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B. ACOUSTIC AND PERCEPTUAL ANALYSIS OF THE SPEECH OF THE DEAFENED

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Abstract

The speech of three persons deafened at ages 8, 9 and 49 years respectively was studied using acoustic and perceptual analysis. The results obtained indicate that all three subjects had speech errors which stem from the acquisition of a profound hearing loss. The speech of the two subjects deafened prior to the onset of puberty contained both segmental and suprasegmental errors whereas that of the speaker deafened later in life deviated mainly in diminished control of prosodic aspects. Overall agreement was found between the acoustic analysis and the perceptual ratings although there were some discrepancies. The significance of the results is discussed as are future possible research directions.

Studies of persons with an acquired hearing loss have highlighted the disruptive effect the loss of auditory monitoring can have on speech production. Zimmermann and Retta Iata (1981) in a cine fluorographic study of a 34 year-old male deafened during adolescence found that his speech differed from that of a normal-hearing control in "movement transition time, voice termination time and tongue dorsum-jaw co-ordination during the VC gesture" (Zimmermann and Retta Iata, 1981; p. 177). Binnie et al (1982) have described the "phonetic disintegration" of a 5 year old boy deafened by meningitis. Over a 9 month period the intelligibility of this child's speech declined rapidly with observed changes including a rise in speaking fundamental frequency (F0) with a reduction in its range, a decline in the rate of articulation, accompanied by elongation of both vowel and consonant segments and perceptively excess nasalization. Plant (1983) analyzed the speech of an 18 year-old Swedish female deafened at age 8 by meningitis. Deviations from normal speech production included a restricted F0 range, use of non-frequency cues to signal emphatic stress in sentences, a slow rate of articulation due to vowel elongation, and a restricted range of vowel formant values.

These findings pose interesting questions as to the role of auditory feedback in normal speech production. Studies of normal hearing speakers deprived of auditory feedback by noise masking have shown that, despite rises in vocal intensity and prolongation of vowels, they "continue to be highly intelligible" (Borden, 1979; p. 163). Borden (1979) believes the feedback system of speech is so highly redundant that

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"when one channel is blocked, the speaker depends more on another channel of information" (Borden, 1979; p. 184). Lane and Tranel (1971) in a study of the Lombard Sign concluded that after the acquisition stage is over, "listening and speaking are not interlocked but are quite separate temporally and ... we are no more obliged to listen to our own speech than that of others" (Lane and Tranel, 1971; p. 701). They believe that tactile and proprioceptive feedback provide sufficient information "to maintain fluent articulation after experimental or traumatic deafness" (Lane and Tranel, 1971; p. 694). Other researchers, however, feel that audition does play a role in the control of speech production. Ladefoged (1967), for example, hypothesized that intonation was monitored primarily by audition, a view disputed by Mallard et al. (1978) who found that auditory masking had little effect on FO control in conversational speech. Mallard et al.'s (1978) study did, however, reveal some changes in FO production with auditory masking. These were a rise in FO accompanied by greater FO variability. They also found that untrained subjects had difficulty performing a tone-matching task when masked, and concluded that "auditory monitoring ... appears to be the primary sensory channel for controlling fundamental frequency prior to vocal training" (Mallard et al., 1978; p. 211). This finding is supported by similar studies performed by Elliott and Niemoeller (1970) and Ward and Burns (1978). All such studies have a major shortcoming in that they necessarily involve relatively short term deprivation, and thus bear little relationship to the situation confronting persons with an acquired hearing loss. Zimmermann and Rettaliata (1981) have hypothesized that speakers do not rely on continuous auditory feedback of their speech but rather use audition to recalibrate and retune the production system when movements exceed the normal range of variability. As a result, the process of deterioration is gradual rather than immediate as "it takes many instances of exceeding the normal range of variability and making errors without knowledge of errors for the patterns to degenerate" (Zimmermann and Rettaliata, 1981; p. 177). If this hypothesis as to the role of audition is correct, it is not surprising that studies involving short-term auditory masking have found few deviations from normal speech production.

