PROJECT REPORT

Sensitivity and Specificity of Audiological Tests in Differential Diagnosis of Auditory Disorders

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Sensitivity and Specificity of Audiological Tests in Differential Diagnosis of Auditory Disorders

A project carried out in 2002 at
Department of Audiology,
All India Institute of Speech and Hearing, Mysore,
(Grants from AIISH Research Fund)

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Introduction

The goal of audiological evaluation is detection and differential diagnosis of auditory disorders. Over the years a number of tests have been developed and used for audiological evaluation. These tests are never administered or interpreted in isolation, but are combined to constitute a test battery. The test battery used in audiological evaluation varies depending on a number of factors, which include age of the client, the signs and symptoms presented by the client and results of initial evaluation. Accurate diagnosis is the key for rehabilitation. Hence it is essential that the test battery chosen for evaluation help in correct identification of the disorder.

The efficiency of a test or a test battery in identifying a disorder can be assessed by estimating its sensitivity and specificity. Sensitivity refers to the true positive in comparison to total number of subjects with disease or abnormality (Turner, 1991). In other words sensitivity refers to the number of individuals with the disorder who can be identified using a given test or a test battery. Specificity refers to the true negative in comparison to the total number of subjects without the disease or abnormality (Turner, 1991). Sensitivity and specificity of each test is essential to determine whether a particular test can be included in the test battery. Depending on the criterion chosen, sensitivity and specificity of a test battery varies. Either a strict criterion or a loose criterion can be used in the interpretation of the test results. If results of all the tests should be positive for the results of the test battery to be positive, then the criterion is strict. If the results of the test battery are considered positive even if the results of any one test are positive, then the criterion is loose (Turner, 1988).

It is essential that the test battery used in identification and differential diagnosis of auditory disorders have good sensitivity and specificity, as diagnosis is the key for rehabilitation. A review of literature shows that tympanogram and acoustic reflex thresholds are good measures for identification of middle ear pathologies (Renvall, Liden, Jungret & Nillson, 1973; Bluestone, Berry & Paradise, 1973; Holmberg, Axelsson, Hanson, and Renvall, 1986). A majority of these studies indicate that sensitivity and specificity of 'B' type tympanogram is very high in detecting middle ear pathologies, whereas 'A' type tympanogram has good sensitivity but low specificity and other types of tympanogram (As, Ad, C, and D) have less sensitivity and specificity (Dempster & Me Kenzie 1971; Renvall & Holmquist, 1976; Muchnik, Hildesheimer, Rubinstein, and Gleitman, 1989). Bluestone et al. (1973) found that the combination of audiometry and tympanometry was more sensitive in detecting middle ear pathologies than any individual test.

The tests used for differentiating cochlear and retrocochlear pathology have undergone metamorphosis over the years. Initial test battery used by the audiologist included pure-tone audiometry, speech audiometry, and behavioral tests such as Alternate Binaural Loudness Balance test (ABLB), Short Increment Sensitivity Index (SISI) and adapatation tests. Inclusion of immittance evaluation in the test battery in 1970's offered several advantages such as objectivity, quick and relatively sensitive differentiation of cochlear status (Hall, 1991). Recording of auditory brainstem response eclipsed the classic test battery after 1977. One of the reasons is the high sensitivity of this test in identification of eighth nerve pathology (Seller and Brackman, 1977). At present the most commonly used test protocol is that recommended by Turner, Frazer and Shepard (1984) where all the individuals suspected with retrocochlear pathology are tested with auditory brainstem response and it has high sensitivity (95%) and specificity (89%). Turner (1988) evaluated the performance of different audiological protocols used in differentiation cochlear and retrocochlear pathology. It was observed that the inclusion of acoustic reflex testing along with auditory brainstem response decreases the sensitivity to 82% but has the advantage of reducing the number of individuals for whom recording of auditory brainstem response is required. Whereas, classical site-of lesion tests, along with acoustic reflexes, had sensitivity of 92% and specificity of 69 % when a loose criterion was used and using a strict criterion increased specificity by 96% but sensitivity decreased to 59%. A test battery consisting of classic site-of-lesion test, acoustic reflexes and auditory brainstem responses had a sensitivity of 89% and specificity of 92%. Thus a review of literature indicates that a number of tests are available for identifying various auditory disorders and the audiologist has to choose the most appropriate test battery.

Need and aims of the study

The tests used in the department of Audiology, All India Institute of Speech and Hearing (AIISH), Mysore, for differential diagnosis of middle ear disorders include pure tone audiometry, speech audiometry and immitance evaluation. Routine immittance evaluation consists of recording tympanogram and acoustic reflexes. The interpretation of the tympanogram is made based on the tympanometric peak pressure, peak compensated admittance at the tympanic membrane, ear canal volume and shape of the tympanogram. Appropriate diagnosis and referrals are made based on the results of the tests. Though the provisional diagnosis written in the client's record includes mainly the degree and type of hearing loss, it is possible to predict the site of lesion based on the results of various tests. It has long been reported that tympanomtery helps in differential diagnosis of middle ear pathologies. However, the criterion used for classification of tympanograms and identification of middle ear pathologies is not same in all the clinics.

Similarly, even when differentiating between cochlear and retrccohlear pathology the criteria used for various tests are not same. For example, speech identification score that is disproportionate to severity of hearing loss is considered as an indication of auditory dys-synchrony or space occupying lesion but there is no clear criteria for considering a score as disproportionate to hearing loss.

The criteria used for differential diagnosis in the Department of Audiology, All India Institute of Speech and Hearing, Mysore are based on a review of literature and some preliminary research. No large-scale study has been carried out to check the correlation among different audiological tests, correlation between audiological tests and medical diagnosis or to check the sensitivity and specificity of these tests in identifying different auditory disorders.

Also, auditory brainstem response is considered as the gold standard for differentiation of cochlear and retrocochlear pathology. Though it is important not to miss subjects with a disorder, of equal importance are the time required for testing and the cost of the test battery. Especially in countries like India, where speech and hearing facilities are not uniformly distributed, carrying out auditory brainstem response on a large number of subjects may be difficult. Hence, there is also a need to study the usefulness of simple tests such as speech identification tests, dynamic range and acoustic reflex testing in the audiological test battery. Hence the present investigation was undertaken.

The present study aimed at checking the sensitivity and specificity of various protocols in identifying different middle ear pathologies and correlation among different audiological measures in subjects with cochlear pathology.

