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Speech in noise: a practical test procedure

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Abstract
A simple and effective speech in noise test is described with clinical findings for patients with normal hearing, cochlear and retrocochlear pathologies and auditory dysacusis. The test utilizes material readily available in Audiology and ENT Departments. It was possible to obtain useful diagnostic information in patients who complain of hearing loss, but who demonstrate normal audiometric thresholds and normal speech in quiet discrimination.

Introduction

Perception of speech is fundamental to linguistic interaction among individuals and is affected by hearing impairment. Research has demonstrated that persons with sensorineural hearing loss experience greater difficulty in understanding speech in noise (Tillman *et al.*, 1970; Cooper and Cutts, 1971; Shapiro *et al.*, 1972; Findlay, 1976; Plomp, 1978), with Acton (1970) being the only investigator to report contradictory findings. As the signal to noise (S/N) ratios become less favourable, the effects on speech discrimination are more pronounced for the sensorineural hearing impaired subjects. It has been reported that persons with sensorineural hearing loss require 30 dB more intense speech compared with normals to achieve 40 per cent discrimination (Tillman *et al.*, 1970). A common observation in studies of speech discrimination in noise in normals was that discrimination scores for monosyllables in noise manifest great variation in comparison with the scores in quiet, but such variability has been even greater for the hearing impaired (Keith and Talis, 1972; Olsen *et al.*, 1975).

Threshold of hearing measured by pure tone audiometry is one of the many factors which influence perception of speech. Present routine methods of testing speech discrimination are all performed in quiet with as little interfering noise as possible (Boothroyd, 1968). The measures obtained under these optimal listening conditions are, very frequently, not comparable with the patients self reported disability, especially in the presence of competing background noise. A speech discrimination test which would provide fast and reliable clinical measurements of the patients capability to recognize speech in a noisy environment is of practical importance although assumptions will have to be made regarding the external validity of the results. Such a test would have important clinical applications in such areas as predicting the benefit of hearing aids (Plomp, 1978), in assessing job suitability and medico legal work (Lutman *et al.*, 1986), in hearing aid fitting and as a test for quantifying the degree of impairment in patients with dysacusis.

Hagerman (1982, 1984) investigated a Swedish sentence test in noise (noise, synthesized from speech material to have the same long term spectrum as speech: speech presented at 65 dB SPL with ± 3 dB S:N ratio) and obtained a very steep intelligibility curve (25 per cent per dB at the maximum) for the normal hearing subjects. However, monosyllabic word lists generally give greater threshold shifts in noise than sentence lists in subjects with a hearing loss, probably because the former does not provide linguistic cues to the same extent as the latter. It could be deduced from this that the performance scores on monosyllabic words are more sensitive indicators of discrimination in noise than scores on sentences. Tests using sentence lists may also impose a demand on the linguistic ability of the patients thus yielding confounded results. For these reasons a monosyllabic word test in noise would be a more appropriate choice in assessing the difficulty the hearing impaired may experience in noise.

It is the considered opinion of many that it is impossible to design a fixed signal to noise (S/N) ratio test that would be applicable for a wide range of subjects (Lutman, 1987) without ceiling or floor effects. This would be so as long as the emphasis is on presenting speech at suprathreshold levels and to equate absolute levels of speech and noise for equal sensation levels (85 dB sound pressure level (SPL) of speech, for example, has the same sensation level as 85 dB SPL noise). This could be overcome by testing the patients with several intensities of noise at the half peak speech discrimination score in quiet and then comparing their performance at a predetermined level of competing noise.

