj*

Abstract

The study aimed at developing a Binaural fusion test in Kannada language and establishing the normative data for the test across the 5 age groups of 7-7.11 years, 8-8.11 years, 9-9.11 years, 10-10.11 years and 11-11.11 years. The test material was developed using a corpora of 360 CVCV words which were taken from age appropriate Kannada textbooks and 50 words which were familiar to all the children. They were then randomly grouped into 2 phonetically balanced lists, containing 25 words each. List I was picturizable and list II was non picturizable. The lists were then filtered using a low pass band of 500 to 700 Hz and a high band pass of 1800 to 2000 Hz with the help of Goldwave digital audio editor software and presented at 40 dBSL (with reference to pure tone average) to one hundred children who participated in the study and normative data was collected. The data obtained was analysed for the presence of age and gender effect. The results showed that there was an improvement in the scores for both List I and List II with an increase in age. The scores for males and females were comparable for both List I and List II, which reflected that there was no gender effect.

Introduction

“The study of central auditory processing disorders has been the cause celebre of countless researchers and practitioners across disciplines for several decades” (Ferre, 2002). Central auditory processes are the auditory system mechanisms and processes responsible for the following behavioural phenomena: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition including, temporal resolution, temporal masking, temporal integration, and temporal ordering; auditory performance with competing acoustic signals; and auditory performance with degraded acoustic signals (ASHA, 1996).

A central auditory processing disorder is defined as “An observed deficiency in one or more of the above listed behaviours. For some, CAPD is presumed to result from the dysfunction of processes and mechanisms dedicated to audition; for others, CAPD may stem from some more general dysfunction, such as an attention deficit or neural timing deficit that affects performance across modalities. It is also possible for CAPD to reflect co-existing dysfunctions of both sorts” (ASHA, 1996).

Comprehensive evaluation of individuals with (C)APD is a challenging task. As (C)APD represents a heterogeneous group of auditory deficits, it is important that a test battery approach be used so that different underlying processes, as well as different levels of functioning within the central auditory nervous system can be assessed. There are numerous tests of central auditory processing that have been developed over the years. However, not all of these tests are equal in their ability to identify auditory processing disorders. Therefore, a battery of tests needs to be developed for assessing the different auditory processes.

Historically, tests of central auditory function have been categorized in a variety of ways. Bellis (1996) categorized central tests as: dichotic speech tests, temporal ordering tasks, monaural low redundancy speech tests, and binaural interaction tests. Tests of binaural...
interaction generally assess the ability of central auditory nervous system to process disparate, but complementary, information presented to the two ears. Unlike dichotic listening tasks, the stimuli utilized in binaural interaction tasks typically are presented in a non simultaneous, sequential condition, or the information presented to each ear is composed of a portion of the entire message, necessitating integration of the information in order for the listener to perceive the whole message. The tests of binaural interaction include- rapidly alternating speech perception test (RASP), masking level difference test, interaural just noticeable differences and binaural fusion test.

Binaural fusion tasks involve the presentation of different portions of a speech stimulus to each ear, necessitating fusion of the information in order for the listener to perceive the entire word. Matzker (1959) was the first to develop binaural fusion test in which bi-syllabic PB words were filtered through a low pass band in one ear and a high pass band in the other ear. Matzker theorised that the two signals were integrated within the brainstem, most likely at the level of the cochlear nuclei and medial geniculate bodies resulting in better intelligibility scores than those obtained by independent presentation of filtered signals. Matzker (1959) and Lynn and Gilroy (1972) presented data indicating that adult patients with confirmed brainstem or temporal lobe pathology tended to perform poorly than normal adults on a measure of binaural fusion.

Binaural fusion test has been found to be sensitive tool to identify auditory processing problems in children. It has been used to study subtle auditory processing disorder in children. Martin and Clark (1977), using the word intelligibility by picture identification found that 50% of their learning disabled children could be found using the binaural fusion task.

**Need of the study**

As it has been reported that binaural fusion test is sensitive in identifying APD in children suspected to have processing problems (Roush & Tait, 1984; Singer, et al. 1998; Welsh & Healy, 1980), the need to develop such a test arises.

1. In the Indian scenario, Shivaprasad (2006) developed a binaural fusion test in English for children in the age range of 7 – 12 years using high band pass and low band pass CVC words. This is the only test developed in Indian population. Owing to the various languages being spoken in different parts of the country and the performance variations dependent on the language (Saleh et al., 2003), there’s a need to develop such a test in Indian languages.

2. Maturational effects are seen on the performance on a majority of the central tests (Bellis, 1996). However, adult values are reached by 11-12 years of age. Hence, there is a need to obtain age specific norms on these tests.

Due to the apparent lack of such tests for assessing auditory processing disorder in children, in the Indian context, there is a need to develop it in various Indian languages and obtain age appropriate norms.
**Aim of the study**

1. To develop a binaural fusion test in Kannada.
2. To obtain normative values using the developed test for different age groups of children.
3. To ascertain if there are any differences in the performance as a result of gender or age.

**Method**

The study was conducted with an aim of developing a binaural fusion test for children in Kannada language. This was done in two stages. Stage one involved development of the test material and in the stage two, normative data were collected for the same.

**Subject selection criteria**

For both the stages, the subjects had to meet the following criteria to be considered for the study

1. Hearing sensitivity within normal limits. The air conduction thresholds should be less than or equal to 15 dBHL at all frequencies from 250 – 8 KHz for both the ears.
2. ‘A’ type tympanograms with normal acoustic reflex thresholds for both the ears.
3. Mother tongue as Kannada as well as the language spoken at home should be Kannada.
4. No history or presence of otological problems like ear pain or ear discharge.
5. Academic performance should be good or average as per the teacher’s report.
6. Should not have auditory processing disorder as indicated by the screening checklist for auditory processing (SCAP) (Yathiraj & Mascarenhas, 2003)

**Stage 1**

This involved development of the test material, checking the test items for their familiarity and recording of the material.