Method

Subjects

This was a retrospective study. All the clients who reported to the All India Institute of Speech and Hearing, Mysore, between May 2000 and April 2001, with the complaint of acquired hearing loss were included in the study. The data consisted of the results of audiological and otorhinolaryngological evaluation of a total of 10,066 ears. Table 1 shows the age and gender distribution of the clients included for the study. The male to female ratio was 3:2.

Table 1: Age and gender distribution of the subjects

Age in **years**	**Male (No. of ears)**	**Female (No. of ears)**
0-5	65(130)	68(136)
5-15	263 (526)	179 (358)
15-25	422 (844)	302(604)
25-35	473(946)	325 (650)
35-45	445 (890)	296 (592)
45-55	446 (892)	282 (564)
55-65	419(838)	275 (550)
65-75	361(722)	176(352)
75-85	154(308)	49 (98)
95 & above	27 (54)	6(12)
Total	**3075(6150)**	**1958(3916)**

Instruments

A calibrated diagnostic audiometer was used for pure-tone and speech audiometry. A calibrated middle ear analyzer was used for recording tympanogram, acoustic reflex thresholds and reflex decay test.

Test material:

Spondees or paired word in the corresponding language was used for establishing speech reception threshold. Speech identification scores were obtained using the list of common monosyllable in Indian languages (Mayadevi, 1978).

Test environment

All the tests were carried out in an acoustically treated two-room suite with adequate lighting.

Test procedure

A detailed case history was taken before the audiological evaluation. All the clients were evaluated with a battery of tests, which included pure tone audiometry, speech audiometry and immitance evaluation. Auditory brainstem responses and otoacoustic emissions were recorded whenever indicated. All the clients were also examined by a qualified otorhinolaryngologist.

Background information

The client history included the present complaint, nature of the problem, duration of the problem, family history of hearing loss and the details of the previous investigations and rehabilitation carried out.

Pure tone audiometry

Pure tone thresholds were obtained at octave intervals from 250 Hz to 8000 Hz for air conduction stimuli and from 250 Hz to 4000 Hz for bone conduction stimuli. The modified Hughson-Westlake method (Carhart and Jerger, 1959) was used for pure tone threshold estimation. The degree of hearing loss was determined based on the modified Goodman's classification (Clark, 1981). Type of hearing loss was determined by comparing the air conduction and bone conduction thresholds. The audiogram was classified into different configurations based on the criteria given by Silman & Silverman (1991).

Speech audiometry

Speech reception thresholds were established using bracketing method. The initial presentation level was 20 dB SL (ref: pure-tone average of 500 Hz, 1000 Hz and 2000 Hz) and the intensity was increased in 5 dB and decreased in 10 dB steps. Four spondees or paired words were presented at each presentation level and the lowest intensity at which subjects repeated at least 50 % of the spondees was considered as speech reception threshold.

Speech identification scores were obtained at 40 dB above speech reception thresholds. If this level exceeded an individual's uncomfortable level, the test was carried out at 10 dB below the uncomfortable level. The subjects were instructed to repeat the sound heard and the percentage of correct responses was calculated.

Conversational speech was presented at speech reception threshold and the presentation level was increased in five dB steps to find out the lowest intensity level at which the subjects first reported a feeling of loudness discomfort. This was noted as the uncomfortable level. The difference between the loudness discomfort level and threshold was considered as dynamic range. Dynamic range of 80 dB or greater was considered normal.

Immitance evaluation

Immittance evaluation included recording of tympanogram and acoustic reflex thresholds (ART). The ear canal was inspected for the presence of any wax, foreign body and ear discharge before immitance evaluation. The probe with an appropriate sized ear tip was selected and was securely inserted into the ear canal to obtain an airtight seal. Compensated admittance tympanogram was recorded using 226Hz probe tone. Admittance at the tympanic membrane, tympanometric peak pressure and ear canal volume was noted for all the subjects. Tympanograms were categorized into different types based on the classification given in Table 2.

Table2: Classification of tympanograms

Type	Admittance at the tymapnic membrane (in ml)	Tympanometric peak pressure (in daPa)
A	0.5 to 1.75	-100 to + 60
As	<0.5	-100 to+ 60
Ad	>1.75	-100 to+ 60
C	0.5 to 1.75	<-100
Cs	<0.5	<-100
B	Cannot be recorded	No peak

The ipsilateral and contralateral acoustic reflex thresholds were established for 500Hz, 1000 Hz, 2000 Hz and 4000 Hz pure-tone stimuli. Acoustic reflex thresholds (ART) between 70 dB HL and lOOdB HL were considered as normal. ART above lOOdB HL was considered as elevated.

Reflex decay test was carried out for contralateral stimulus presented at lOdB above the acoustic reflex threshold, and if the reflex amplitude decreased by 50% within 5 sec, it was considered as positive reflex decay.

Analysis

The audiological and otorhinolaryngological data were fed into a computer using a coding system. The following information was fed into the computer:

> Case Number

> Age

> Gender

> Case history which included chief complaints of the client, age of onset, duration of the problem

> Degree, type and configuration of hearing loss

> Speech reception threshold and speech identification score

> Dynamic range

y Type of tymopanogram

> Tympanometric peak pressure, ear canal volume and peak compensated admittance at the tympanic membrane

> Ipsilateral and contralateral acoustic reflex thresholds

> Results of reflex decay test

> Medical diagnosis

SPSS software was used to categorize the data into different groups and calculate sensitivity and specificity.

Results and Discussion

Preliminary analysis of the data revealed that 2485 ears had normal hearing, 2372 ears had conductive hearing loss, 3229 ears had sensorineural hearing loss and 1980 ears had mixed hearing loss. Analyses were carried out separately for ears with middle ear disorders and ears with sensor neural hearing loss. Ears with normal hearing formed the control group.

Middle ear disorders

The sensitivity and specificity audiological tests in identification otitis media with effusion, otosclerois and eustachian tube malfunction was calculated separately. The sensitivity and specificity these tests in identifying other disorders could not be calculated as the number of subjects was very less. Sensitivity and specificity was calculated based on the recommendation given by Turner (1988). The number of correctly identified individuals with disorder divided by the total number of individuals with disorder was taken as sensitivity or the hit rate. False alarm was calculated by finding out the percentage of individuals without disorder incorrectly identified as having the disorder. 100% minus false alarm was taken as the specificity.

Otitis media with effusion

Otitis media with effusion (OME) or middle ear infection denotes the presence of inflammation in the middle ear cleft, regardless of cause or type of effusion. Otitis media is a common health problem especially among children. It has been reported that the incidence estimates ranges from 24% to 62%, whereas prevalence estimates are between 2% to 52%. (Darly, 1991). The incidence and prevalence is high in pre-school children. It is more prevalent in children under 2 year of age. Darly (1991) reported that otitis media would not differ significantly among children of different races and gender. But it is related to season and social-economic status. There is also a high prevalence of otitis media in children who have congenital condition such as cleft palate, Down syndrome.