Many researchers have investigated the potential of speech discrimination scores in white noise as a diagnostic indicator of abnormality at different levels of the auditory pathway. Most of these investigations have employed monosyllabic words presented at a high sensation level (SL) of 40 dB with reference to the speech reception threshold (SRT) with white noise as competing stimulus at an overall sound pressure level (SPL) equal to, or 10 dB less than that of the primary signal. Abnormal findings have been reported for the speech in noise task in ears with

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Menière's disease (0 dB S/N—Olsen *et al.*, 1975), in ears ipsilateral to VIIIth nerve lesions (Katinsky *et al.*, 1972; Olsen *et al.*, 1975), in one or both ears of patients with intra-axial lesions (0 and 5 dB S/N—Morales-Garcia and Poole, 1972; 0 dB S/N—Noffsinger *et al.*, 1972), in patients with multiple sclerosis (+10 dB S/N—Dayal *et al.*, 1972; Noffsinger *et al.*, 1972), in both ears of split brain patients, with poorer scores on the left compared with the right ear (Musiek *et al.*, 1979), and in ears contralateral to temporal lobe pathologies (Sinha, 1959; Morales-Garcia and Poole, 1972; Heilman *et al.*, 1973; Olsen *et al.*, 1975).

Olsen *et al.* (1975) reported, in what has been regarded as a definitive investigation of the site of lesion and speech in noise findings (Rintelmann, 1985) results of a speech in noise test (0 dB S/N ratio) for six groups of normal, noise trauma, Menière's disease, VIIIth nerve tumour, multiple sclerosis and temporal lobe lesion. The results were not suggestive of cochlear-retrocochlear differentiation and the authors concluded that the clinical significance of speech in noise tests is not helpful in suggesting a particular site of involvement.

In almost all the tests above, the investigators have chosen to present the primary message at a high sensation level (40 dB SL) and white noise at the same level or 10 dB less than speech. This does not guarantee 0 dB or +10 dB S/N ratio because the sensation level for speech and noise differ. As an illustration, consider a patient with a SRT of 45 dB A and noise detection threshold of 15 dB A. This patient would perceive speech and noise at 40 and 65 dB respectively when the two stimuli are presented at 0 dB S/N ratio (presentation level of 80 dB SPL, for example). Another patient with a SRT of 45 dB and noise detection threshold of 10 dB would receive the two signals at different sensation levels in this instance. In other words, identical dial settings for all patients for speech and noise (measured in SPL), as in the above studies, do not guarantee a 0 dB S/N ratio (measured in sensation level).

Furthermore, most studies above have obtained discrimination scores at fixed S/N ratios (0 or +10 dB). Testing speech discrimination at a single presentation level does not ensure that it is the patient's best performance, unless the scores approximate to 100 per cent (Carhart, 1965). Therefore, in a situation where the maximum discrimination scores for the different clinical populations were not equal (Olsen *et al.*, 1975), it would be difficult to equate a drop of 40 percentage points in speech discrimination from 85 to 45 with a drop of 40 percentage points from 98 to 58. Therefore, the purpose of this study was to

1) develop a protocol for fast and reliable measurements of speech discrimination in noise, using monosyllables, and then to evaluate the performance of normals and hearing impaired on this protocol,
2) determine a speech in noise threshold level which would differentiate among normal, conductive, cochlear, acoustic neuroma and dysacusis groups, and
3) to correlate the speech in noise scores with 3-frequency and 4-frequency pure tone averages and to see if speech in noise scores can be predicted from these.

Method

A group of 30 normals (60 ears, 22 male and 38 females), with an age range of 15–62 years (mean age: 35.7 years), with no history of either audiological or otological pathology, provided the normative data for comparison. Pure tone thresholds for normals were no poorer than 20 dB for frequencies from 250 Hz to 8 KHz and all had maximum speech discrimination score of 100 per cent in quiet. Four clinical populations consisting of conductive loss (10 patients, 16 ears; 10 males and six females, mean age: 40.8 years), cochlear hearing loss (34 subjects, 57 ears; 32 males and 25 females, mean age: 47.7 years), a group of 10 patients with unilateral acoustic neuroma (six males and four females, mean age 50.7 years) and a group of 10 patients with auditory dysacusis (18 ears, six males and 12 females, mean age 28.5 years) were tested. Auditory dysacusis is defined as a difficulty in hearing speech in noise when otologically the patients appear normal with normal pure tone audiogram and normal speech discrimination scores in quiet. The diagnosis in each case was confirmed by diagnostic audiology and Magnetic Resonance Imaging (MRI) when necessary.

