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HOW DEAF IS TOTALLY DEAF? A CASE STUDY

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ABSTRACT

The speech perception and production skills of a subject with an average hearing loss greater than 120 dB HTL were measured in an attempt to determine whether the subject derived benefit from a high-powered hearing aid (H.A.I.C. M.P.O. — 147 dB SPL). Materials used ranged in complexity from vowel and consonant recognition to sentence perception. The scores obtained indicated that the subject derived significant benefit from hearing aid use. The auditory information available to the subject appears to be limited to low frequency cues enabling reliable identification of the first formants of vowels, consonant voicing and, to a lesser extent, consonant manner of articulation. This information enabled limited perception of open set words and sentences via audition alone and resulted in significant improvements in auditory-visual perception of the sentence materials. The significance of the results for hearing aid selection with profoundly deaf persons is discussed.

INTRODUCTION

The past 15 years have seen a rapid development in the availability of devices providing acoustic information to persons with profound hearing losses. High powered hearing aids have provided assistance to many persons who were previously considered unsuitable for hearing aid use (Owens et al, 1982; Fujikawa and Owens, 1978). For those persons who derive little benefit from conventional hearing aids the development of single and multi-channel cochlear implants (Hochmair-Desoyer et al, 1985; Fourcin et al, 1982; Clark et al, 1984; House, 1976) and vibrotactile aids (Franklin, 1984, Spens and Plant, 1983) have resulted in significant improvements in visual speech perception (Plant, 1986; Robbins et al, 1985; Clark et al, 1984, 1983). Some subjects using multi-channel cochlear implants also receive some open set speech recognition via electrical stimulation without lipreading cues (Clark et al, 1984; Miller et al, 1984).

The availability of alternative devices for the profoundly deaf has high-lighted the need for the development of procedures to assist in the selection of the appropriate device for individual cases. Martin (1986) believes that with "the introduction of cochlear implants, and to a lesser extent the greater availability of very high powered hearing aids, it now has become of considerable importance to produce an agreed operational definition of total deafness (Martin, 1986; p. 85). He proposes that "a person with normal or near normal middle ear function shall be deemed to be totally deaf for acoustic stimulation if a valid response (not tactile) cannot be elicited at 130 dB HL in the range 500 to 4,000 Hz or at the maximum output of the same audiometre at lower frequencies. If responses are obtained for less than three frequencies at 120 dB HL or greater (or equivalent maximum values at low frequencies) that person will also be deemed to be totally deaf" (Martin, 1986; p. 88). It would appear that Martin (1986) believes that a person with a total hearing loss would not benefit from hearing aid use but could be a suitable candidate for cochlear implantation or the use of a vibrotactile aid.

Other definitions of total deafness are not as rigorous as that proposed by Martin (1986), Fujikawa and Owens (1978) for example define total hearing loss as "an absence of measurable hearing from 500 to 8,000 Hz with minimal or no hearing at 250 or 125 Hz on audiometers with limits of 110 dB HL from 500 to 4,000 Hz, 90 dB at 8,000 and 250 Hz and 80 dB at 125 Hz "(Fujikawa and Owens, 1978; p. 446). Fujikawa and Owens (1978) found that when hearing aid evaluation were carried out with 18 subjects who met their criteria for total deafness only "8 were unable to use an aid to advantage" (Fujikawa and Owens, 1978; p. 446). They concluded that it was "important that all persons with total postlingual hearing loss be afforded the opportunity of a careful hearing aid evaluation "(Fujikawa and Owens, 1978; p. 446). The criteria adopted by House et al (1979) to select candidates for cochlear implantation were unaided responses "no better than 90 dB HL at 500 Hz, 100 dB at 1,000 Hz and 110 dB at 2,000 Hz" (House et al, 1979; p. 177). They also stipulated that the subjects must also be unable to "obtain a speech reception threshold on a closed set of spondees using an appropriate hearing aid" (House et al, 1979; p. 177). Determining what constitutes an appropriate hearing aid for individual profoundly deaf subjects, however, creates many difficulties. Comparatively little research has been conducted in this area despite the obvious need to develop effective fitting procedures for the profoundly deaf. Newall et al (1986) have commented that "although there is a substantial body of knowledge about the amplification requirements of the mildly and moderately hearing impaired, far less attention has been given to the requirements of the very severely and profoundly hearing impaired". This paper presents results for a subject who would be classified as being totally deaf if audiometric data were used as the sole criterion for selection. The subject's speech perception skills using an extremely high powered hearing aid, however, indicated that he was utilising auditory information at a very high performance level. Testing was undertaken with this subject to determine the extent of his auditory capabilities and the results of this testing are presented in this paper.