Untreated otitis media or middle ear infection will lead to several complications in the middle ear cleft and temporal bone. Early identification of OME helps in avoiding the complication. The hearing loss resulting from otitis media most commonly is conductive in nature. However, in later stages sensorineural and mixed hearing loss may also result from this infection process (Pappas, 1985). Zamoch and Balkany (1977) reported that, infants who develop effusion during the newborn period seem more likely to develop chronic middle ear diseases. Furthermore, children with a long history of middle ear disease frequently have associated speech, language and education delays. Although the life threatening complications of middle ear effusion are uncommon in adult, this is not in case of young children effusions can act as a source for the bacteria and directly affect the brain through bloodstream.

Evaluation of children with otitis media includes otologic examination and audiologic evaluation. Pure tone audiometry, sometimes, fails to rule out middle infections, especially during the early stages of otitis media. In such cases, tympanometry will be the more useful. A review of literature indicates that tympanometry is a sensitive tool in identifying middle ear infection. Tympanometry has become a routine test in audiology and otology clinics and is considered indispensable for those who are involved in the clinical evaluation (Margolis, 1977). The characteristics of tympanogram are altered in individuals with otitis media with effusion. The admittance at the tympanic membrane may be reduced because the middle ear system is already stiffened by the presence of fluid. Also there may be little or no change in admittance with alteration in the ear canal pressure (Northern, 1975). Table 3 summarizes the reports of different investigators on sensitivity and specificity of tympanograms in identifying otitis media.

Table 3: Summary of investigations on sensitivity and specificity of tympanograms in identifying OME

Author	Subjects	Criteria used	Sensitivity	Specificity
Schwartz & Schwatz (1980)	103 children (4m-17y)	Btype& absent reflexes	74.5%	
Buckingham, Faraq, & Geick(1980)	41 ears	Btype	82.9%	
Holmbergetal. (1986)	50 children	Btype	95%	-
Dempster & Mackenzie (1991)	285 children	Btype	93%	76%
Finitzo, Friel-patti, Chinn & Brown, (1992)	86 children	Btype	90%	86%
Fileds, Allison, Corwin, White & Doherty (1993)	50 children	Btype	83.4%	75%
		B, C type	99%	75%
		B, Cs type	94.4%	71.8%
Multicenter otitis media study group (1999)	1153 children	Btype	90%	-
		B, Cs type	95%	-'
Palmu, Puhakka, Rahka & Takala(1999)	58 Infants	Btype	70%	98%
Lous, Hansen & Goksu (2000)	9540 children	Btype	90%	

In the present study, 1946 ears were diagnosed as having OME by a qualified otorhinolaryngologist. Immitance evaluation was not done for 353 ears either due to active ear discharge or inability to build the ear canal pressure. To calculate the specificity, two control groups were used. Control group I included only subjects with normal middle ear whereas control group II included subjects with normal middle ear as well as ears with otosclerosis. Control group I included 4971 ears and control group II included 5188 ears. The sensitivity and specificity of audiological evaluation in identification of ears with OME was established for the following tests:

* Tympanometry
* Tymapanometry and acoustic reflexes,
* Tympanometry, acoustic reflexes and pure-one audiometry

Tympanometry in identification of OME

Results revealed that out of 1593 ears with OME, only 938 ears had "B" type or flat type tympanogram. The sensitivity of tympanometry in detecting OME was only 0.58 and the specificity was 0.95 for the control group I and 0.94 for the control group II. Earlier reports in literature show that type "B" tympanogram has sensitivity of more than 85% in detection of OME (Holmberg et al., 1986; Dempster & Mac Kenzie, 1991; Palm.et.al., 1999; Lous, Hansen & Felding, 2000). The sensitivity observed in the present study was smaller than the earlier reports, may be due to the selection criteria of subjects. In the present study, OME was taken as one group irrespective of duration of onset and type of infection. However, a flat type of tympanogram was not observed in all stages of OME. Otitis media produces a characteristic sequence of change in tympanogram both in development stage and recovery stage (Jerger, 1975). There may be only change in the middle ear pressure or decrease in the stiffness of the middle ear in initial stage, according to ex vacuo theory, due to mechanical or functional Eustachian tube obstruction leads to absorption of gas in the middle ear, initially causing negative pressure and development of fluid in the middle ear cleft (Jung & Rhee, 1991). So the negative middle ear pressure also is an indication of OME. Hence in the second criteria, type "B" and type "C" tympanograms were taken as indicators of OME.

Including "C" type tympanogram increased sensitivity to 0.75 but the specificity reduced slightly. It was 0.89 for control group I and control group II. Fileds et al. (1993) studied fifty children with OME and they found that type B & type C tympanogram has good (above 90%) sensitivity in detecting OME. Sensitivity and specificity of "C" type tympanograms in detection of middle ear pathology will depend on the criteria used for classification. In the present study, tympanogram was considred as "C" type, if the tympanometric peak pressure was less than -100 daPa. Thus, clients with a mild Eustachian tube malfunction without any middle ear infection will also have "C" type tympanogram and this will reduce the specificity. Sensitivity and specificity will probably increase if a cut off of lesser tympanometric peak pressure (such as -200 daPa) is used in identifying OME.

The onset of otitis media may not be the same in all the subjects. Otitis media due to viral or bacterial infection will not show a negative middle ear pressure (Brooks, 1968) but may result only in reduction in the mobility of the tympanic membrane. Hence, in the third criteria type "B", "C", and "As" type tympanograms were considered as indication of OME. Tympanogram was classified as As type if the admittance at the tympanic membrane was less than 0.5 ml. With this criteria the sensitivity was increased to 0.85 but specificity reduced further. It was 0.69 for control group I and 0.68 for control group II. Further analysis was carried out to check if the results vary if the admittance value of less than 0.3 ml is considered as "As" type. This criterion decreased the sensitivity to 0.78 but specificity increased to 0.85 for control group I and 0.84 for control Group II.

Figure 1 summarizes the sensitivity and specificity of different tympanometric criteria in identifying OME. It can be observed that when a loose criteria is used, the sensitivity increases gradually but the specificity decreases. Either the second criteria ("B" or "C" type tympanogram) or the fourth criteria ("B", "C" or "As" type with static admittance of less than 0.3 ml) is recommended for identifying middle ear infection.