Each subject underwent a preliminary test battery consisting of speech pattern noise (SPN) threshold detection, and speech discrimination in quiet. All testing was done in a sound proof room. Speech discrimination testing was done using tape recorded isophonemic word lists (Boothroyd, 1968). The speech signal was presented at five levels although more were used as required to specify the complete form of the curve and to identify roll over. The nontest ear was excluded by suitable levels of masking. From this data half peak threshold, defined as the intensity at which a subject scores 50 per cent of his maximum, was determined for each individual and for each ear.

Speech discrimination testing in noise was performed. The speech signal was presented at half peak threshold level along with SPN at threshold level to the same ear and the discrimination score obtained. Thereafter, keeping the speech level constant, the signal to noise (S:N) ratio was progressively decreased in 5 dB steps till the subject gave a discrimination score of 0 per cent. All speech tests was done monaurally through a audiometer (GSI 16) with a Marantz BX125E tape recorder. SPN was calibrated in effective masking level and consisted of equal energy per Hz from 250 Hz to 1 kHz with a 12 dB/octave roll-off 1 kHz to 6 kHz.

Results

The mean audiometric thresholds, mean half peak scores, mean SPN detection thresholds and the mean of the maximum speech discrimination scores in quiet are given in Table I with the corresponding standard deviations. Patients with dysacusis had essentially normal sensitivity and speech discrimination in quiet. Only subjects in the acoustic neuroma group failed to achieve 100 per cent maximum speech discrimination score in quiet.

The mean speech discrimination scores as a percentage of half peak level in noise, for the five groups, are given in Table II. As speech testing in noise was started at half peak level (50 per cent of the subjects maximum), and since some of the subjects scored a maximum of less than 100 per cent, it was necessary to convert these scores into percentages relative to the level at which the test was initiated for each subject. This was necessitated only in the case of subjects in the acoustic neuroma group as can be seen in Table I. The scores were converted into z scores using the

TABLE I

SHOWING THE MEAN PURE TONE THRESHOLDS, MEAN SPEECH PATTERN NOISE (SPN) DETECTION THRESHOLDS (IN dB), MEAN 3- AND 4-FREQUENCY PURE TONE AVERAGES (PTA), MEAN HALF PEAK DISCRIMINATION SCORES (HPLE) AND MEAN OF THE MAXIMUM SPEECH DISCRIMINATION SCORES IN QUIET FOR THE FIVE GROUPS AND THE STANDARD DEVIATION (SD).

Subjects	250	500	1K	Frequencies 2K	4K	8K	3PTA	4PTA	SPN	HPLE	Max. Disc(%)
Normals											
Mean	10.4	8.1	5.4	3.2	5.6	10.2	5.6	5.7	0.9	15.9	100.0
SD	6.8	7.0	5.6	5.3	9.3	10.5	4.5	4.9	2.4	5.2	
Conductive											
Mean	30.3	25.0	23.4	26.8	38.4	47.5	25.2	28.5	19.06	37.1	100.0
SD	14.3	12.2	11.5	17.2	21.8	26.1	12.1	13.8	7.89	10.5	
Cochlear											
Mean	33.2	31.5	31.7	35.6	49.0	56.3	33.4	37.3	22.28	40.0	100.0
SD	22.6	25.8	25.6	23.8	27.9	27.0	23.7	23.3	11.68	21.9	
Acoustic Neuroma											
Mean	49.0	45.5	48.0	50.0	50.0	61.1	47.9	51.2	33.50	55.1	94.0
SD	22.8	24.3	30.4	28.5	16.0	16.5	26.8	26.9	12.4	24.7	12.7
Dysacusis											
Mean	13.3	10.3	7.5	6.6	6.6	7.8	8.3	7.8	4.16	14.6	100.0
SD	8.0	8.8	6.9	7.5	7.7	9.8	6.7	7.8	2.4	4.9	

formula z = (x−y)/x(100) where 'x' denotes the half peak level and 'y' the drop in speech discrimination score at each noise level. These 'z' scores indicate the percentage of half peak discrimination score achieved at each of the noise levels and are plotted in Figure 1.