**Development and familiarity checking of test material**

A Corpora of 360 CVCV Kannada words that are commonly used were selected from Kannada dictionary, English to Kannada translation book and a story book entitled - Sri Krishnadevaraya and Appaji’s stories. These 360 words were selected by 5 native Kannada speakers with the criteria that they are familiar and whether they are picturizable or not.

**Evaluation of familiarity of test items**

20 children in the age range of 7+ to 8 years, who met the subject selection criteria, participated in this evaluation. These children, participating in the familiarity check of the test items, were instructed to classify the words on a three point scale as – “Highly familiar”, “Familiar”, or ‘Not familiar'.
The words that were considered ‘highly familiar’ or ‘familiar’ by 90% of the subjects were utilized for the final construction of the test.

50 words which were rated as ‘highly familiar’ and ‘familiar’ by all the twenty children were finalised for developing the test material. These words were grouped into 2 lists consisting of 25 words. List I consisted of picturizable words and list II consisted of non picturizable words. It was ensured that both the lists were phonetically balanced as per the frequency of occurrence of Kannada speech sounds (Ramakrishna et al. 1962).

For List I, four pictures were presented for every target word and the children had to point to the target picture. Out of the four pictures, one was that of the target, one picture was that of a similar sounding word (Homophone), one of another word from the same lexical category and the last was a picture selected at random. The order of occurrence of the target word’s picture was varied randomly throughout the list.

**Recording of the test material**

Recording was done using an adult female speaker whose mother tongue was Kannada. To ensure that the two lists are of equal difficulty, the recorded stimuli before filtering was presented to the twenty children in the age range of 7+ to 8 years who participated in the familiarity check of the test items. Once it was found out that the lists were of equal difficulty, the filtering of the lists was carried out.

The test items were recorded using Adobe Audition version 3.0 software and band passed using Goldwave digital audio editor software. A low pass band of 500 to 700 Hz and a high band pass of 1800 to 2000 Hz were used to filter the words.

A 1 KHz calibration tone was recorded preceding each list and a six seconds inter stimulus interval was maintained.

**Stage 2**

This involved administration of the test to obtain normative data.

**Subjects**

One hundred normal hearing children who met the subject selection criteria and who were in the age range of 7+ to 12 years were taken for the collection of normative data. These children were grouped into 5 age groups-

- Group I – 7+ to 8 years
- Group II- 8+ to 9 years
- Group III- 9+ to 10 years
- Group IV- 10+ to 11 years
- Group V -11+ to 12 years

Each group consisted of 20 children; out of which 10 were boys and 10 were girls.

**Instrumentation**

The following instruments were used-
A Pentium 4 computer with Adobe Audition version 3.0 software was used to record the speech stimuli and Goldwave editing software for filtering the stimuli.

A calibrated dual channel diagnostic audiometer (Orbiter 922) with TDH-39 headphones housed in MX-4/AR cushion was used for running the test material. The calibration standards were as recommended by ANSI(S3.6 1996).

Calibrated GSI- tympstar middle ear analyzer was used to rule out the presence of any middle ear pathology.

A CD (CD_R 700MB) player was used for playing the recorded test material.

Test environment

Testing was done in a sound treated double room. The ambient noise levels were within permissible limits as recommended by ANSI (S3.1 1991).

Procedure

1. Pure tone audiometry was done for all the children. Air conduction thresholds were checked for frequencies between 250 Hz – 8 KHz. Bone conduction thresholds were checked for frequencies between 250 Hz – 4KHz.
2. Tympanometry was carried out on all the children using 226 Hz probe tone and acoustic reflexes thresholds were recorded at frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.
3. SCAP was administered for all the children.

The binaural fusion list was administered at 40 dBSL with reference to pure tone average and the children were asked to point to the target word’s picture for list I and repeat the words for list II. Each correct response was given a score of one and a wrong response a score of zero.

Reliability check

10 percent of the children were subjected to retesting after a time gap of at least 2 days. Test- retest reliability was checked using this data.

Statistical analysis

Appropriate statistical analyses were carried out to analyse the age effect and gender effect.

Results and Discussion

The data obtained was analysed using Statistical Package for the Social Sciences (SPSS) version 15 software.

The following statistical tools were used for analyzing the data-

- Descriptive statistics to calculate the mean and standard deviation for the scores obtained on list I and list II across all age groups.
- Mixed ANOVA (repeated measure ANOVA) to find out if there is any statistical significant difference across age, gender and list.
Duncan’s Post- Hoc test to find out the pair wise comparison of all age groups.

- Independent t-test for comparison of scores across gender in each age group.
- Paired t-test for comparison of lists within each age group.

I. Comparison of Lists, Age & Gender

The mean and standard deviations for all the five age groups across gender are given in table 1. The results are given for the two lists which were developed for establishing the normative data for the five age groups.