Another factor which needs to be considered in examining the effects of an acquired hearing loss on speech production is the age of onset of deafness. The critical importance of audition during speech acquisition can be seen in the enormous difficulties which confront the
congenitally deaf child attempting to acquire intelligible speech. Edmondson (1977) believes that once the speech acquisition process is over "articulation can proceed largely independent of acoustic monitoring; the monitoring becomes kinesthetic" (Edmondson, 1977; p. 2). Kent (1976) in a review of research into speech acquisition concluded that "maturation of motor skills in speech is not completed until the child reaches puberty" (Kent, 1976; p. 440). This conclusion was based on studies examining the age at which children have acquired adult-like precision of both vowel-formant frequencies and voice-onset-time for stop consonants (Eyuchi and Hirsh, 1969) and the full range of consonant sounds (Sander, 1972). Further support for this conclusion can be found in the work of Tahta et al (1981a, b) who, in a study of second language learners, reported that the ability to acquire a native accent declines with increasing age with minimal chance of success "if acquisition begins during or after adolescence" (Tahta et al, 1981a; p. 271). Similarly, the ability of children to replicate the intonation patterns of another language was poor by age 11 (Tahta et al, 1981b). If maturation of stability for speech is attained around puberty it is possible, as Edmondson (1977) has speculated, that the speech quality degradation of persons deafened before and after puberty will differ both in severity and type. The speaker possessing the full speech inventory for his/her language would seem to have greater opportunities to rely on stabilized motor patterns and feedback mechanisms to overcome the loss of audition. This hypothesis has not been tested as yet, for most studies of the speech of the deafened have been of persons deafened prior to the onset of puberty (Monsen, 1981; Binnie et al, 1982; Plant, 1983). It is an area, however, which merits special attention if appropriate training materials to overcome the effects of an acquired hearing loss are to be developed. Research in this area also offers, as Edmondson (1977) has suggested, the possibility of obtaining insights into the processes underlying articulatory maturation.

This present paper is part of a long-term study aimed at acquiring a detailed knowledge of the speech of the deafened with a view to developing more effective rehabilitative techniques. Aural rehabilitation programmes currently available, although stressing the importance of speech conservation exercises, offer little concrete advice on the approaches which should be adopted to help alleviate any speech errors which arise as a consequence of an acquired hearing loss. It is hoped that through the systematic study of the speech of a large number of
deafened persons, training materials and perhaps more effective sensory aids to provide speech feedback may be developed.

Method

Subjects

The experimental subjects of the present study were three native speakers of Swedish with acquired profound hearing losses. The subjects' pure-tone-auditory thresholds are presented in Fig. 1. Subject 1 is an 18 year-old female deafened at age 8 by meningitis. The subject reported receiving no assistance from a hearing aid and relies upon lipreading for receptive communication. She was educated at both a school for the partially hearing and a secondary school for hearing children following the onset of deafness. At the time of this study Subject 1 was fitted with a vibrotactile aid (Spens and Plant, 1983) and was receiving training in its use as a lipreading aid. She was also attending classes in Swedish Sign Language as she hoped to use a signing interpreter to assist her in following lectures at a tertiary level. A detailed description of this subject's speech is found in Plant (1983).

Subject 2 is an 18 year-old male deafened at age 9 by meningitis. This subject also reported receiving little assistance from a hearing aid, and uses sign as his primary means of receptive and expressive communication. His schooling following the onset of deafness has been at schools for the deaf. Subject 3 is a 59 year-old male who has been profoundly deaf for 10 years as a result of Meniere's disease. This subject relies upon lipreading plus the Mouth Hand System for his receptive communication needs.

For purposes of comparison ten normally-hearing Swedish speakers (six male and four female) were used as a control group.

Materials

The aim of the present study was to gain a general overview of the experimental subjects' speech using both connected discourse and isolated words. In order to obtain a sample of connected discourse, recordings were made of the subjects reading a short story of 81 words. Recordings were also made of each of the subjects readings of the test sentence, "Uno belånade gården i Boden" (Uno mortgaged the farm in Boden) in a neutral manner, and then four different versions in which the words "Uno", "belånade", "gården" and "Boden" were each stressed in turn. The question form "Belånade Uno gården i Boden?" was also re-
Fig. 1. Audiometric thresholds for the three experimental subjects.
recorded. Recordings were also made of the experimental subjects reading a list of 37 Swedish words designed to provide a representative sampling of Swedish consonants and vowels (Öster and Martony, 1983).