Figure 1 shows the percentage drop in discrimination from the half peak level with the introduction of noise. In the case of normals, with noise at SPN detection threshold there was a drop of 8 per cent from the half peak level, progressively decreasing with steepest gradient of 35.2 per cent with increase in noise from 10 dB to 15 dB. In other words, the maximum steepness was 7.04 per cent/dB which is slightly higher than the 4 per cent/dB reported for discrimination in quiet for this material (Boothroyd, 1968). The curve for the conductive loss group overlaps the curve for normals. The steepest gradient was observed with the introduction of noise at the threshold level for the cochlear, acoustic neuroma and dysacusis groups and were 4.9, 11.4 and 12.85 per cent/dB, respectively.

The mean percentage of the half peak level discrimination scores at different levels of noise (these scores when subtracted from 100 give the percentage drop in speech discrimination from the half peak level) are given in Table II for the five groups. As could be expected from the intelligibility curves in Figure 1 there was no significant difference between the mean discrimination scores as a percentage of half peak level of normal and conductive groups at any of the noise levels. However, all the remaining intergroup differences in means were significant at the 0.005 level for an one-tailed distribution except at 20 dB noise for the conductive-cochlear and at 15 dB for the cochlear-acoustic neuroma group difference which were not significant.

The results in Table II indicate that the introduction of SPN at the threshold level will result in a small fall in discrimination (8 per cent of half peak level) in the case of normal and conductive loss groups while it falls by a much greater amount (50–64 per cent of half peak level) in the other hearing impaired groups. The magnitude of the decrease in half peak speech discrimination level is even greater with increase in the level of noise (at 5 dB: normals 21.8 per cent, conductive 25.6 per cent, cochlear 49.5 per cent, acoustic neuroma 80 per cent, and dysacusis 87 per cent) and the intergroup difference in the decrease in discrimination is significant for all comparisons bar that between normal and conductive groups, and that between

TABLE II

SHOWING THE MEAN DISCRIMINATION SCORES AS A PERCENTAGE OF HALF PEAK LEVEL AND STANDARD DEVIATIONS (SD) AT DIFFERENT NOISE LEVELS

	Noise level (in dB) 0	5	10	15	20	25	30	35
Normals								
Mean	92.0	78.2	56.5	21.3	5.8	0.8	0.2	0.0
SD	11.0	18.5	26.1	27.3	17.8	4.2	1.7	
Conductive								
Mean	92.1	74.4	56.8	19.4	9.9	3.4	0.0	
SD	11.9	22.3	25.8	20.7	17.3	7.4		
Cochlear								
Mean	75.6	51.5	27.5	7.8	1.1	0.0		
SD	26.1	30.1	26.0	16.4	4.2			
Acoustic Neuroma								
Mean	42.8	20.0	8.0	0.6	0.0			
SD	17.3	17.2	15.5	1.9				
Dysacusis								
Mean	36.0	13.0	0.0					
SD	15.7	10.6						

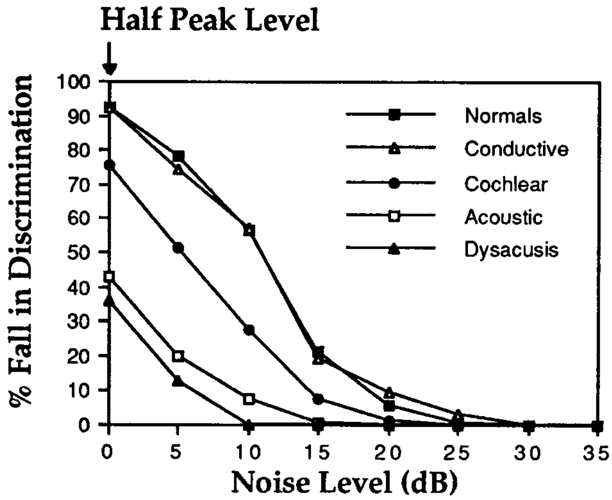

FIG. 1

Showing the mean percentage fall in speech discrimination from the half peak level with the introduction of SPN in the clinical groups. 3PTA is an average of thresholds at 0.5, 1 and 2 kHz, 4PTA is an average of thresholds at 0.5, 1, 2 and 4 kHz.