Table 1: Mean and Standard deviation (S.D) of Binaural fusion test scores for List I & II for males and females across all age groups.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Gender</th>
<th>List I Max. score:25</th>
<th>List II Max. score:25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>7+ to 8</td>
<td>Male</td>
<td>17.70</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>18.40</td>
<td>1.42</td>
</tr>
<tr>
<td>8+ to 9</td>
<td>Male</td>
<td>19.20</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>20.20</td>
<td>1.54</td>
</tr>
<tr>
<td>9+ to 10</td>
<td>Male</td>
<td>20.90</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>20.80</td>
<td>1.22</td>
</tr>
<tr>
<td>10+ to 11</td>
<td>Male</td>
<td>21.40</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>21.60</td>
<td>0.51</td>
</tr>
<tr>
<td>11+ to 12</td>
<td>Male</td>
<td>22.30</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22.70</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Table 1 shows the mean scores for list I and II. It may be noted that the mean scores increase from the younger age group to the higher age groups. It may also be noted that for list I there is a slight difference in mean scores obtained for the two genders. The scores are more for the females compared to the males for 7+ to 8 years and 8+ to 9 years age groups. However, for rest of the age groups and for list II the mean scores of males and females are comparable. Figure 1 shows the graphical depiction of the mean scores of both the genders for List I which increase with age.

![Figure 1: Comparison of mean scores for List I across the gender for each age group.](image-url)
Even for list II it can be seen from Figure 2 that the mean scores increase as the age increases. However there is an overlap of mean scores for the two genders.

![Comparison of mean scores for List II across the gender for each age group.](image)

Figure 2: Comparison of mean scores for List II across the gender for each age group.

Figure 3 shows the comparison of the mean scores obtained on the two lists for each age group (both the genders put together). From Figure 3, one can see that there is an improvement in scores as the age increases. It is also clear from Figure 3 that the scores for the two lists are comparable for all the age groups.

![Comparison of mean scores across age group for the two lists.](image)

Figure 3: Comparison of mean scores across age group for the two lists.

Mixed analysis of Variance (ANOVA) was done to see if there is any statistical difference between the lists, between the age groups and between the genders. The results of Mixed ANOVA are as given in Table 2.

Table 2: The results of Mixed ANOVA comparing the lists, age groups and genders

<table>
<thead>
<tr>
<th>Measure</th>
<th>F value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>List</td>
<td>F(1, 90) = 0.28, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Age</td>
<td>F(4, 90) = 53.196, p&lt;0.001</td>
<td>Significant difference</td>
</tr>
<tr>
<td>Gender</td>
<td>F(1.90)= 1.085, p&gt; 0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td>Age and Gender</td>
<td>F (4, 90) = 0.251, p&gt;0.05</td>
<td>No significant interaction</td>
</tr>
<tr>
<td>Age and List</td>
<td>F (4,90)= 2.429, p&gt;0.05</td>
<td>No significant interaction</td>
</tr>
<tr>
<td>Age, Gender and List</td>
<td>F(4, 90) =1.245, p&gt;0.05</td>
<td>No significant interaction</td>
</tr>
</tbody>
</table>
Duncan’s Post Hoc test was done to see which of the age groups were significantly different from each other. Results of Duncan’s Post Hoc test revealed that all age groups were significantly different from one another at 5% level of significance.

The results of the present study are concurrent with the findings of Plakke, et al. (1981) who reported of a systematic improvement in binaural fusion scores with increasing age in normal hearing children of 4, 6 and 8 years of age. Also, Neijenhuis et al. (2002) found an age effect within their group of 9-12 year old children as well as when children and adolescents were compared to adults on a variety of APD tests including Binaural fusion test. Binaural interaction has been found to reach adult values by ages 6-8 (Whitelaw and Yuskow, 2006). However, the results of the present study show that the increase in scores with increase in age is seen up to 12 years and hence gives an indication of maturation of auditory processing taking place even during adolescence.

Similarly, Stollman et al. (2004) also reported of an effect of age in 6-12 year old children on a battery of APD tests including Binaural Fusion test. In the Indian context, Shivaprasad (2006) reported similar findings on binaural fusion task indicating an age effect up to 12 years. The results of the present study also showed age and maturational effects till 12 years, indicating maturation of auditory processing, at least, up to an age of 12-13 years which is in good agreement on development of auditory processing abilities and electrophysiological studies of the maturation of the cortical auditory function (Cunningham et al., 2000; Johnstone et al., 1996; Ponton et al., 1996; Sharma et al. 1997).

The present findings thus suggest the importance of having age appropriate norms while assessing children using the developed binaural fusion test.

II. Comparison of Gender in each Age group

Independent t-test was done to see if there was any significant difference between list I and list II scores for both the genders across ages. Results of the Independent t-test (table 3) revealed that there was no significant difference between gender scores for all the age groups.

Table 3: The results of Independent t-test comparing the Gender effect in each age group.

<table>
<thead>
<tr>
<th>Age Group (years)</th>
<th>‘t’ value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>7+ to 8</td>
<td>List 1 - t(18)= 0.974, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td>List 2 - t(18)= 0.172, p&gt;0.05</td>
<td></td>
</tr>
<tr>
<td>8+ to 9</td>
<td>List 1 - t(18)=1.698, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td>List 2 - t(18)= 0.293, p&gt;0.05</td>
<td></td>
</tr>
<tr>
<td>9+ to 10</td>
<td>List 1 - t(18)= 0.221, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td>List 2 - t(18)= 0.383, p&gt;0.05</td>
<td></td>
</tr>
<tr>
<td>10+ to 11</td>
<td>List 1 - t(18)= 0.866, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td>List 2 - t(18)= 1.2, p&gt;0.05</td>
<td></td>
</tr>
<tr>
<td>11+ to 12</td>
<td>List 1 - t(18)= 1.007, p&gt;0.05</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td>List 2 - t(18)= 1.116, p&gt;0.05</td>
<td></td>
</tr>
</tbody>
</table>
The present findings support the results of Stollman et al. (2004) who also did not find any significant difference between the scores of males and females on a variety of APD tests including binaural fusion test. Shivaprasad (2006) also did not report any significant difference in the performance of males and females in the age range of 7-11.11 years on a measure of binaural fusion test.