**Recordings**

Recordings of the experimental subjects reading the test materials were made using a TEAC A-3340 4-channel tape-recorder with inputs from an air microphone, plus accelerometers attached to the subject's throat and nose. The recordings were made with the subjects seated in an anechoic test room in order to ensure high quality sound reproduction. The ten normally-hearing speakers read the short story and the different versions of the test sentence. These latter recordings were made using a Revox 2-channel tape-recorder with inputs from an air microphone and an accelerometer attached to the speaker's throat.

**Data analysis**

Both the experimental subjects and the control group's readings of the short story and the test sentence were analyzed using a computer program developed by Ternström (1983). This plots F0 contours as a function of time, calculates mean F0 and standard deviation and plots an F0 histogram. Wide band spectrograms were made for each of the words in the test list using a Voice-Print Spectrograph. Spectrograms were also made of the subjects' reading of the test sentence - "En pojke kom en dag" (A boy came one day).

The experimental subjects' reading of the short story were also judged by a panel of four experienced logopedists who are staff members in the phoniatrics department at Huddinge Hospital, Stockholm. Prior to this perceptual rating one of the authors (BH) had determined that the areas warranting special attention were overall pitch, the pitch contour and stress patterns, voice quality, articulation and tempo. The logopedists taking part in the rating were asked to comment on each of these factors for each of the individual speakers.

**Results**

**Fundamental frequency analysis**

The results obtained by the three experimental subjects and the normally-hearing subjects are presented in Table I. Although the mean F0 for each of the experimental subjects appears to be within normal limits, the F0 range of both Subjects 1 and 2 is restricted when com-
Normal Hearing Control Group

<table>
<thead>
<tr>
<th></th>
<th>Mean $F_o$</th>
<th>S.D. (Hz)</th>
<th>S.D. as a % of mean $F_o$</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MALE SUBJECTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>139</td>
<td>21.5</td>
<td>15.5%</td>
<td>28.6</td>
</tr>
<tr>
<td>2</td>
<td>131</td>
<td>14.75</td>
<td>11.25%</td>
<td>30.6</td>
</tr>
<tr>
<td>3</td>
<td>115</td>
<td>11.19</td>
<td>9.75%</td>
<td>23.6</td>
</tr>
<tr>
<td>4</td>
<td>107</td>
<td>9.51</td>
<td>8.90%</td>
<td>24.2</td>
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<tr>
<td>5</td>
<td>125</td>
<td>20.7</td>
<td>16.5%</td>
<td>25.3</td>
</tr>
<tr>
<td>6</td>
<td>147</td>
<td>18.5</td>
<td>12.5%</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td><strong>127</strong></td>
<td><strong>16.1</strong></td>
<td><strong>12.4%</strong></td>
<td><strong>25.5</strong></td>
</tr>
</tbody>
</table>

| **FEMALE SUBJECTS** | | | | |
| 1 | 222 | 32.2 | 14.5% | 25.9 |
| 2 | 177 | 35.0 | 19.75% | 28.4 |
| 3 | 215 | 38.3 | 17.80% | 24.3 |
| 4 | 162 | 34.5 | 21.25% | 24.7 |
|    | **194** | **35.0** | **18.3%** | **25.8** |

| **DEAFENED SUBJECTS** | | | | |
| (subject 1, female; 2 & 3 male) | | | | |
| 1 | 219 | 11.2 | 5.10% | 40.65 |
| 2 | 133 | 8.89 | 6.70% | 66.07 |
| 3 | 129 | 13.84 | 10.70% | 39.80 |

**TABLE I.** Mean $F_o$ and standard deviation and time for reading of short story by normal-hearing controls and the deafened subjects.
pared with those obtained from the normal hearing controls. The FO range for Subject 3, although relatively small, appears to be within the normal range being slightly greater than that obtained by 2 of the male subjects in the control group.