TABLE III

SHOWING THE T-SCORES FOR THE SIGNIFICANCE OF DIFFERENCE BETWEEN MEAN DROP IN DISCRIMINATION SCORES FROM THE HALF PEAK LEVEL AT DIFFERENT NOISE LEVELS. THE T-SCORES HAVE BEEN OBTAINED BY CORRECTING FOR BONFERRONI'S INEQUALITY SO THAT MULTIPLE COMPARISONS COULD BE MADE. THE SIGNIFICANCE LEVEL (0.05) WAS DIVIDED BY A FACTOR OF 10 (THE NUMBER OF COMPARISONS THAT COULD BE MADE AT EACH NOISE LEVEL) TO GET A NEW SIGNIFICANCE LEVEL OF 0.005 FOR MULTIPLE COMPARISONS

	Noise level (in dB)				
	0	5	10	15	20
Normal v Conductive	0.02*	0.52*	0.05*	0.30*	1.06*
Normal v cochlear	4.78	5.59	6.31	3.26	1.9
Normal v acoustic neuroma	7.88	6.17	6.07	–	–
Normal v dysacusis	11.24	9.39	–	–	–
Conductive v cochlear	3.33	3.31	4.16	1.83*	2.28*
Conductive v acoustic neuroma	6.7	4.99	5.16	–	–
Conductive v dysacusis	8.79	7.05	–	–	–
Cochlear v acoustic neuroma	5.29	3.14	2.64	–	–
Cochlear v dysacusis	7.89	5.51	–	–	–
Acoustic neuroma v dysacusis	0.82*	1.04*	–	–	–
Degrees of freedom	157	157	140	131	131

*not significant at 0.005 level, two-tailed test.

acoustic neuroma and dysacusis groups (at 0.005 level for a two-tailed distribution) (Table III).

Relation to tone thresholds

In order to investigate further the relationship between puretone audiometric data and the speech in noise scores, Spearman Rank order difference correlation coefficients were calculated between 3-frequency average (500 Hz, 1 and 2K) and speech in noise scores as well as between 4-frequency average (500 Hz, 1, 2 and 4K) and speech in noise scores. The results are given in Table IV together with correlation coefficients between 3- and 4-frequency averages and 50 per cent level in quiet. The results show a significant positive correlation between puretone averages and 50 per cent discrimination score in quiet (one per cent level) but no significant correlation between pure tone averages and speech in noise scores. Table IV also shows the absence of any significant correlation between speech in quiet (50 per cent level) scores and speech in noise scores.

Differential diagnosis

Figure 2 is an histogram of the distribution of the percentage drop in discrimination scores from half peak level scores at the 5 dB noise level. It shows that speech discrimination falls below 60 per cent of half peak level in the case of all the dysacusis and acoustic neuroma patients and in about 31 per cent of the cochlear group.

Another result from Figure 2 was that it enabled specification of a criteria for the differential diagnosis of cochlear and retrocochlear disorders. Specifying a criterion of a drop of 60 per cent score at half peak level at the 5 dB noise level would give us a hit rate of 100 per cent for the acoustic neuroma group, but a high false alarm rate of 31.6 per cent for the cochlear disorders. Further, the difference in the mean drop in discrimination score from the half peak level with the introduction of SPN is significant between the cochlear and the retrocochlear groups.