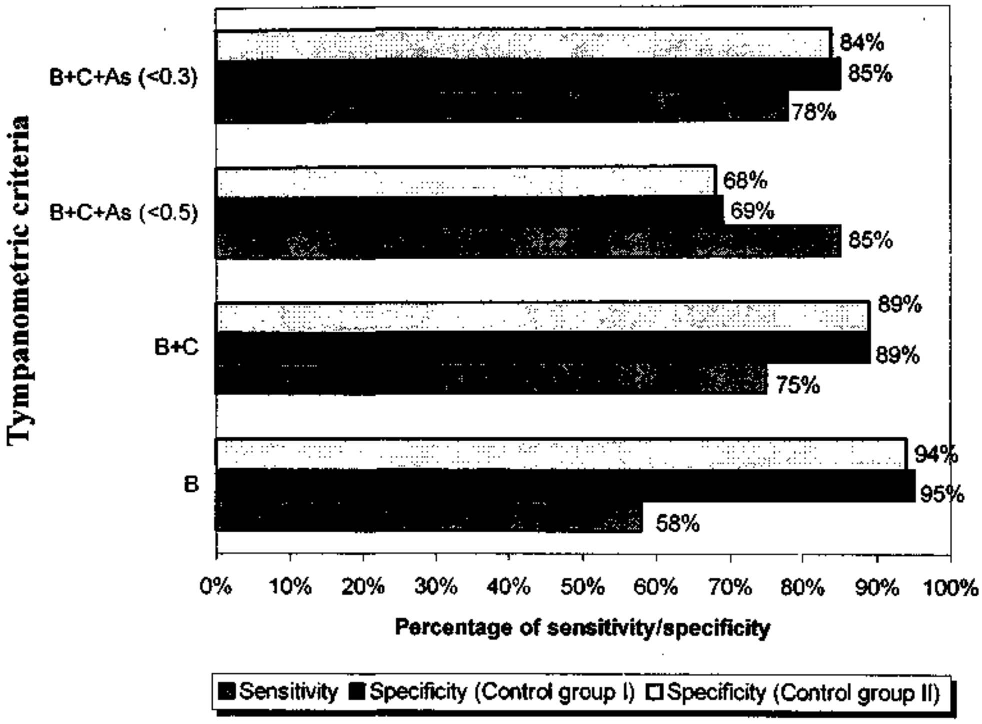

Figure 1: Graph depicting sensitivity and specificity of different tympanometric criteria in identifying middle ear infection.

Tympanometry and acoustic reflexes in identification of OME

It has been reported in literature that acoustic reflexes are more sensitive than tympanograms in identifying middle ear pathology (Brooks, 1978). Both ipsilateral and contralateral stapedial reflexes are absent in ears with middle ear infection (Wiley & Fowler, 1997). Kazana & Maw (1994) also reported that the sensitivity increases when the absence of stapedial reflex is included in the test battery for detection of OME. The acoustic reflex usually disappears during very early stage of otitis media, due to gross increase in middle ear impedance. (Jerger, 1975). In the present study the sensitivity of acoustic reflexes in detecting OME was 0.92. However, the specificity reduces if only acoustic reflexes are used in identifying otitis media with effusion. This is expected, as middle ear infection is not the only condition in which acoustic reflexes are absent. Probability of obtaining acoustic reflexes reduces with increase in degree of hearing loss even in subjects with sensorineural hearing loss. Also any middle ear disorder will abolish acoustic reflexes in the probe ear. Thus acoustic reflexes will not help in differential diagnosis of middle ear disorders. Presence or absence of acoustic reflexes along with tympanometry will give more information. The results of the present study showed that test battery including tympanometry and acoustic reflexes had a sensitivity of 0.74 and specificity of 0.90.

Tympanometry. acoustic reflexes and pure-tone audiometry in identification of OME

A test battery including tympanometry, acoustic reflexes and pure-tone audiometry had a sensitivity of 0.70 and specificity of 0.93 for both the groups, if strict criteria are used. The sensitivity increases to 0.92 if a lenient criterion is used but the specificity will also decrease.

Among those with middle ear infection, hearing was within normal limits in 150 ears. Among them, tympanometry was abnormal (B, C or As) in 65 ears. Among the remaining 85 ears, acoustic reflexes were absent in 19 ears. In other words tympanometry and acoustic reflexes could identify middle ear infection in 84 ears with normal pure-tone audiometry. These results support the notion that immittance evaluation is more sensitive than audiometry in identifying middle ear infection.

Otosclerosis

Otosclerosis is an inherited disorder of bone growth that mainly affects the stapes and the bony labyrinth of the cochlea. The actual bone change consists of simultaneous laying down of new bone with a concomitant resorption of the older bone producing a spongy type of bone (Ginsberg & White, 1994). It is more common in adults. It occurs in twice as many females as males and the onset in women is often associated with pregnancy.

Pure-tone audiogram is characterized by mild low frequency conductive hearing loss in the initial stages. As the disease progresses the air conduction audiometric pattern flattens because mass component will be added along with the stiffhess component.

With the increase in resistive component, the magnitude of hearing loss increases (Silman & Silverman, 1991). A dip at 2000 Hz in the bone conduction thresholds, known as Carhart's notch is seen in the initial stages of otosclerosis (Carhart, 1950).

In clients with otosclerosis and related ossicular chain fixation, the tympanogram is usually a shallow type "A", the admittance at the tympanic membrane is usually in the range from 0.20 to 0.40ml, and both ipilateral as well as contralateral acoustic reflexes are not observed (Liden, 1969; Jerger, 1970; Liden, Peterson & Bjorkman, 1970; Albert! & Kristensen, 1970; Jerger, Anthony, Jerger & Mauldin, 1974).

In the present study 224 ears were diagnosed as having otosclerosis by a qualified otorhinolaryngologist. Among them, immittance evaluation could not be done for seven ears due to inability to maintain ear canal pressure during testing. Therefore, data from only 217 ears were considered for analysis. Specificity was calculated by analyzing the data from a control group, which included clients with normal middle ear.