Earlier studies have shown that young girls in the age range of 1-5 years are more proficient in language skills, learn to talk at an early age, produce longer utterances and have longer vocabularies than that of boys (Ruble and Martin, 1998, cited in Plotnik 1999). However, even though there appears to be a gender difference in verbal abilities favouring females, this difference is relatively small (Hyde, 1994, cited in Plotnik 1999).

III. Comparison of Lists within each Age group

Paired t-test was done to see if there was any significance difference between list I and list II scores across ages. The results of the Paired t-test showed that there was no significant difference between lists for age groups 7+ to 8 years- \[ t(19) = 0.900, p>0.05 \], 8+ to 9 years –[\( t(19) = 0.860, p>0.05 \)], 10+ to 11 years- \[ t(19) = 0.490, p>0.05 \]. However, there was a significant difference between the lists for age groups 9+ to 10 years- \[ t(19) = 2.131, p<0.05 \] and 11+ to 12 years- \[ t(19) = 2.604, p<0.05 \]

The significant difference between the lists for age groups 9+ to 10 years and 11+ to 12 years could be attributed to any chance factor.

IV. Test–Retest reliability

To find out the Test- Retest reliability, Reliability coefficient á was calculated for both the lists. Reliability coefficient was 0.86 for list I and 0.85 for list II.

Conclusions

The present study aimed at developing a Binaural fusion test in Kannada language and establishing the normative data for the test across the 5 age groups of 7-7.11 years, 8-8.11 years, 9-9.11 years, 10-10.11 years and 11-11.11 years.

The test material was developed using a corpora of 360 CVCV words which were taken from age appropriate Kannada textbooks and 50 words which were familiar to all the children. They were then randomly grouped into 2 phonetically balanced lists, containing 25 words each. List I was picturizable and list II was non picturizable.

The lists were then filtered using a low pass band of 500 to 700 Hz and a high band pass of 1800 to 2000 Hz with the help of Goldwave digital audio editor software and presented at 40 dBSL (with reference to pure tone average) to one hundred children who participated in the study and normative data was collected.
The data obtained was analysed for the presence of age and gender effect. The results showed that there was an improvement in the scores for both List I and List II with an increase in age. These findings are supported by earlier investigations by Plakke, et al. (1981); Neijenhuis et al. (2002); Stollman et al. (2004) and Shivaprasad (2006) who also found an age effect in the scores on Binaural fusion test in children. This increase in age has been attributed to the neuromaturation that takes place in central auditory nervous system till the age of 11-12 years.

The scores for males and females were comparable for both List I and List II, which reflected that there was no gender effect. This was supported by the findings of Stollman et al. (2004) and Shivaprasad (2006) who also reported the absence of any gender effect in the scores on Binaural fusion test for children aged 6-12 years.

Thus, the Binaural fusion test in Kannada developed in the study can be used to assess children from 7-12 years of age for the presence of any auditory processing disorder. It can be used clinically as an assessment tool for auditory processing disorder in Kannada speaking children.

Limitations

Only two lists for Binaural fusion test were developed in the present study. Additional lists would have helped in finding out if there was any apparent ear effect on the scores.

Future implications

The Binaural fusion test developed in the study can be administered on children with known auditory processing disorder to find out the sensitivity and specificity of the developed test. Also, further research can be done to develop the test in other Indian languages for assessment of auditory processing disorder.

References


Utility of Vestibular Evoked Myogenic Potentials in the Differential Diagnosis of Suspected Meniere's Disease and Benign Paroxysmal Positional Vertigo

Vivekanandh M. & Animesh Barman*

Abstract

VEMP is a valuable clinical tool in the differential diagnosis of various conditions affecting the normal physiology of the vestibular system. It provides information about the functioning of the otolith organ and the functional integrity of the inferior vestibular nerve. Meniere’s disease (MD) and benign paroxysmal positional vertigo (BPPV), which exhibit almost similar patterns of symptom, has to be differentiated from each other. Hence, the present study was aimed to identify the pattern of VEMP’s results in individuals with MD and BPPV and also how these wave forms are different from waveform that are recorded from the individuals with any vestibular abnormalities. The results indicated a significant difference in the latency of the p13 and n23 and also the peak to peak amplitude across the groups. The VEMP’s responses rates of the MD group were the least among the groups. The interaural amplitude difference ratio was significantly higher in the MD group. A difference in the VEMP responses between the unaffected and affected side in individuals with unilateral MD was also observed. Thus, the IADR value could be used to identify individuals with MD.

Abbreviations: VEMP: Vestibular Evoked Myogenic Potentials.
MD: Meniere’s Disease
BPPV: Benign Paroxysmal Positional Vertigo
IADR: Interaural Amplitude Difference Ratio

Introduction

Vestibular evoked myogenic potential (VEMP) is an electromyographic response to loud auditory stimuli that is recorded from the sternocleidomastoid muscle during tonic contraction. It is used as a clinical test to assess vestibular system as it provides information about the functioning of the otolith organ and the functional integrity of the inferior vestibular nerve. (Zhou & Cox, 2004).

Vestibular neuritis, benign paroxysmal positional vertigo (BPPV), and Meniere’s disease (MD) are the most common diseases that cause peripheral vertigo. The development of peripheral vertigo can be associated with the saccule or inferior vestibular nerve. Patients with vestibular neuritis also show unilateral peripheral vestibular dysfunction mainly in the superior vestibular nerve (Fetter & Dichgans, 1996). Recent studies have also demonstrated that some patients with having vestibular neuritis in the inferior vestibular nerve (Halmagyi, Aw, Karlberg, Curthoys, & Todd, 2001).