Discussion

One of the characteristics of intelligibiltiy curves for the three hearing impaired groups (other than conductive loss) was their steeper gradient compared with normals. The steepness of these curves indicated that speech discrimination in the presence of noise falls rapidly in the case of cochlear, acoustic neuroma and dysacusis groups compared with the normals. The steepest fall was in the case of dysacusis patients. Although this indicated that the patients in the hearing impaired categories other than conductive loss have problems in discriminating speech in the presence of noise, the high standard deviation around the mean (and the broad range of scores within each group) make the relationship an imperfect one. However, an analysis of the distribution of the scores at each noise level indicated that testing patients at 5 dB SL would clearly differentiate patients who would experience difficulty in noise from those who will not. Patients with hearing impairment other than conductive loss, are more likely to show a drop from half peak level of 50–87 percentage points in their discrimination at 5 dB noise compared with an average of 21 per cent in normals. This is statistically significant (0.005 level) despite the large intragroup variability in scores.

There is a statistically significant difference between the drop in discrimination scores from the half peak level in noise for the normal, cochlear and the acoustic neuroma

TABLE IV

SHOWING THE SPEARMAN RANK ORDER DIFFERENCE CORRELATION BETWEEN THE 3-FREQUENCY (3 PTA), 4 FREQUENCY (4 PTA) PURETONE AVERAGE, HALF PEAK DISCRIMINATION SCORE IN QUIET (HPLE) AND THE SPEECH IN NOISE SCORE (DROP IN DISCRIMINATION SCORE FROM THE HALF PEAK LEVEL AT DIFFERENT LEVELS OF NOISE). ALL THE CORRELATIONS BETWEEN PURE TONE AVERAGES (3 PTA AND 4 PTA) AND HPLE IN QUIET ARE SIGNIFICANT EXCEPT THE 4 PTA SCORE FOR THE ACOUSTIC NEUROMA GROUP

	HPLE	0 dB	5 dB	10 dB	15 dB	20 dB	25 dB
Normals (df:59)							
3PTA	0.33*	−0.13	−0.28	−0.05	0.09	0.34*	0.45*
4PTA	0.51*	−0.17	−0.20	−0.18	−0.01	0.28	0.45*
HPLE	–	−0.13	−0.31	−0.32	−0.23	−0.20	0.39*
Conductive (df:14)							
3PTA	0.89*	0.73*	0.32	0.19	0.22	0.34	0.16
4PTA	0.83*	0.76	0.33	0.21	0.2	0.3	0.25
HPLE	–	0.66*	0.16	0.03	−0.02	−0.21	0.11
Cochlear (df:55)							
3PTA	0.91*	0.21	0.09	0.08	0.21	0.48*	
4PTA	0.89*	0.12	0.02	0.04	0.23	0.48*	
HPLE	–	0.1	0.00	0.04	0.14	0.45*	
Acoustic Neuroma (df:8)							
3PTA	0.74*	0.66	0.64	0.79*			
4PTA	0.71	0.69	0.61	0.79*			
HPLE	–	0.42	0.29	0.42			
Dysacusis (df:16)							
3PTA	0.78*	0.01	−0.34				
4PTA	0.78*	0.06	−0.29				
HPLE	–	0.05	−0.21				

* = correlation significant at 0.01 level, two-tailed distribution.
d.f. = degrees of freedom.

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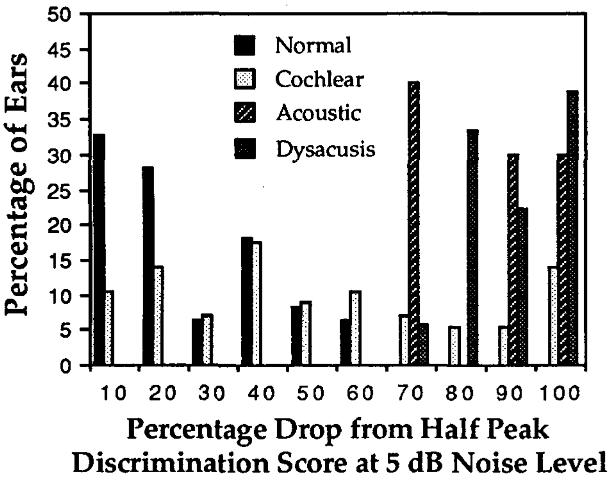