Results of tympanometry showed that 86 ears with otosclerosis had "As" type tympanogram. The sensitivity of "As" type tympanogram in detecting otosclerosis was 40% whereas the specificity was 80% when peak compensated admittance value of 0.5ml was taken as criteria to classify "As" type tympanogram. Changing the criteria to 0.3 ml, increased the specificity to 98% but decreased sensitivity to 8%. Jerger (1972) reported that the overlap between the distribution of tympanogram in subjects with normal middle ear and those with otosclerosis is so great that one cannot really differentiate the otosclerosis from the normal middle ear based on the tympanogram. Theoretically it is expected that otosclerosis reduces the mobility of the ossicular chain, which in turn decreases the compliance at the tympanic membrane. However initial stages of otosclerosis or ossicular chain fixation will not show a significant decrease in the peak compensated admittnce. Also a client who had admittance value at the upper limits of the normal range may have admittance in the lower limits of the normal range after stapes fixation. So his tympanograms will be classified as A type both before and after stapes fixation. Thus one cannot expect "As" type tympanogram to have good sensitivity in identifying ears with otosclerosis. Even in the present study, results of "t test" showed that there is no significant difference in admittance at the tympanic membrane of subjects with normal hearing and those with otosclerosis.

Analysis of the data in the present study revealed that 37% of the ears showed type "A" tympanogram. Thus, the sensitivity increased to 77 % if either "A "or "As" type tympanogram was taken as indicator of otosclerostic ear. However, this will not be a good criteria for identification as subjects with normal hearing and senssorineural hearing loss will also have "A " type tympanogram.

It has been reported that, although the tympanogram may often be within normal limits, both ipsilateral and contralateral acoustic reflexes are generally not observed in ears with middle ear problems (Terkildsen, Osterhammel & Bretiau 1973; Jerger et al. (1974). Brooks (1978) reported that acoustic reflex measurement was highly sensitive in the identification of the middle ear disorder. Forquer and Shechy (1987) reported that 75% of the ears had acoustic reflex finding indicative of ossicular fixation in probable cochlear otosclerosis. Jerger et al. (1974) also reported that stapedial reflex could not be elicited in 80% of the subjects with otosclerosis. Results of the present study showed that the sensitivity of this criteria, A or As type tympanogram and absent reflexes, could identify otosclerosis in 72% of the subjects but the specificity was only 66%. This reduction in the specificity was because the control group included both clients with normal hearing and those with sensorineural hearing loss. Probabability of getting acoustic reflexes reduces with increase in degree of sensorineural hearing loss. Adding presence of air bone gap to the criteria increased the sensitivity to 73% and specificity to 92%.

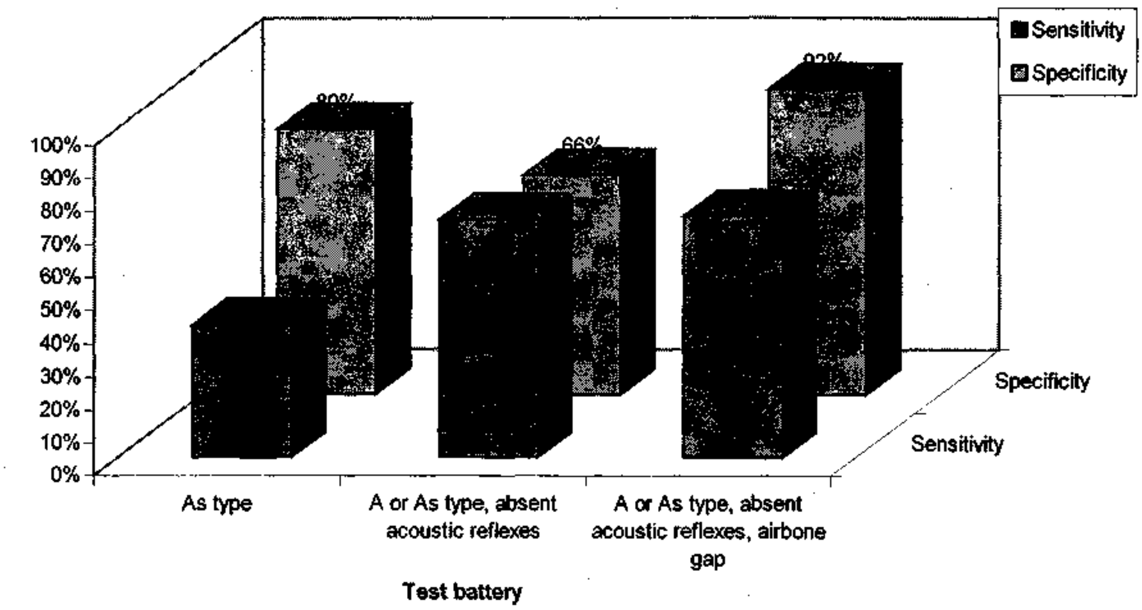

Figure2 : Sensitivity and specificity of audiological tests in identifying otosclerosis

Figure 2, summarizes the sensitivity and specificity for different criteria in identifying ears with otosclerosis. The third criteria (A or As type tympanoram with absent acoustic reflexes and airbone gap) is the best criteria for detecting ears with otosclerosis, both in terms of sensitivity and specificity. Inclusion of additional tests such as multifrequency tympanometry may increase the sensitivity and specificity of the audiological test battery in identifying otosclerosis.

Eustachian tube malfunction

One of the main functions of the Eustachian tube is maintaining the air pressure in the middle ear by equalising the pressure in the middle ear to that of the atmospheric pressure. Eustachian tube is normally closed but opens during certain activities such as yawning, swallowing or when there is a difference in pressure of the middle ear and nasopharynx. Pathological blocking of the Eustachian tube will impair this function. According to ex vacuao theory, large negative intratympanic pressure would develop if the interval between Eustachian tube openings is too long (Margolis & Shanks, 1991). Thus, Eustachian tube malfunction leads to conductive hearing loss which is generally a mild loss at low frequency in the initial stages. The peak in the tympanogram is expected to shift towards negative side ("C" type) indicating negative middle ear pressure.

Otorhinolaryngologist suspected Eustachian tube malfunction in 382 ears. Among them immittance was not carried out for three ears. The results showed that C type tympanogram had a sensitivity of only 0.2 in identifying Eustachian tube malfucntion but the specificity was very good (0.96). Various criteria have been used by different clinicians to classify "C" type tympanogram or identify eustachian tube malfunction. For example, Brooks (1980) has that normal tympanometric peak pressure varies from +50 daPa to - 50 daPa whereas Renvall, Liden, Jungert and Nilsson (1975) consider -150 daPa as the lower limit for normal middle ears. The criteria used in this investigation^ 100 to +60 daPa) is one of the lenient criteria. Hence, analysis was carried out to check if the sensitivity increases if the criterion is changed. The results revealed that if tympanometric peak pressure of less than -50 daPa was considered as C type, the sensitivity increased slightly (0.32) but the specificity reduced (0.87). Changing the criteria to - 25 daPa , did not improve the efficacy of tympanometry in identifying individuals with Eustachian tube malfunction. The sensitivity increased to 0.37 and specificity reduced to 0.84. Thus, it is recommended that the -50 daPa be used as a cut off differentiate between subjects with normal and abnormal Eustachian tube malfunction. But tymapanometric peak pressure or type of tympanogram is not sensitive in detecting Eustachian tube malfunction. These results indicate that abnormal negative peak pressure is not always associated with Eustachian tube malfunction. Wiley, Oviatt and Block (1987) have reported that the middle ear pressure is slightly positive after a period of Eustachian tube closure suggesting bidirectional diffusion process. Further studies need to be carried to check if inclusion of special tests such as pressure swallow tests in the test battery will increase the sensitivity of tympanometry in identifying ears with Eustachian tube malfunction.