METHOD

Subject

The subject of this study is a 34 year old male with a diagnosis of familial cochlear otosclerosis. He first attended the Commonwealth Acoustic Laboratories (now the National Acoustic Laboratories) in 1963 following referral

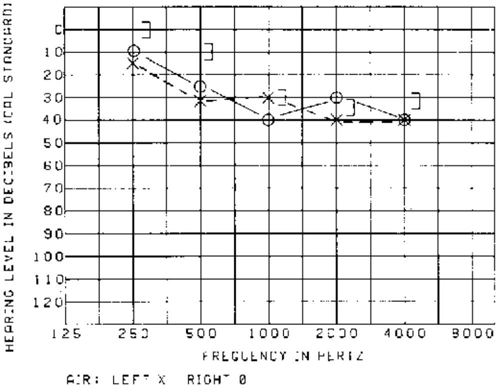

Figure 1: The Subject's unaided audiogram in 1963 (CAL standard).

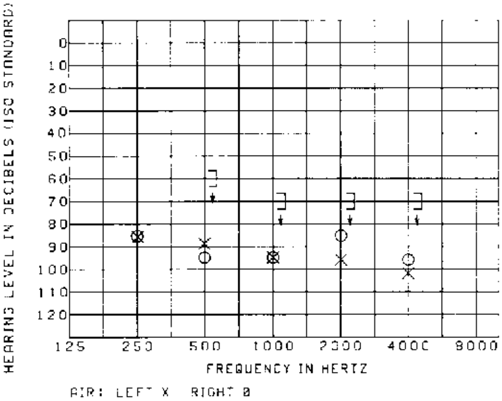

Figure 2: The subject;s unaided audiogram in 1971 (I.S.A. standard).

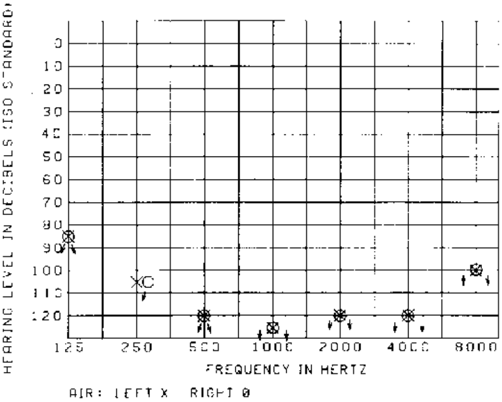

Figure 3: The subject's unaided audiogram in 1985 (I.S.O. standard).

from his otologist. At that time he was aged 11 years and presented with a mild predominantly sensorineural loss bilaterally (Figure 1). By 1971 testing revealed a severe to profound sensorineural loss in both ears (Figure 2). In 1972 he underwent exploratory surgery to the right ear when a partial stapedectomy was achieved (Willis, 1985). Testing conducted in 1985 showed a profound sensorineural loss bilaterally with the only response to air conduction testing being 105 dB HTL at 250 Hz in the left ear (Figure 3). There were no responses to bone conduction from either mastoid at the limits of the audiometer. In seeking responses beyond the audiometer's limits an insert outputs were 135 dB SPL at 250 Hz; 130 dB SPL at 500 1,000 and 2,000 Hz and 110 dB SPL at 4,000 Hz. Responses could only be elicited from the left ear at 125 dB SPL at 250 Hz and 130 dB SPL at 500 Hz. All audiometric testing was performed within an NAL hearing centre utilising a sound treated test booth.