Analysis of the control groups production of the test sentence revealed that emphatic stress was marked by a substantial rise in the FO contour in the stressed word. An attempt at normalization of the data for the six male subjects in the control group is presented in Fig. 2. Each of the subject's productions of the test sentence with emphatic stress on "Uno", "belånade", "gården" and "Boden" was divided into ten equal parts and the FO measured at each of these points. The subjects' mean FO for their reading of the short story was assigned the reference value 0 Hz and each measurement for the test sentences was then expressed as plus or minus this value. The FO contours for each of the four emphatically stressed versions of the sentence presented in Fig. 2 represent the mean FO values for the six subjects. It can be seen that emphatic stress results in an FO peak on the stressed word. The limitations of the normalization technique used are recognized, but it is felt that this means does provide a broad appreciation of the FO changes marking emphatic stress. A second measure involved calculating the peak FO for the emphasized word and expressing it as a percentage of the mean FO for the short story. For the male speakers in the control group emphatic stress on the words "Uno", "belånade", "gården" and "Boden" led to peak FO values which were 41.5%, 41.5%, 41.25% and 24.1% respectively above the reference frequency.

The FO contours for the test sentences produced by the experimental subjects are given in Figs. 3, 4 and 5. The productions of Subjects 1 and 2 are quite different from those obtained with the normal-hearing controls. For both of these speakers emphatic stress is not accompanied by systematic FO changes. Subject 1, however, uses a durational cue to signal the stressed word in the sentence. This subject pauses after the stressed word as a means of signalling emphasis whereas Subject 2 appears to have no means of signalling emphatic stress in sentences. Subject 3's productions of the test sentence indicate that he is able to partially control FO changes to signal emphatic stress. The peak FO of each emphasized word was measured for Subject 3 and then expressed as a percentage of his mean FO for the short story. The percentage changes for the four stressed words were 45.7%, 33.3%, 14.72% and 27.1% respectively.
Fig. 2. Normalized F0 contours for six normally-hearing, male Swedish speakers producing the test sentence with emphasis on "Uno" (A), "belånade" (B), "gården" (C) and "Boden" (D).

Fig. 3. F0 contours for experimental Subject 1 producing the test sentence in a neutral fashion (A), with emphasis on "Uno" (B), "belånade" (C), "gården" (D) and "Boden" (E) and the question form of the sentence (F).
Fig. 4. FO contours for experimental Subject 2 producing the test sentence. See Fig. 3 for a description of the letter code.

Fig. 5. FO contours for experimental Subject 3 producing the test sentence. See Fig. 3 for a description of the letter code.
Duration

The times taken to read the passage for the control group members and the experimental subjects are also presented in Table I. All three experimental subjects had reading times which were substantially greater than those of the control group. The longest time taken by any member of the control group was 30.6 seconds, whereas the shortest time for any of the experimental group was 39.8 seconds for Subject 3. It is felt this represents a very real tendency towards a slower rate of articulation on the part of the experimental group rather than other factors such as poor reading skills or unfamiliarity with the test passage. Prior to recording the subjects were asked to read the passage through several times to familiarize themselves with its contents. Practice readings of the passage were also used to set the recording levels prior to the test recording. Subject 2's total reading time of 66.07 seconds is extremely slow and reflects an abnormally large number of pauses in his production plus word elongation. Figs. 6, 7, 8 and 9 present the spectrograms of the first phrase of the short story (En pojke kom en dag) as spoken by a 17 year-old normally-hearing female and by experimental subjects 1, 2 and 3. The times taken for these four speakers to produce this phrase were 1.1 seconds, 1.9 seconds, 3.1 seconds and 1.6 seconds respectively. In each case the deafened subjects show a tendency towards vowel elongation plus longer pauses between each of the words.