Sensorineural hearing loss

From the original database the results of 3229 ears with sensorineural hearing loss were analyzed separately. A male preponderance was observed in adults as well as geriatrics with a male to female ratio of almost 2:1. From this database, audiological profile of 855 ears of adults and 1127 ears of geriatrics with normal auditory brainstem or no other indications for retroccohlear pathology was analyzed. The profile includes information on severity of hearing loss, configuration of hearing loss, speech identification scores, acoustic reflex threshold and dynamic range. An attempt is made to compare the results of elderly subjects (more than 55 years) with that of adults (18 years to 55 years). The sensitivity and specificity of these tests in identifying cochlear pathology is also discussed wherever applicable.

Pure tone audigram:

It was observed that more number of subjects reported to the clinic had moderate or moderately severe hearing loss. Figure 3 shows the percentage adults and geriatrics with different degree of hearing loss. A majority of adults (47.9%) showed flat hearing loss, followed by gradually sloping configuration (27.6%). Steeply sloping and raising configuration was not common with a frequency of 6.2 % and 2.7 % respectively. Gradually sloping audiogram was the most frequently observed audiometric configuration (48,5 %) in the elderly. 31.1 % of the elderly showed raising configuration. The configuration of the audiogram varies depending on the etiology of the hearing loss. It has been reported that the hearing loss associated with presbycusis affects the high frequencies first and then the low frequencies (Silman and Silverman, 1991). With increase in hearing loss, the sloping configuration changes to flat. It was observed in the present study that the proportion of subjects with sloping hearing loss was more in mild and moderate category whereas the number of subjects with flat hearing loss was more in elderly subjects with higher degree of hearing loss.

Comparison of hearing thresholds of left and right ear revealed that the hearing loss was symmetrical in a majority of the elderly (59%) but it was asymmetrical or unilateral in a majority of the adults (79 %) . 3 1 % of elderly and 49 % of adults showed greater loss in the left ear when compared to right ear whereas 2 6 % of the elderly and 3 0 % of adults showed more hearing loss in the right ear. This trend was similar in males and females but the proportion of subjects showing poorer left ear threshold was more in male group than in female group. Me Fadden (1998) has reported that in normal hearing adults, right ear is 2 to 3 dB more sensitive than left ear. It has also been reported that this right ear superiority is more pronounced in males than in females. Otoacoustic emissios are also stronger in right ear when compared to left ear (Roninette, 2003). These findings suggest that right cochlea is more active than left cochlea. The results of the present study indicate that probably right ear is also more resistant to the effect of aging and other noxious agents.

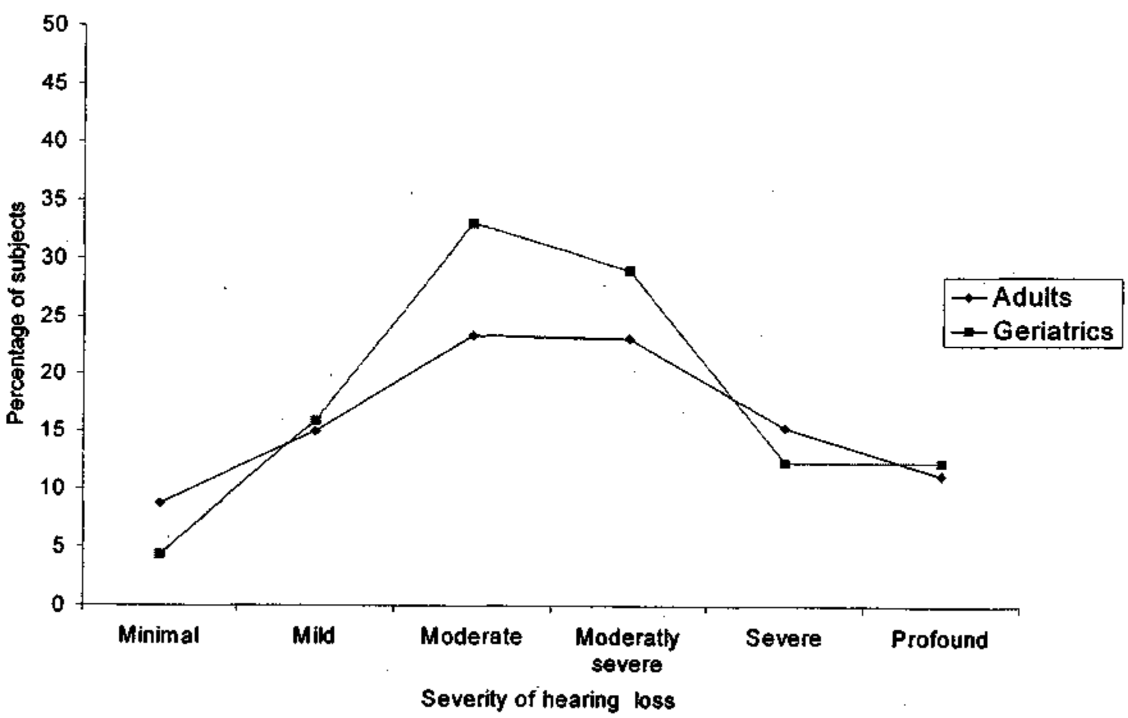

Figure 3: Percentage of subjects with different degree of sensorineural hearing loss

Speech identification scores:

The speech reception threshold correlated with the pure-tone average in a majority of the subjects except those with functional hearing loss. In subjects with steeply sloping audiogram, speech reception thresholds correlated with the average of frequencies that had better thresholds.