Sound field aided thresholds were also obtained at the subject's preferred listening level. The subject currently wears a commercial body worn hearing aid (Bosch MT 80 SP) in the left ear. Maximum peak gain is 91 dB (HAIC, 84 dB). Maximum power output at 1,000 Hz is 150 dB SPL (HAIC, 147 dB SPL). Fitter controls are adjusted for maximum gain, power and low frequency performance. Frequency modulated warble tones were the stimuli utilised which conformed with the recommendations of Dillon and Walker (1982 a,b). Aided thresholds for the left ear (Figure 4) were obtained at 60 dB SPL at 250 Hz and rise gently to 50 dB SPL at 2,000 Hz. No responses were obtained beyond 2,000 Hz for inputs of 80 dB SPL. Comparison with the average Australian speech spectrum (Byrne, 1977), which is based on an overall speech level of 70 dB SPL measured at 1 metre, indicate aided hearing to be within the speech spectrum to 2,000 Hz.

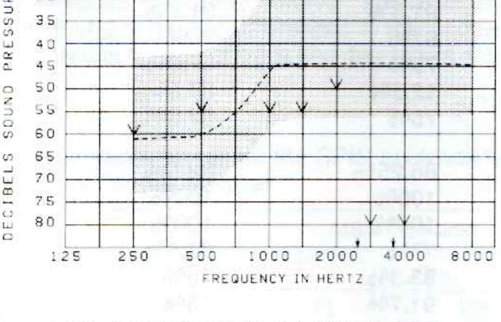

Figure 4: The subject's aided audiogram in 1985.

Materials and presentation

The aim of the present study was to evaluate the speech perception and production skills of the subject. The speech perception testing was administered live voice in a sound treated test booth with the subject seated 1 metre from the speaker. For all auditory and auditory-visual tests the subject's hearing aid was set at his preferred level. For the visual alone tests the subject's hearing aid was turned off. Two speakers were used in the study — 1 adult male and 1 adult female. Both are native speakers of Australian English. In all the perception tests the subject was asked to write down his response to ensure scoring accuracy.

Vowel perception. The vowels i, ɪ, ɛ ,æ, ə , ʌ, ɒ , ɔ , ʊ, ɜ , u , were presented in a/hvd/ via audition alone. Both speakers presented each of vowels twice in a random order.

Consonant perception. The consonants, /p,b,t,d,k,g,m,n,f,v,s,z,ʃ,h,tʃ,dʒ,l,w,j,r/ were presented in an əCa frame in three sensory conditions — auditory alone, visual alone and auditory-visually — by both speakers. The consonants were presented in lists of 40 items with each consonant occurring twice in a random order.

Word perception. Two lists of the Tonality Test from the Institute of Aural Rehabilitation at the University of Tennessee were presented via audition alone. One list by each speaker. Each list consists of 30 monosyllabic words which are divided into 3 groups of 10 denoted as low, mid or high tonality words.

Sentence perception. Lists A,C,E, and G of the SPIN Test (Kallikow, Stevens and Elliott, 1977) were used to assess the subject's sentence perception in 3 presentation conditions. The female speaker presented List E auditory alone. List G visual alone and List C auditory-visually while the male speaker presented List G auditory alone, List E visual alone and List A auditory-visually.

The subject's lipreading ability was also tested using the sentence subtest of the NAL Lipreading Test (Plant and Macrae, 1981). A film version of the test was presented without sound with the subject seated 2 metres from the television monitor.

Speech production. Spectrograms were made of the subject producing the vowels /i,ɪ,ɛ ,æ, ə, ʌ, ɒ, ʊ, ɔ , ɜ ,u/ in a /hVd/ frame using a Kay 7800 Digital Sona-Graph. Spectrograms were also made of the subject saying the words 'ship', 'sheep', 'cut', 'cart', 'dog', 'door', 'shoe', 'cat' and 'bird' each preceded by the carrier phrase 'I can see a ...' The analysis filter bandwidth used was 300 Hz with the analysis range being 0-8 kHz.

Response

Stimulus	i	ɪ	ɛ	æ	a	ʌ	ɒ	ɔ	ʊ	u	ɜ
i	1									3	
ɪ		3							1		
ɛ			1						1		2
æ				1		3					
a					4						
ʌ				1		3					
ɒ				2		1	1				
ɔ								4			
ʊ									4		
u	1									3	
ɜ								2			2

Figure 5: The subject's audiotory responses for vowels prescribed in an /hVd/ context.

RESULTS

Speech perception

The subject's scores for the auditory vowel perception task were 63.6% correct for the female speaker and 59.1% correct for the male speaker. An analysis of the subject's responses (Figure 5) showed that vowel length was correctly identified on 95.5% of presentations and that the direction of error responses was towards vowels with similar first formant (F1) frequencies but differing second formant (F2) frequencies. For example [i] was mispercieved as [u] on 75% of presentations.