FIG. 2

Distribution curves for speech in noise discrimination tests. The percentage drop in discrimination from the half peak level with the introduction of noise is divided into 10 ranges: 0–10, 11–20 etc. Note that the shape of the distributions differs significantly from Gaussian with equal variance.

diagnostic groups. The authors do not suggest that speech in noise be used routinely as a procedure for cochlear-acoustic neuroma differential diagnosis due to the accuracy of other test procedures, notably auditory brainstem responses (House and Brackmann, 1979; Cashman *et al.*, 1983; Moffat *et al.*, 1989), though it might be useful in the absence of such techniques. Speech in noise testing using this protocol does give a better hit rate for acoustic neuroma than other previously reported speech discrimination tests (Turner *et al.*, 1984). It should be noted that there is considerable overlap between the cochlear and retrocochlear group, and that this will give rise to poor sensitivity and specificity ratings. That a proportion of patients with cochlear hearing loss give very poor speech in noise scores may be due to retrograde degeneration in the VIIIth nerve in association with cochlear pathology.

The speech discrimination score in noise gives a new and important perspective upon hearing impairment particularly as it is not corrrelated to the audiometric thresholds. In other words, the drop in discrimination score from half peak level in noise cannot be predicted from either the puretone threshold or discrimination score in quiet. The speech discrimination score in quiet is, however, well related to both the 3-frequency and 4-frequency puretone averages. It is suggested therefore that the speech discrimination score in noise is more sensitive to auditory impairment (excluding conductive loss) than that in quiet. It is this finding which may be useful in some patient assessment for hearing aids, or more rarely in medico-legal investigation of auditory impairment.

The confirmation of auditory abnormality in patients complaining of dysacusis with speech in noise unfortunately does not avail information as to the cause of that disorder. Identification of these patients will however allow for more detailed study of their condition, and then identification of the site of the lesion.

The test seems to be especially well-suited to give information on the hearing impairment of people who have very high discrimination scores in quiet. However, we have not tested any patients who had very poor discrimination scores in quiet. The lowest of the maximum discrimination score in quiet studied here was 57 per cent in the case of a patient with an acoustic neuroma.

We have repeatedly mentioned the large intragroup variability despite the significance of difference of the means. Perhaps a factor which could minimize this variability is the accurate measurement of the half peak level. Even a difference ± 1 dB could make a substantial difference in the discrimination score in the presence of noise. The factors of the age and sex of the patients tested has not been considered in the analysis, and these have been shown to have an effect upon other auditory tests, such as auditory brainstem responses (Abramovich, 1990). The use of two ears from some patients may have amplified this influence. Further analysis will consider the effect of these factors.

This test does not require equipment over and above that found in nearly all Audiology clinics. Neither does it require a large amount of time or effort on behalf of the patient or the tester, the maximum time of testing in this study being 10 mins more than normal speech audiometry. This test does, however, yield important information about the auditory system in a situation very similar to normal listening.

This study indicates that it is possible to obtain useful diagnostic information in patients complaining of hearing loss, who demonstrate normal audiometric thresholds and normal speech in quiet discrimination.

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References

Abramovich, S. J. (1990) *Electric Response Audiometry in Clinical Practice*. Churchill Livingstone, London.

Acton, W. I. (1970) Speech intelligibility in a background noise and noise induced hearing loss. *Ergonomics*, **13:** 546–554.

Boothroyd, A. (1968) Developments in speech audiometry. *Sound* **2:** 3–10.

Carhart, R. (1965) Problems in the measurement of speech discrimination. *Archives of Otolaryngology*, **82:** 253–260.

Cashman, M. Z., Rossman, R. N., Nedzelski, J. M. (1983) Cerebellopontine angle lesions: an audiological test protocol. *Journal of Otolaryngology*, **12:** 180–186.