Table 4 shows the mean, standard deviation and lower bound of 95 % confidence limits for speech identification scores in adults and geriatrics with sensorineural hearing loss. It can be observed from the table that the mean speech identification scores decreased with increase in hearing loss and the scores for geriatric group was lesser than those for adults. Two-way ANOVA was carried out investigate the effect of age and degree of hearing loss on speech identification scores. Results revealed that there was a main effect of age ($F= 22.52$, $p < 0.01$) and degree of hearing loss ($F= 20.48$, $p < 0.01$). Scheffe's post hoc test revealed that the scores for mild and profound hearing loss were significantly different from those of other groups. There was no significant difference between scores obtained for moderate and moderately hearing loss but the scores for moderate group differed significantly from those of other groups. Similarly there was no significant difference between scores for severe and moderately severe hearing loss but the scores for sever hearing loss differed significantly from those of other groups. The scores for moderately severe hearing loss differed significantly from those of mild and profound hearing loss. Results of ANOVA also revealed a significant interaction of age and hearing loss on speech identification scores ($F= 3.99$; $p< 0.05$). It can be observed from Figure 4 that the speech identification scores for adults and geriatrics overlap for subjects with mild hearing loss but geriatrics with greater degree of hearing loss had lower scores than adults.

Table 4: Mean. SD and lower bound of 95 % confidence limits (LB) of SIS for adults and geriatrics with different degree of hearing loss

Degree of hearing loss	Adults			Geriatrics		
	Mean	SD	LB	Mean	SD	LB
Mild loss	92.7	19.6	82.15	84.78	9.94	81.70
Moderate loss	85	12.47	83.56	77.98	11.71	72.55
Moderately severe loss	77.55	13.89	76.44	70.05	16.81	67.93
Severe loss	66.45	17.94	77.99	67.35	18.12	65.45
Profound loss	67	15.25	49.28	58.8	16.6	55.30

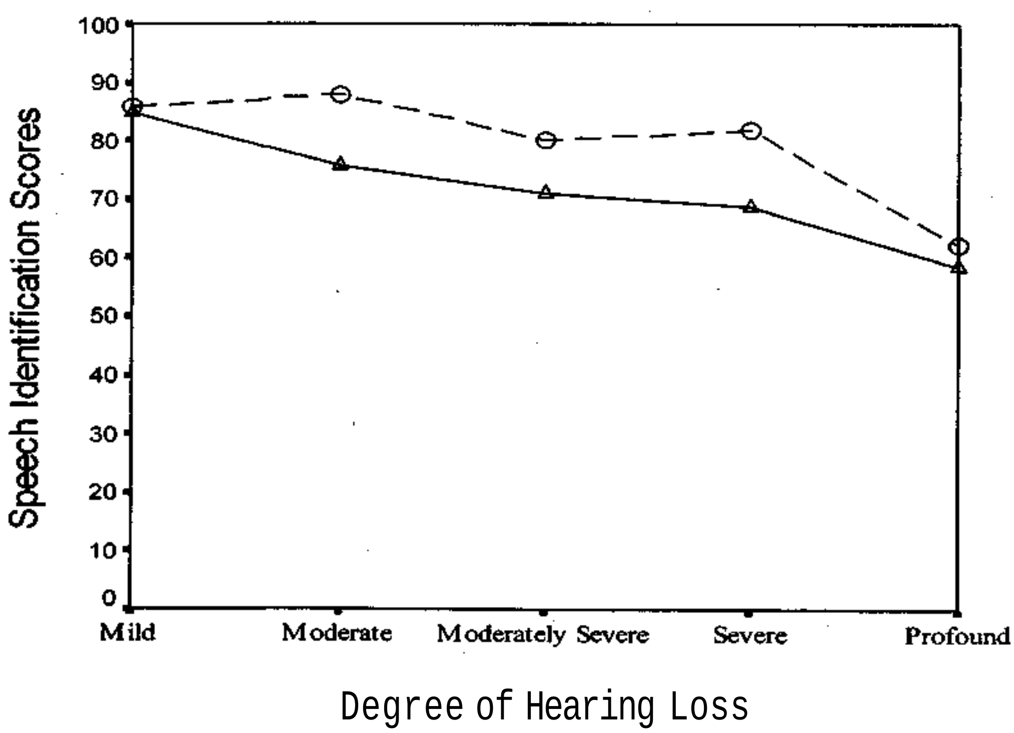

Figure 4: Comparison of mean speech identification scores of adults and geriatrics with different degree of hearing loss

Poor speech identification in the geriatric subjects is an expected finding as phonemic regression or poor speech identification scores has been described as one of the features of presbycusis (Weinstein, 1994). The results indicate that speech identification in quiet was not significantly affected by age in subjects with mild hearing loss. Probably neural degeneration was more in subjects with greater degree of hearing loss and hence speech identification scores reduced.

The speech identification scores are affected by a number of factors that include degree and etiology of hearing loss. It has been reported that speech identification scores are proportionate to the degree of hearing loss in subjects with cochlear pathology and poor speech identification scores give an indication of retrocochlear or retro-outer hair cell dysfunction (Johnson, 1987; Olsen Noffsinger and Kurdziel, 1975; Starr, Picton, Sinniger, Hood, and Berlin, 1996). The present study included subjects with cochlear hearing loss but the etiology of the hearing loss was not controlled. Pearson product moment correlation analysis showed a significant negative correlation between the pure-tone thresholds and speech identification scores in both the groups ($r = -0.62$; $p>0.01$ in adults and $r = -0.13$; $p>0.01$ in geriatrics). A lower correlation seen in geriatrics indicates the variability in the etiology of hearing loss in the elderly. It has been reported in literature that in elderly subjects there is degeneration in the cochlea as well as neural structures (Wienstein, 1994). As the geriatric group studied will include subjects with only cochlear degeneration as well as those with neural degeneration, there was a poor correlation. The results suggest that in adults with cochlear hearing loss, pure-tone thresholds can explain the variability in speech identification scores to some extent. The lower bound of 95% confidence limits can be taken as the cutoff scores to suspect retrocochlear pathology in adults.