The subject's consonant perception scores for the 3 presentation conditions are presented in Table I. The percent correct scores for the auditory alone and the visual alone conditions are very similar and show that the subject's ability to perceive consonantal contrasts via either audition or vision is relatively limited. The scores obtained auditory-visually, however, are much higher and indicate that overall the subject is able to fuse the information available from the two separate sensory modules thereby overcoming many of the difficulties encountered in either unisensory condition. Confusion matrices were drawn up from the subject's responses and these were used to determine the subject's abil-

TABLE I

Analysis of the subject's consonant perception responses in the 3 sensory conditions — auditory alone, visual alone and auditory-visual combined.

	Auditory	Visual	Auditory-visual
Overall	33.75%	38.75%	71.25%
Voicing	95%	63,75%	97.5%
Manner-overall	61.25%	66.25%	83.75%
Stops	75%	62.5%	75%
Fricatives	50%	91.5%	91.7%
Sibilants	33.3%	67%	75%
Affricates	25%	75%	87.5%
Nasals	100%	12.5%	87.5%
Semi-vowels	68.75%	75%	87.5%
Place-overall	35%	86.25%	82.5%
Bilabials	8.3%	100%	100%
Labio-dentals	12.5%	100%	100%
Rounded labials	0%	75%	87.5%
Alveolars	45.8%	83.3%	75%
Post-alveolars	50%	91.7%	75%
Velars	41.7%	75%	75%
Glottal	100%	75%	75%

ity to detect consonantal features in the 3 presentation conditions. The results of this analysis offer interesting insights into the relationship between consonant information available via audition and vision. The subject's ability to perceive the voicing distinction via vision alone (64% correct) is near chance level but very high (95% correct) via audition. When the subject has both auditory and visual inputs the score obtained in 97.5% correct. Conversely the subject's place of articulation score via audition was only 35% correct whereas the score obtained in the vision alone condition was 86% correct. The subject's auditory-visual score in this case was 82.5% correct. For both voicing and placing of articulation one sensory modality appears to be primary for the specific feature detection, vision for place of articulation and audition for voicing. The situation for consonant manner of articulation is more complex. In this case the percent correct scores vision alone (66%) and audition alone (61%) are very similar but in the combined condition the score rises to 84% correct. Table I also presents the percent correct scores for the various manners of articulation in the three presentation conditions. The relative importance of audition and vision varies from feature to feature. Only two features (stops and nasals) are detected with a high degree of proficiency in the auditory condition whereas vision gives relatively reliable information on the fricatives and to a lesser extent the sibilants, affricates and semi-vowels. When the two sensory modalities are combined, however, the subject is able to identify almost all features with a high degree of reliability. Analysis of the scores obtained for perception of place of articulation revealed that in two cases (the alveolars and post-alveolars) the auditory-visual score was less than that obtained in the visual alone condition while the auditory-visual score for the glottal [h] was less than that obtained in the auditory-alone condition. The differences in scores, however, are relatively small and represent differences in raw scores of only one or two test items and may reflect only test reliability. Overall the findings support Summerfield's (1983) contention that "audition and vision are complementary and synergistic in speech perception" (Summerfield, 1983; p. 176).

The subject's word perception scores of 6.7% for the female speaker and 16.7% for the male speaker appear to be rather poor but an analysis of the subject's responses revealed definite error patterns indicating good underlying auditory skills. For example, the subject was able to correctly identify the vocalic nucleii of the words on almost 50% of presentations.

Where errors were made the misperceptions were consistent with the vowel perception data reported earlier in this paper although there was some blurring of the subject's consonant responses indicated that he was usually able to reliably identify consonant voicing and to a lesser extent manner of articulation but not place of articulation. Examples of the subject's error responses include 'ball'/bɔl / mispercieved as 'born'/bↄ n/, cheese/+ʃiz/ mispercieved as 'trees'/triz/,'heart'/hat/ as 'part'/pak/ and 'teeth'/tiθ/ as 'peace'/pis'.