Heide, Freitag, Wollenberg, Schimrigk, and Dillmann (1999) reviewed VEMP response in three BPPV patients, in which all the patients had normal VEMP responses.

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However, a more recent study on BPPV patients indicated that 30% of the patients had abnormal VEMP responses (Akkuzu, Akkuzu & Ozluoglu, 2006). Matsuzaki and Murofushi, (2001) reported bilateral absence of VEMPs in cases with bilateral vestibulopathy. Ochi, Ohashi, and Watanabe, (2003) reported abnormal VEMPs and its recovery in patients with ipsilateral vestibular neuritis.

Vestibular-dependent short-latency electromyographic (EMG) responses to intense sound were initially recorded from the posterior neck muscles inserting at the inion, (Bickford, Jacobson & Cody, 1964). VEMPs are now recorded using symmetric sites over the sternocleidomastoid muscles (SCMs), (Colebatch, Halmagyi, & Skuse, 1994). The response consists of an initial positivity or inhibition (p13) followed by a negativity or excitation (n23). Later components (n34, p44) have a lower stimulus threshold and are non-vestibular (probably cochlear) in origin.

The VEMP arises from modulation of background EMG activity and it requires tonic contraction of the muscle. It is best observed in averaged unrectified EMG (Colebatch & Rothwell, 2004).

A morphologic and physiologic study in experimental animals confirms that intense sound selectively activates otolith afferents, (Murofushi, Curthoys, & Gilchrist, 1996). Stimulation of the saccular nerve in cats results in inhibitory postsynaptic potentials in the ipsilateral SCM motor neurons, which travel in the medial vestibulospinal tract, (Uchino, Sato, & Sasaki, 1997; Kushiro, Zakir, Ogawa, Sato, & Uchino, 1999) with only weak effects on the contralateral neurons. Utricular nerve stimulation, in contrast, evokes excitatory postsynaptic potentials in about two-thirds of contralateral SCM neurons, (Uchino, Sato, & Sasaki, 1997). Thus, the predominantly ipsilateral, inhibitory SCM responses (e.g., click VEMPs) are likely to represent saccular activation, and prominent crossed responses (observed in direct current and tap-evoked VEMPs) may indicate utricular stimulation.

By using the vestibular apparatus, VEMP has been used to assess not only the inferior vestibular nerve, also the activity of extra ocular muscles using Ocular-VEMP (Iwasaki et al, 2007), the crossed and uncrossed pathways of spinal cord (Rudisill, & Hain, 2008), and vestibular evoked potentials recorded from human masseter muscles and from scalp electrodes are the new techniques whose characteristics are still being explored.

**Need for the study**

Vestibular-evoked myogenic potential testing may provide additional information about the vestibular system and allow site of lesion testing (e.g. saccule and inferior vestibular nerve) in patients of all ages. Its role has yet to be defined in the diagnosis and treatment of common vestibular disorders, including Meniere's disease, vestibular neuronitis, labyrinthitis, and other diseases. Further, research is needed to support its clinical usefulness in patients with balance disorders, to optimize patient selection, and to establish its cost effectiveness (Honaker, & Samy, 2007).
New applications for vestibular evoked myogenic potential is needed in diagnosis and monitoring of neurotologic disease, and in shedding light on inner ear diseases by mapping anatomic sites of involvement. The most informative work is still in the areas of Benign paroxysmal positional vertigo and in Meniere’s disease. Also, many aspects of vestibular evoked myogenic potential and its use have not yet been adequately studied or described. It holds great promise for diagnosing and monitoring Meniere’s disease and Benign paroxysmal positional vertigo. The methods, equipment, and applications for vestibular evoked myogenic potential testing are not yet standardized (Rauch, 2006).

VEMP is a testing method that evaluates the saccule and the inferior vestibular nerve in the peripheral vestibular system. The test is easy, noninvasive and causes minimal patient discomfort. VEMP has been used as a complimentary test with the conventional vestibular function test in patients with peripheral vertigo. The main parameters of the VEMP responses used in clinical diagnosis are p13 and n23 latencies and the peak to peak amplitude. Recently, interaural amplitude difference ratio (IADR) has been recognized as one of the valuable clinical tools in the assessing individuals with vestibular dysfunction (Young, Huang & Cheng, 2003). Any conditions affecting the normal physiology of the vestibular system will have a significant effect on its evoked potentials. The most common conditions affecting the vestibular system are Meniere’s disease and benign paroxysmal positional vertigo. IADR might throw some important information in identification of BPPV and MD. Thus, the current study has been taken up, with the following aim.

Aim of the study

- To identify the pattern of VEMP responses in individuals with normal auditory and vestibular functioning, individuals with MD and in individuals with BPPV.
- To compare the parameters of VEMP responses between the groups.
- To compare the interaural amplitude difference ratio (IADR) across the groups.
- To check for ear effect on VEMP responses for individuals with unilateral MD.

Method

The main aim of the study was to identify the pattern of VEMP’s recorded from individuals with conditions indicating disturbances of vestibular system and to compare it with the VEMP’s recorded from normal individuals. Three groups of subjects were taken to arrive at the objectives.