Vowel formant frequencies

The first and second formants for each of the vowels in the word lists were measured and the values for each of the experimental subjects are plotted in Figs. 10, 11 and 12. The ability of the subjects to produce appropriate vowel formant patterns varied considerably. Subject 3 appears to produce a range of formant values which is appropriate for a male speaker of Stockholm Swedish (Ståhlhammar, 1983). Subjects 1 and 2, however, show a number of deviations from normal production. Subject 1's range of first formant values appears to be within normal limits but her range of second formant values is restricted relative to that of normally-hearing subjects (Ståhlhammar, 1983). Subject 2 appears to have a restricted range of both first and second formant values. An interesting aspect of Subject 2's vowel production is the absence of diphthongization despite his being a native speaker of southern Swedish.
Fig. 6. Spectrogram of the phrase "En pojke kom en dag" as produced by a 17-year-old normally-hearing female speaker.
Fig. 7. Spectrogram of "En poike kom en daq" produced by Subject 1.
Fig. 8. Spectrogram of "En pojke kan en dag" produced by Subject 2.
Fig. 9. Spectrogram of "En pojke kom en dag" produced by Subject 3.
Bruce (1970) in a study of diphthongization in the Malmö dialect found that "all of the long vowel phonemes are more or less diphthongized" (Bruce, 1970; p. 6). Diphthongization involves the movement of the articulators from one target to another, and this may be an excessively difficult task for deaf speakers to accomplish, relying as they do on non-auditory feedback to determine the adequacy of their production. Binnie et al (1982) have speculated that modifications which occur in the speech of the deafened represent attempts to maximize articulatory control, and the absence of diphthongization in Subject 2's vowels may be an example of this mechanism. By holding the articulators in a fixed position the speaker should maximize the available feedback. It should be noted that no normative values are presented with which to contrast Subject 2's vowel formant frequencies. Unfortunately, except for data obtained for one 18 year-old male speaker (Bruce, 1970) no research appears to have been conducted into the vowel formant values for speakers of southern Swedish.

**Vowel duration**

The spectrograms for the words in the test list were also used to measure the duration of the experimental subjects' vowels. The mean durations for the long and short vowels in the medial position are presented in Fig. 13. Stålhammar et al (1973) in a study of short/long vowel duration in Swedish gave the following formula for modelling Swedish vowel duration:

\[
V_k = 30 + 0.5 V_l \text{ msec.}
\]

"where \(V_k\) is the duration of the short vowel and \(V_l\) is the duration of the long vowel" (Stålhammar et al, 1973; p. 7). The overall short/long vowel durations for the three experimental subjects were 249.5 msec/502.3 msec, 152.6 msec/283.6 msec and 134.6/232 msec, respectively. This indicates that in all three cases the overall ratio of long/short vowels is relatively normal. There are, however, some deviations in the productions of both Subjects 1 and 2. In both these cases there is considerable overlap between the long and short vowels - a situation not found with normally hearing speakers. The vowels produced by Subject 1, and to a lesser extent Subject 2, are also considerably elongated with some of the short vowels produced by Subject 1 having durations which exceed some of the long vowels produced by Subject 3. Subject 2's short
Fig. 10. F1/F2 plots for vowels produced by Subject 1 (x) compared with mean values for ten normally-hearing female speakers of Stockholm Swedish (●). Normative values are from Stålhammar (1983).

Fig. 11. F1/F2 plots for vowels produced by Subject 2. Filled circles denote each instance of a vowel produced more than once. Crosses indicate vowels produced only once. No substantial body of normative data exists for comparative purposes.
Fig. 12. $F_1/F_2$ plots for the vowels produced by Subject 1. Filled circles denote individual instances of vowels occurring more than once, crosses signify vowels produced only once, unfilled circles are narrative values for ten normal-hearing male speakers of Stockholm Swedish (Stålnacke, 1963).

Fig. 13. Mean vowel duration for the Swedish long and short vowels as produced by the three experimental subjects.
vowels tend to be closely related in length whereas his long vowels range in duration from 150-430 msec.

Perceptual analysis

The comments of the four logopedists showed a very strong agreement across all judgements. A summary of their ratings of the three experimental subjects is given below.

All four panelists rated the pitch of Subject 1 to be somewhat higher than normal, and all characterised her pitch contour as monotonous. This subject's stress patterns were judged to be deviant in that there was little difference between stressed and unstressed syllables. Three of the judges also noted a tendency for excess stress at the end of phrases accompanied by a rising pitch contour. Her overall voice quality was rated as being slightly breathy with a tendency towards a pressed or stressed quality. All four judges rated the subject's vowel quality as being distorted, and her consonants were considered overarticulated. The subject's overall rate was judged to be slower than normal.

Subject 2's pitch was considered to be quite normal, but his overall pitch contour was judged to be monotonous. The stress patterns used were also judged to be deviant with one judge describing this subject's speech as "staccato" and consisting of "one-word sentences". The subject's voice quality was characterised as "nasalized", "lacking in sonority", "restrained" and evidencing poor breath control. Articulation errors noted concentrated on consonant production with all judges commenting on the simplification of consonant clusters. For example /fr/ was realised as /f/. The subject's overall rate was again judged to be excessively slow.