The subject's scores for the SPIN Test sentences presented by the two speakers are presented in Table II. These show relatively poor performance in both unisensory conditions with a marked improvement in the bisensory condition. It should be noted that in an evaluation of the SPIN Test as a lipreading test Plant et al (1984) found that List E was significantly more difficult that Lists A, C and G. This may explain the difference in scores between the 2 speakers for the auditory alone and visual alone conditions. The results obtained also showed the great contribution context makes to the subject's overall speech understanding. In all cases the scores for the high predictability items were higher than those obtained with the low predictability items.

The subject obtained a score of 38% for the NAL Lipreading Test. This score is better than 47% of subjects administered the test by Plant and Macrae (1981) indicating an average Lipreading ability.

TABLE II

The subject's scores for the SPIN sentence lists presented in 3 sensory conditions by one male and one female speaker.

	Male Speaker		Female Speaker		Overall
	List No.	% correct	List No.	% correct	% correct
Auditory	G	22%	E	6%	14%
Visual	E	8%	G	14%	11%
Auditory-visual	A	76%	C	58%	67%

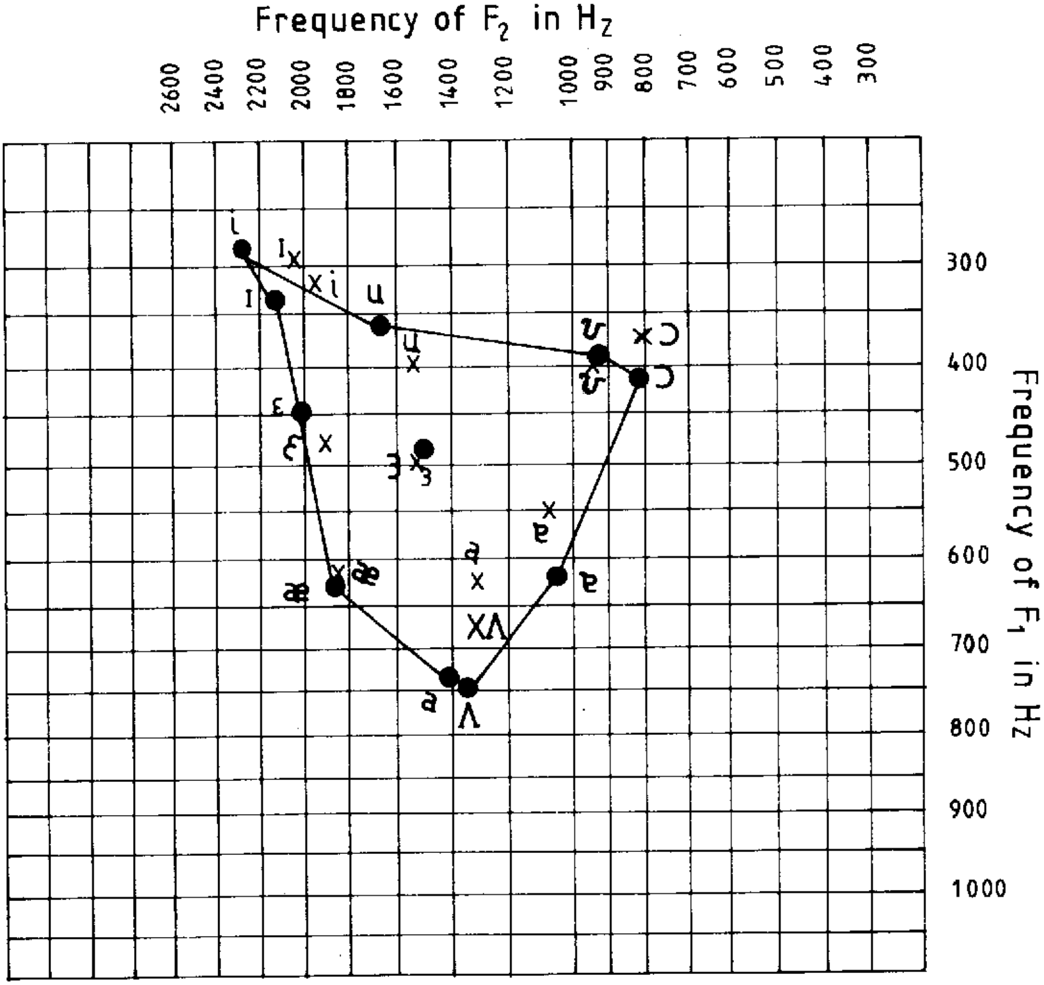

Figure 6: First and second for vowels produced in an /hVd/ frame. Circles are the moon values reported by Bernard (1967) for normal hearing Australian males. Crosses are values obtained by the subject.