Subjects

A total of 75 ears of 43 subjects were taken for the study. They were divided into three groups. Group I consisted of individuals with normal hearing sensitivity without vestibular symptoms served as the control; group II consisted of individuals who were diagnosed as having Meniere’s Disease, and group III consisted of individuals who were diagnosed as having BPPV by an otologist.
Group I

Consisted of 33 ears of 20 individuals with normal auditory and vestibular functioning and was ruled out by taking detailed case history. These individuals were between the age range of 18-24 years with a mean age of 20.45 years. The subjects were selected based on the following criteria:

Selection Criteria

- Pure tone audiometric thresholds were within 15 dB HL in octave frequencies from 250 Hz to 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction.
- Uncomfortable level was equal to or greater than 100 dB HL for Speech.
- All the subjects had ‘A’ type tympanogram with acoustic reflex threshold within normal limits, indicating a normal middle ear function.
- Auditory brainstem evoked response (ABR) results did not indicate of having space occupying lesions (retro cochlear pathology).
- No relevant otologic history was present in those subjects.
- No history of any observable medical or neurological signs.

Group II

Consisted of 22 ears of 12 individuals with suspected Meniere’s disease. Out of 12 individuals 8 individuals had bilateral and 4 individuals had unilateral indications of Meniere’s disease. These individuals were between the age range of 20-60 years with a mean age of 41.3 years.

Group III

This group had 21 ears from 11 individuals with suspected BPPV. The mean age of this group was 39.7 years with a range of 20 to 60 years.

Selection Criteria for group II and III

- The hearing sensitivity varied from normal hearing sensitivity to severe sensori-neural hearing loss for meniere’s group whereas for BPPV group the thresholds varied from normal hearing to mild sensorineural hearing loss.
- All the subjects had uncomfortable level greater than 100 dB HL for Speech.
- All of them had ‘A’ type tympanogram with normal, elevated or absent acoustic reflexes.
- No relevant history of middle ear pathology was reported.
- All of them were devoid of having retro cochlear pathology (RCP), which was ruled out based on ABR results.
- The subjects diagnosed as having Meniere’s disease or BPPV by an experienced otologist or a neurologist was taken for the study.
All the subjects had the triad symptoms of Meniere’s disease: fluctuating hearing loss, tinnitus and, giddiness.

All the subjects with BPPV had symptoms of tinnitus, and giddiness induced by rapid head movement.

**Procedure**

A detailed case history was taken from all the subjects. Later all of them underwent routine audiological assessment which consisted of pure tone audiometry, speech audiometry, immittance testing. Auditory brainstem response (ABR) was also administered using standard test protocol to rule the presence of any retro-cochlear pathology.

Inter wave latency was noted from the ABR waveform recorded at 11.1/sec stimulus rate and wave morphology and presence or absence of ABR wave V was noted from the ABR wave recorded at 90.1/sec stimulus rate to identify retro-cochlear pathology (RCP). Those who had normal inter wave latency and good morphology at 90.1/sec was considered as not having RCP and was included for the study.

All the subjects selected for the study had undergone VEMP recording. Procedure cited below has been adopted to record VEMP. The subjects were placed in a comfortable environment, where the subjects were made to sit upright position on an arm chair. The subjects were asked to turn their head to one side (opposite to the ear being stimulated) to tense the Sternocleidomastoid (SCM) muscle. The SCM muscle tension were monitored to be within 30–100 micro volt Electromyographic (EMG) level for the reliable recording of VEMP responses. Protocol given by Damen, (2007) was used to record VEMP is shown in the Table 1.

<table>
<thead>
<tr>
<th><strong>Stimulus Parameters</strong></th>
<th><strong>Acquisition Parameters</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stimulus</strong></td>
<td>500 Hz Tone Burst</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>10 ms</td>
</tr>
<tr>
<td><strong>Stimulus rate</strong></td>
<td>5.1 per sec</td>
</tr>
<tr>
<td><strong>Polarity</strong></td>
<td>Alternating</td>
</tr>
<tr>
<td><strong>No. of Sweeps</strong></td>
<td>200</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>95 dBnHL</td>
</tr>
<tr>
<td><strong>Transducer</strong></td>
<td>ER 3A Insert receiver</td>
</tr>
<tr>
<td><strong>Mode</strong></td>
<td>Ipsilateral</td>
</tr>
<tr>
<td><strong>Electrode type</strong></td>
<td>Disc electrode</td>
</tr>
<tr>
<td><strong>Electrode montage</strong></td>
<td>Ground: Forehead</td>
</tr>
<tr>
<td></td>
<td>Non inverting : middle portion of Sternocleidomastoid (SCM)</td>
</tr>
<tr>
<td></td>
<td>Inverting : Sterno-clavicular junction</td>
</tr>
<tr>
<td><strong>Analysis window</strong></td>
<td>-30 to 70 ms</td>
</tr>
<tr>
<td><strong>Filter settings</strong></td>
<td>10 to 1500 Hz</td>
</tr>
<tr>
<td><strong>Notch Filter</strong></td>
<td>Off</td>
</tr>
<tr>
<td><strong>Impedance</strong></td>
<td>Intra electrode : &lt; 5 k ohm</td>
</tr>
<tr>
<td></td>
<td>Inter electrode: within 2 k ohm</td>
</tr>
</tbody>
</table>

Acoustically evoked VEMPs were recorded twice to check for its reliability and stored in the computer. Later it was retrieved and shown to three audiologists independently to identify the VEMP waves. The p13 and n23 peak latency and also peak to peak amplitude was noted, in case there was an agreement in identifying peaks among the audiologists. The interaural amplitude difference ratio was calculated for all the three groups.
**Results**

The P13 and N23 latency and peak to peak amplitude was noted from all the subjects for all the three groups. The data were subjected to appropriate statistical analysis. The VEMP responses were present in 100% of individuals with normal auditory and vestibular functioning, 42% in Meniere’s disease group, and 60% in individuals with BPPV.