Cooper, J. C. Jr., Cutts, B. P. (1971) Speech discrimination in noise. *Journal of Speech and Hearing Research*, **14:** 332–337.

Dayal, V. S., Tarantino, L., Swisher, L. P. (1966) Neuro-otologic studies in multiple sclerosis. *Laryngoscope*, **76:** 1798–1809.

Findlay, R. C. (1976) Auditory dysfunction accompanying noise induced hearing loss. *Journal of Speech Hearing Disorders*, **41:** 374–380.

Hagerman, B. (1982) Sentences for testing speech intelligibility in noise. *Scandinavian Audiology*, **11:** 79–87.

Hagerman, B. (1984) Clinical measurement of speech reception threshold in noise. *Scandinavian Audiology*, **13:** 57–63.

Heilman, K. M., Hanner, L. C., Wilder, B. J. (1973) An audiometric defect in temporal lobe dysfunction. *Neurology*, **23:** 384–386.

House, J. W., Brackmann, D. E. (1979) Brainstem audiometry in neurotologic diagnosis. *Archives of Otolaryngology*, **105:** 305–309.

Katinsy, S., Lovrinic, J., Buchheit, W. (1972) Cochlear findings in VIIIth nerve tumours. *Audiology*, **11:** 213–218.

Keith, R. W., Talis, H. P. (1972) The effect of white noise on PB scores of normal and hearing impaired listeners. *Audiology*, **11:** 117–125.

Lutman, M. E. (1987) In Speech Audiometry (Martin, M., ed). Taylor and Francis: London, p. 63–73.
Lutman, M. E., Brown, E. J., Coles, R. R. A. (1986) Self reported disability and handicap in the population in relation to pure tone threshold, age, sex and type of hearing loss. *British Journal of Audiology,* **21:** 45–58.
Moffat, D. A., Hardy, D. G., Baguley, D. M. (1989) The strategy and benefits of acoustic neuroma searching. *Journal of Laryngology and Otology,* **103:** 51–59.
Morales-Garcia, C., Poole, J. O. (1972) Masked speech audiometry in central deafness. *Acta Otolaryngologica,* **74:** 307–316.
Musiek, F. E., Wilson, D. H., Pinheiro, M. L. (1979) Audiological manifestations in 'split brain' patients. *Journal of the American Audiology Society,* **5:** 25–29.
Noffsinger, P. D., Olsen, W. O., Carhart, R., Hart, C. W., Sahgal, V. (1972) Auditory and vestibular abberations in multiple sclerosis. *Acta Otolaryngologica,* **Supplement 303:** 1–63.
Olsen, W. O., Noffsinger, D., Kurdziel, S. (1975) Speech discrimination in quiet and in white noise by pateints with peripheral and central lesions. *Acta Otolaryngologica,* **80:** 375–382.
Plomp, R. (1978) Auditory handicap of hearing impairment and the limited benefit of hearing aids. *Journal of the Acoustical Society of America,* **63:** 533–549.
Rintelmann, W. F. (1985) In *Assessment of central auditory dysfunction: Foundations and clinical correlates* (Pinheiro, M. L. and Musiek, F. E., Eds), Williams and Wilkins: Baltimore. p. 173–200.
Shapiro, M. T., Melnik, W., VerMuelen, N. (1972) Effects of modulated noise on speech intilligibility of people with sensorineural hearing loss. *Annals of Otology, Rhinology and Laryngology,* **81:** 241–248.
Sinha, S. O. (1959) The role of the temporal lobe in hearing. Thesis: McGill University, Canada.
Tillman, T. W., Carhart, R., Olsen, W. O. (1970) Hearing aid efficiency in a competing speech situation. *Journal of Speech Hearing Research,* **13:** 789–811.
Turner, R. G., Shepard, N. T., Frazer, G. J. (1984) Clinical performance of audiological and related diagnostic tests. *Ear and Hearing,* **5:** 187–194.

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