Speech production

The first, second and third formant frequencies (F_1, F_2, F_3) were measured for the vowels produced in the /hvd/ frame and for the words recorded in the carrier phrase 'I can see a . . .'. The subject's F_1, and F_2, values for the vowels in the /hvd/ context are presented in Figure 6 compared to the mean values reported by Bernard (1967) for normally hearing male speakers of Australian English. It can be seen that, although there may be a slight tendency towards vowel centering, the subject has a relatively normal vowel space. The formant values for the vowels in the words produced in the carrier phrase are shown in Figure 7. In this case they are compared with the mean values and range obtained by 10 normally hearing male speakers of Australian English (Plant, Unpublished research). Again it can be seen that the subject has a relatively normal vowel space witha slight tendency towards vowel centering.

One area where the subject does appear to deviate from normal vowel production is in duration. The vowel durations for the words presented in the carrier phrase show overall a tendency towards vowel elongation by the subject. This phenomenon has been noted in other studies of the speech of the adventitiously hearing imparied (Plant, 1983, Plant and Hammarberg, 1983, Cowie and Douglas — Cowie, 1983).

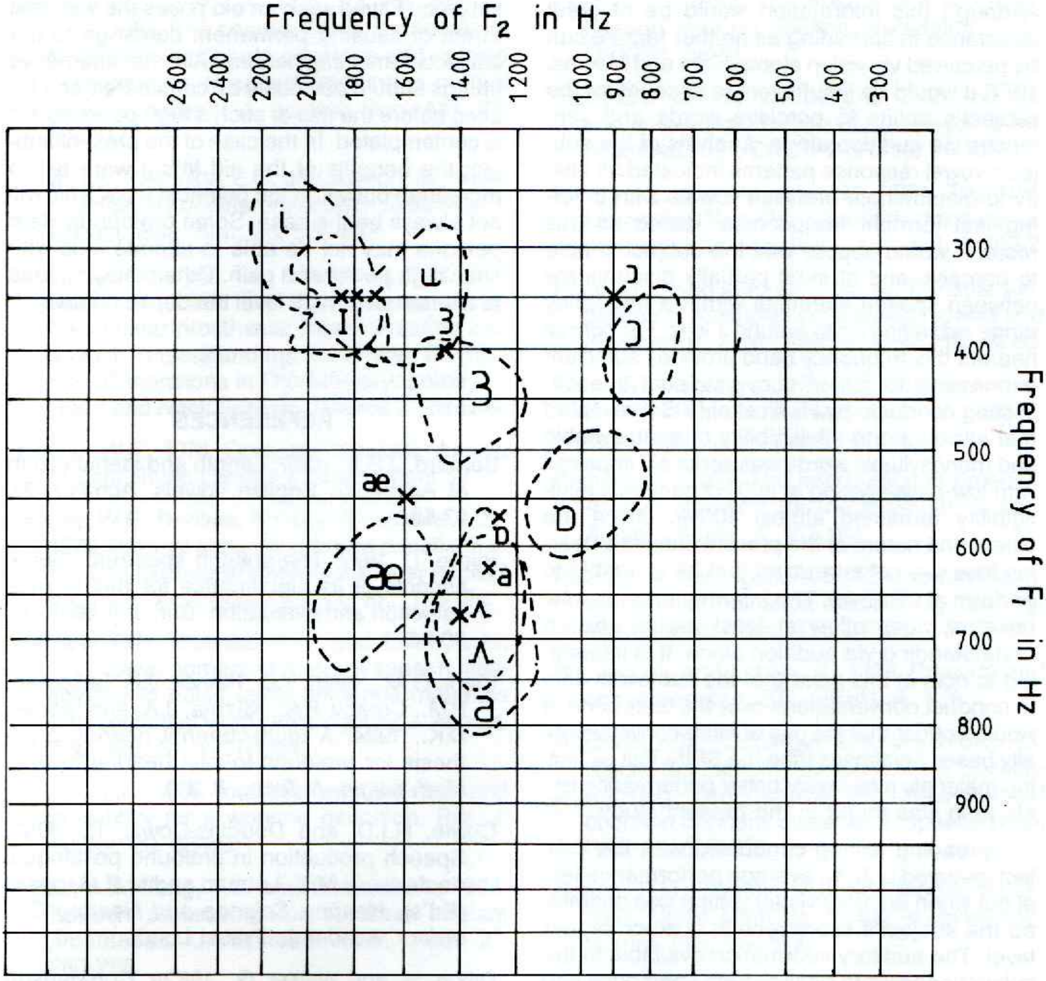

Figure 7: First and second formant frequencies for vowels produced in meaningful words. Areas designated by broken lines represent the range of values for 10 normally hearing males producing the words. The subject's formant values are indicated by crosses.

CONCLUSION

The subject's performance across all the speech perception tests administered shows that he derives considerable benefit from hearing aid usage. Given the subject's aided thresholds this is perhaps not surprising. A number of studies (Grant et al, 1985; Plant et al, 1984; Rosen et al, 1981; Risberg and Lubker, 1978; Risberg, 1974) have shown that even limited auditory information leads to improvements in lipreading performance. Rosen et al (1981) for example found that the lipreading performance of both hearing and hearing-impaired subjects was greatly enhanced when the visual signal was supplemented by auditorily presented fundamental frequency variations. Plant et al (1984) reported a significant improvement in lipreading scores when a fixed frequency (115 Hz) cue to voicing and intensity was introduced. Neither of these signals, however, would allow open set speech discrimination without lipreading. Testing via audition alone with the subject of the paper revealed he was able to percieve open set words and sentences albeit at a relatively low performance level. Analysis of the subject's error patterns for the vowel and consonant tasks showed that he was able to perceive many speech features via audition alone. For example the subject is able to identify the consonantal features voicing and nasality at a very high level indicating an ability to percieve low frequency speech cues.