A group comparison was made by comparing the responses recorded from the three groups by analyzing the latencies of p13 and n23 peaks and the peak to peak amplitude. Also the mean and standard deviation for the individual parameters were calculated using descriptive statistics. For the group comparison the VEMP responses of right and left ear were combined for all the groups as there was no significant difference in latency or amplitude values between the ears for all the groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean p13</th>
<th>Mean n23</th>
<th>Mean PPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normals</td>
<td>13.81</td>
<td>21.00</td>
<td>59.19</td>
</tr>
<tr>
<td>MD</td>
<td>16.53</td>
<td>22.43</td>
<td>25.44</td>
</tr>
<tr>
<td>BPPV</td>
<td>17.81</td>
<td>27.08</td>
<td>29.61</td>
</tr>
</tbody>
</table>

It is apparent from the table 2 that the latency values obtained from individuals with normal auditory and vestibular functioning were shorter when compared to the clinical group. Within the clinical group, MD group’s latency was shorter than the BPPV group. Also, BPPV group had maximum variation in latency values than the MD group and individuals with normal auditory and vestibular functioning. Individuals with normal auditory and vestibular functioning had highest peak to peak amplitude followed by BPPV group and the MD group had the least peak to peak amplitude. Also, there was maximum variation in the peak to peak amplitude recorded from individuals with normal auditory and vestibular functioning, whereas the MD group had the least variation.

To see the significant difference among the latencies of p13 and n23 and peak to peak amplitude of the VEMP responses recorded from the three groups, MANOVA was done. The results of the MANOVA revealed that there was a significant difference in the latencies of p13 [F (2, 53) = 8.912, p<0.001], n23 [F (2, 53) = 12.335, p<0.001] and also for the peak to peak amplitude [F (2, 53) = 15.414, p<0.001] across the three groups.

Since, there was uneven sample size among the three groups taken for the study due to presence of no responses which cannot be taken for statistical analysis; Kruskal-wallis test was done to cross check the results of the MANOVA. The results of Kruskal-wallis also
revealed that there was a significant difference in the latency values of p13, n23 and peak to peak amplitude respectively which is in accordance with the results of MANOVA (Table 3).

Table 3: Chi square values along with significant level across the groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Chi Square Value</th>
<th>Degree of Freedom</th>
<th>Sig. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>p13</td>
<td>12.996</td>
<td>2</td>
<td>.002*</td>
</tr>
<tr>
<td>n23</td>
<td>9.171</td>
<td>2</td>
<td>.010*</td>
</tr>
<tr>
<td>PPA</td>
<td>21.273</td>
<td>2</td>
<td>.000*</td>
</tr>
</tbody>
</table>

Duncan’s Post hoc test was done to compare the latencies of p13 and n23 and peak to peak amplitude between any two groups since the MANOVA showed significant differences across the groups. For the positive peak p13, the individuals with normal auditory and vestibular functioning group had significantly shorter p13 latency than the individuals with MD and BPPV group. However, individuals with MD and BPPV group did not differ significantly in the p13 latency obtained.

There was no significant difference in n23 latency observed between normal group and MD group. However, BPPV group significantly differed from the other two groups. For the peak to peak amplitude, there was no significant difference in peak to peak amplitude observed between MD group and BPPV group. Whereas, there was a significant difference observed when compared with the individuals with normal auditory and vestibular functioning group.

**Inter-aural amplitude difference**

The mean IADR was calculated for normal group and MD group and not for BPPV group since only two patients showed bilateral VEMP responses which cannot be considered for statistical analysis. The mean and SD of IADR value was calculated for the normal and MD group which is given in the figure 1.

![Figure I: Mean and SD values of IADR measured for normal group and MD group.](image)

The mean IADR of MD group (0.3775) is greater than the IADR of normal group (0.1578). The Mann Whitney-U test was done to see the significant difference in IADR values between the groups. The results revealed a significant difference between the IADR values of normal group and MD group (Z = 2.551, p< 0.05).
Ear effect in Meniere’s disease group

Out of 12 individuals with MD, 4 of them had unilateral MD. The mean latencies of p13 and n23 from the unaffected side of the unilateral subjects were 16.95 ms and 24.05 ms respectively. And the mean peak to peak amplitude in these subjects was 25.48 micro volts. However, in the affected side 2 individuals showed absent VEMP responses and the others showed prolonged latencies and reduced amplitude values. The Wilcoxon’s signed rank test was done to compare the latency and amplitude between the unaffected and affected ears of unilateral MD group.

Table VI: Z-values and significant levels of the VEMP parameters obtained between the ears in individuals with unilateral Meniere’s disease.

<table>
<thead>
<tr>
<th></th>
<th>Z-value</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>P13</td>
<td>1.342</td>
<td>.180</td>
</tr>
<tr>
<td>N23</td>
<td>1.342</td>
<td>.180</td>
</tr>
<tr>
<td>PPA</td>
<td>0.447</td>
<td>.655</td>
</tr>
</tbody>
</table>

The result showed that there were no significant differences among latency and amplitude values between the ears. Whereas, descriptively the latency of p13 and n23 of the unaffected ears were shorter than the latency values of the affected ears. The amplitude of unaffected ears showed greater value than the affected ears. The VEMP responses were either absent or delayed in latency and reduced in amplitude in the affected ear when compared with the responses from the unaffected ear.

Discussion

VEMP responses in individuals with normal auditory and vestibular functioning, Meniere’s disease, and BPPV.