Acoustic reflex thresholds:

Pearson product-moment correlation showed a significant (at 0.01 level) positive correlation between the acoustic reflex thresholds and pure-tone thresholds (refer Table 5 for r values) in both the groups. Figure 6 shows the number of ears with normal elevated and absent reflexes for ipsilateral and contralateral stimulation at 500 Hz, 1000 Hz, 2000

Hz and 4000 Hz. It can be observed that the probability of obtaining acoustic reflexes reduced with increase in severity of hearing loss. There is not much difference in the percentage of subjects with absent reflexes in the mild and moderate category. This is probably because acoustic reflex thresholds is not affected in a majority of the subjects with lesser degree of cochlear hearing loss as they have softness imperception and the acoustic reflex thresholds depends on the loudness perceived at high intensities. Metz (1946) was the first to report that acoustic reflex thresholds of cochlear hearing impaired ears are similar to that of normal hearing individuals. Jerger et al. (1972) concluded that acoustic reflex thresholds at sensation levels less than 60 dB are consistent with cochlear hearing loss. However, Gelfand (1983) reported that acoustic reflex thresholds are essentially unaffected by the hearing loss of less than 50 -55 dB HL and beyond 55 dB HL, the acoustic reflex threshold increases directly with the degree of hearing loss. It can also be observed that acoustic reflexes at 4000 Hz was absent in a majority of the subjects even when the degree of hearing loss was less. A number of subjects with normal hearing also did not have reflexes at 4000 Hz. Hence, checking reflexes at 4000 Hz does not have diagnostic value.

Table 5: Correlation between ART and pure-tone thresholds in adults and geriatrics

Frequency	r value (adults)	r value (geriatrics)
500 Hz (I)	0.39	0.3
500 Hz (C)	0.24	0.21
1000 Hz (I)	0.39	0.3
1000 Hz(C)	0.26	0.21
2000 Hz (I)	0.39	0.29
2000 Hz(C)	0.36	0.15
4000 Hz (I)	0.38	0.20
4000 Hz(C)	0.28	0.13

Table 6 and 7 shows the sensitivity if acoustic reflexes in identifying cochlear pathology in adults and geriatrics respectively. It can be observed that the sensitivity is relatively better for 500 Hz and 1000 Hz in both the groups. Also ART has greater sensitivity in identifying cochlear pathology when the severity of hearing loss is less than 55 dBHL.

Table 6: Sensitivity of acoustic reflexes in identifying cochlear pathology in adults

Frequencies	Mild loss	Moderate loss	Moderately severe loss	Severe loss
500 Hz (I)	47.9	52.1	37.2	9.6
1000 Hz (I)	46.3	48.5	34.5	8.0
2000 Hz (I)	37.2	33.5	19.9	2.0
4000 Hz (I)	13.2	7.2	4.7	0
500 Hz (C)	38.1	45.8	35.3	15.2
1000 Hz (C)	41.6	45.4	31.7	15.2
2000 Hz (C)	37	39	25.7	12.0
4000 Hz (C)	19	17.7	13	3.2

Table 7: Sensitivity of acoustic reflexes in identifying cochlear pathology in geriatrics

Frequencies	Mild loss	Moderate loss	Moderately severe loss	Severe loss
500 Hz (I)	56	46.8	29.0	9.3
1000 Hz (I)	62	44.8	28.5	7.5
2000 Hz (I)	58	29.9	19.5	2.5
4000 Hz (I)	28	5.3	3.8	0
500 Hz (C)	571	39.9	25.5	12.6
1000 Hz (C)	57.2	38	25.3	10.1
2000 Hz (C)	59.1	31.6	23.6	6.7
4000 Hz (C)	20.9	10.3	4.5	0

Dynamic range:

Dynamic range was measured by calculating the difference between an individual's uncomfortable level for speech and speech reception threshold. Based on the analysis of normal results, dynamic range of less than 90 dB was considered as reduced dynamic range. Figure 7 shows the percentage ears with reduced dynamic range in both the groups. Reduced dynamic range observed in the present study reinforces that concept that in subjects with cochlear pathology, perception of soft signals is affected whereas perception of loud signals is normal. The term "recruitment" was earlier used to describe this phenomenon, however Florentine (2003) proposed the term "softness imperception" to explain this phenomenon. The sensitivity of this test in identifying cochlear pathology decreased with increase in severity of hearing loss in adults whereas this was not true in geriatrics. Table 8 shows the sensitivity values for clients with different severity of hearing loss.

Table 8: Sensitivity of dynamic range in identifying cochlear pathology

Degree of hearing loss	Sensitivity in adults	Sensitivity in geriatrics
Mild	49.6	22.6
Moderate	35.8	39.5
Moderately severe	37.2	39.4
Severe	32.4	42.1
Profound	27.6	30.8

Summary and conclusions

An audiologist includes audiologcal tests in a test based upon its sensitivity and specificity. The sensitivity and specificity of a test or a test battery depends on the criteria used for interpretation. At present, there is a lack of uniformity among audiologists in the criteria used for diagnosis of auditory disorders. The present investigation was undertaken to study the sensitivity and specificity of some of the audiological tests in differential diagnosis of auditory disorders at the All India Institute of Speech and Hearing, Mysore. Sensitivity and specificity of strict and loose criteria for test battery consisting of various tests were studied. The investigation also aimed at recommending test protocols for identification of different auditory disorders.

A retrospective analysis of the results of the audiological and otorhinolaryngological evaluation was carried out. Data from 2485 ears with normal hearing, 2372 ears with conductive hearing loss, 3229 ears with sensorineural hearing loss and 1980 ears with had mixed hearing loss were considered for analysis. The audiological tests evaluated included pure-tone audiometry, speech audiometry and immittance evaluation.

The following conclusions were drawn from the results of the present study:

* Test battery of pure-tone audiometry, tympanometry and acoustic reflexes is helpful in identifying otitis media with effusion and otosclerosis
* Otitis media can be suspected if the client has B or C type of tymapnogram and acoustic reflexes are absent. Immittance evaluation may suggest middle ear infection even when the audiometric results are within normal results. If As type of tymapnogram is used as a criterion to suspect otitis media with effusion, the lower cut off for admittance at the tympanic membrane should be 0.3 ml.
* Single component low frequency tympanometry and admittance at the tympanic membrane does not help in identification of otosclerosis. Otosclerosis can be suspected if the audiological results show A or As type of

tympanogram with absent acoustic reflexes in a client with conductive or mixed hearing loss.

* Tymapnometry is not a good tool for identifying individuals with Eustachian tube malfunction. One needs to evaluate the efficacy of special tests such as pressure swallow test in identifying individuals with Eustachian tube malfunction.
* There is a significant effect of age and degree of hearing loss on speech identification scores in subjects with sensorineural hearing loss
* Two simple and quick measures of identifying cochlear pathology, which can be administered in both unilateral as well as bilateral hearing loss are Metz recruitment test and dynamic range. These two tests have do not have good sensitivity in identifying cochlear pathology. The sensitivity is relatively higher for subjects with hearing loss of less than 55 dB HL. The sensitivity of this test is less as the maximum intensity of the signal that is available in the instrument limits the number of subjects in whom these measures can be checked.

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