Although this information would be of great assistance in lipreading as neither feature can be perceived via vision alone (Plant and Macrae, 1977) it would be insufficient to account for the subject's ability to percieve words and sentences via audition alone. Analysis of the subjects vowel response patterns indicated an ability to discriminate between vowels with differing first formant frequencies. Based on this result it would appear that the subject is able to perceive and at least partially discriminate between speech elements within a frequency range extending up to around 1 kHz. For normal hearers this frequency band provides sufficient information to follow conversational speech. Testing conducte by Hirsh et al (1954) revealed that although the intelligibility of multi-syllabic and monosyllabic words was seriously impaired with low-pass-filtering at 800 Hz sentence intelligibility remained almost 100%. Given the extent and nature of the present subject's hearing loss it is not surprising that he is unable to perform at this level. The information available, however, does allow at least partial speech understanding via audition alone. It is interesting to note at this point that the subject is able to conduct conversations over the telephone. It would appear that the use of more conversationally based sentences than the SPIN Test as testing materials may reveal better performance levels than was found in the present study.

Lipreading testing conducted with the subject revealed only an average performance level but when auditory-visual testing was attempted the subject's score rose to a much higher level. The auditory information available to the subject appears to provide both segmental and suprasegmental information which serves to overcome many of the errors and confusions which occur via lipreading alone. Informal conversation with the subject in a quiet room revealed a very good understanding of speech face-to-face. In noisy situations, however, the subject reports that he experiences great difficulty in understanding. He further reports that a radio frequency aid affords considerable benefits in such situations.

The results obtained by the subject highlight the need to comprehensively evaluate the possibility of hearing aid use even with those subjects whose unaided thresholds exceed commonly accepted definitions of total deafness. This should not, however, be seen as a justification for the routine fitting of very high powered aids to profoundly deaf persons. The subject of this paper should be seen as an exceptional case and no assumptions made as to the suitability of his aid fitting for other profoundly deaf subjects. Fitting such an aid poses the very real threat of causing permanent damange to the subjects remaining hearing. All other alternative fittings should obviously be considered and trialled before the use of such a high-powered aid is contemplated. In the case of the present subject the benefits of the aid fitting were felt to more than outweigh the potential risks. This will not always be the case. Some profoundly deaf persons may not be able to tolerate aids with such high power and gain. Others may be able to tolerate such high level but derive no benefit.

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