The present study revealed a 100% response rate in individuals with normal auditory and vestibular functioning. This is in accordance with the results obtained by Castelein, Deggouj, Wuyts and Gersdorff, (2008). The mean p13 and n23 latencies recorded in the present study were 13.81±1.66 ms and 21±1.97 ms respectively. Welgampola and Colebatch (2001) found that the average p13 and n23 latencies to a tone burst stimulus were 13.1 and 22.8 ms respectively.

The peak to peak amplitude obtained in the present study was 59.19±24.50 micro volts with a range from 1.54 to 104.60 micro volts. Castelein, et al. (2008) also cited that the amplitude of the p13 n23 varies widely among individuals making it difficult to use the amplitude parameter for clinical evaluation.

In the present study VEMP responses were recorded from 42% of individuals with MD with poor wave morphology. De Waele et al., (1999) reported a 46% response rate in individuals with MD. The mean p13 and n23 latency in the present study was 16.53±2.54 ms and 22.43±3.64 ms respectively. The mean peak to peak amplitude was about 25.44±15.11 micro volts. Hong et al (2008) obtained the mean p13 and n23 latency of about 17.1±3.2 ms
and 23.0±3.2 ms respectively and also the peak to peak amplitude of about 20.8±19.7 micro volts.

In the present study VEMP responses were recorded in individuals with BPPV with a response rate of 60% and the mean p13 and n23 latencies were 17.81±5.48 ms and 27.08±6.21 ms respectively whereas the mean peak to peak amplitude was 29.61±15.67 micro volts. Hong, Yeo, Kim and Cha, (2008) recorded VEMP responses in 75% of individuals with BPPV with mean p13 and n23 latency of about 16.5±2.6 ms and 22.6±2.8 ms respectively with mean peak to peak amplitude of about 15.3±22.0 micro volts.

Comparison of VEMP responses across the groups

A significant difference in the p13 and n23 latency and also the peak to peak amplitude across the groups was observed. Akkuzu, Akkuzzu, & Ozluoglu, (2006) also found similar results from their study by comparing VEMP responses from individuals with MD and BPPV and concluded that there was a significant difference in the VEMP responses recorded from these two clinical groups.

The latency of the first positive peak p13 obtained from the individuals with normal auditory and vestibular functioning group were significantly shorter than the individuals with MD and BPPV group. However, individuals with MD and BPPV group did not differ significantly in the p13 latency obtained. This is in contrary to Hong et al. (2008), according to them the prolongation of the p13 latency in BPPV group helped in differentiating from the individual with MD and vestibular neuritis.

The present study also showed n23 latency for BPPV group was significantly different when compared with either normal or MD group. There was no significant difference in peak to peak amplitude observed between MD group and BPPV group. The difference in the prolongation VEMP in individuals with BPPV can be attributed to the direct involvement of the saccular maculae, whereas in the MD group the hydrops could have been confined only to the cochlea thereby affecting the sound transmission to the saccule but not affecting the physiology of saccule directly (Welling et al, 1997 & Hong et al, 2008).

Inter-aural amplitude difference ratio

The mean IADR of MD group (0.3775±0.17) was greater than the IADR of normal group (0.1578±0.22). This result was in accordance with the study done by Young, Huang and Cheng (2003). They studied the IADR and grouped the MD individuals into different stages. They grouped individuals with MD with an IADR of 0.30±0.30 into Stage III, which is characterized by a depressed or absent VEMP responses and also flat audiometric configuration. A dilated saccule with an atrophied saccular macula, which was described in one histopathologic study of Meniere’s disease (Schuknecht & Gulya, 1983), could be an explanation for depressed VEMPs which supports the results of the present study. So, the increased IADR in the MD group can be attributed to the presence of an atrophied macula.
Ear effect in Meniere’s disease group

In the present study, the VEMP responses recorded in individuals with unilateral MD showed either prolonged latencies with reduced amplitude or absent responses in the affected side. But the unaffected side showed VEMP responses in all the ears. This difference among the unaffected and the affected ears were not statistically significant but it was observed that the latency was relatively shorter in the unaffected side. Also, the peak to peak amplitude was relatively greater in the unaffected side. A recent study compared VEMP in patients with Vestibular Drop Attacks (VDA) and non-VDA secondary to MD and reported that the incidence of absent VEMP in the affected ear with VDA was significantly larger than that in the affected ear with non-VDA (Timmer et al., 2006). While their findings suggested that VDA could arise from damaged otolithic organs, their results did not reveal reversibility of damage or the possible existence of endolymphatic hydrops in the otolithic organ.

Conclusions

The present study aimed at differentiating Meniere’s disease and benign paroxysmal positional vertigo based on VEMP results. The VEMP response rates of the MD group were the least among the groups. There was a significant difference in the latency of p13 and n23 and also the peak to peak amplitude across the groups. The p13 latency of MD and the BPPV group were comparable whereas the n23 latency of the BPPV group was significantly prolonged than the MD group. There was difference in the VEMP responses of MD and BPPV group between the ears descriptively but statistically it was not significant. The Interaural amplitude difference ratio was significantly higher in MD group. Descriptively, there was a difference in the VEMP responses between the unaffected and affected side in individuals with unilateral MD. Thus, the IADR value could be used to identify individuals with MD.

Implications of the study

- The peak latency and the amplitude data can be used as normative for future research and clinical evaluation.
- The VEMP response rate, peak latencies, IADR can be used as reliable tools to differentially diagnose between MD and BPPV.
- The results can be added to the current literature in the evaluation of vestibular disorders using VEMP.
References