Subject 3's overall pitch was judged to be somewhat lower than normal, and his pitch contour was again considered monotonous. The subject's voice quality was characterised as being "pressed"; that is, hyperfunctional, with strangled phrase endings. Articulation overall was judged to be quite normal although a tendency towards retroflexion was noted. The subject's overall rate was judged to be within normal limits.

Discussion

The results obtained from both the acoustic and perceptual analyses
indicate that the acquisition of a profound hearing loss has led to a decline in the speech of all three subjects studied. It appears, however, that the degree of speech degradation is not the same for all three subjects despite their having had a profound hearing loss for approximately the same period of time. Both Subjects 1 and 2, who acquired their hearing loss prior to the onset of puberty, have many more speech errors than Subject 3, whose loss occurred in adulthood. This finding offers support for Eldmondson's (1977) contention that the effects of an acquired hearing loss will vary according to the age of onset. It should be noted, however, that Subject 3's speech does appear to have been affected to some extent. This is especially true of his intonation contour which was rated by the listening panel as being monotonous. There is an apparent inconsistency in this case between the perceptual rating and the acoustic analysis, but examination of this speaker's FO contour plotted for the short story revealed a trend which may partially explain this situation. This speaker appears to produce a relatively flat intonation contour with few upward excursions and a rapid terminal fall for each intonation group. The FO histogram obtained by this speaker is positively skewed indicating that the bulk of his FO change is in a downward direction. Speaker 3's ability to use FO change to signal emphatic stress also appears to be reduced, but not to the same extent found with the other two speakers. In the case of Subject 3 this is most marked in the question form of the test sentence. The normally-hearing control group produced the question sentence with a rising FO contour at the beginning of the sentence which is not found in Subject 3's production. This subjects articulation was rated as being within normal limits - a finding supported by the spectrographic analysis of his vowel formant frequencies as well as his vowel durations. The only other feature of Subject 3's speech which was felt to be deviant was his use of a pressed voice quality. This may stem from an increase in sub-glottal pressure and laryngeal tension in an attempt to maximize non-auditory feedback as to phonation.

The speech of Subjects 1 and 2 appears to have been far more adversely affected by the acquisition of a profound hearing loss. The speech of both subjects is marked by a monotonous pitch contour with little differentiation between stressed and unstressed syllables. Neither of these two subjects appears able to use FO change to signal emphatic stress or to signal the question form. Subject 1 compensates for the inability to control FO changes by the use of a durational cue
but it appears that Subject 2 has developed no such compensatory mechanism. Analysis of the vowel articulation of both Subjects 1 and 2 revealed a restricted range of vowel formant frequencies plus a "blurring" of the long/short vowel distinction. Although no record of Subject 2's speech prior to the onset of deafness exists, his lack of vowel diphthongization suggests that he may have modified his vowel articulation in an attempt to increase the feedback available. Consonant articulation for these two speakers also seems to have been affected but to a lesser extent. Subject 2 has a tendency to simplify consonant clusters, a feature noted in the speech of the child studied by Binnie et al (1982). The presence of excess nasality in the speech of Subject 2 and the overarticulated consonants of Subject 1 may, again, represent attempts on the part of the speakers to maximize the available feedback.

Although the number of subjects in the present study is too small to allow any definitive conclusions to be drawn, some overall trends are apparent. Firstly, the speech of the subjects deafened prior to puberty does appear to have been far more adversely affected than that of the speaker deafened during middle-age. But this latter speaker still evidences some deterioration in his overall speech control, especially in the use of intonational contrasts. The vowel formant frequencies obtained by Subject 3 appear to cast some doubt on Zimmermann and Retta-liata's (1981) contention that positioning and co-ordination of the tongue dorsum is biologically dependent upon auditory information. Subject 3's vowel quality appears to be relatively stable despite his having had a profound hearing loss for ten years. Further studies involving much larger numbers of subjects with varying ages of onset and time since onset need to be undertaken. There also exists a need for longitudinal studies which examine the effects of remedial programmes aimed at alleviating the speech production problems resulting from an acquired hearing loss. Another area which merits attention is the effect of a partial hearing loss on speech production. Again, the insights gained from such studies should increase understanding of the normal processes of speech control and lead to the development, where applicable, of more adequate remediation programmes and sensory aids.

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