PROSODY AND AIRFLOW IN DEAF SPEECH AND VISUAL FEEDBACK REMEDIATION

Corinne Adams

Department of Behavioural Sciences in Medicine
University of Sydney

ABSTRACT - An acoustic/aerodynamic investigation of the speech of normal-hearing and profoundly deaf children is reported. The speech of the latter improved significantly following visual feedback remediation.

INTRODUCTION

Whereas the normal-hearing child in the process of speech acquisition regularly and expertly uses the principles of feedback control, the profoundly deaf child is unable to follow his speech output aurally. He learns to speak in a discrete word-by-word fashion and his relatively limited experience in communicating orally in connected sentences leads as a rule to unintelligible utterance which is charactrised not only by obvious articulatory defects but also by less readily identifiable abnormal aerodynamic and prosodic patterning.

In the study reported here investigation was undertaken of the acoustic correlates of some prosodic features and aerodynamic behaviour in the speech of 19 profoundly prelingually deaf children aged between 6 and 16 years and 19 normal-hearing children matched with them for age and sex. The test material consisted of 10 sentences which ranged from an extremely simple five-syllable item to more complicated sentences of ten and eleven syllables.

RESULTS

The results showed disordered airflow functioning in the speech of the deaf children which was accompanied by inappropriate linguistic structuring and aberrant patterning of fundamental frequency, amplitude, and duration. These factors contributed to their reduced intelligibility because high volume of expiratory airflow per syllable plus non-phonatory expiration led to linguistically inappropriate pausing for inspiration of air, which resulted in anomalous breath group organisation and concomitant mismanagement of the prosodic features.

AIRFLOW

Two distinctly different patterns were found: *Type I*, the normal pattern, and *Type II*, the typical pattern produced by the hearing-impaired children. *Type* I consisted of a preliminary inspiration; a single expiration constituting the utterance or breath group; and, usually, a much smaller non-phonatory expiration following speech. Although minor variations to this pattern occurred in the preliminary inspiration phase, they did not interfere with the utterance itself and of 190 sentences examined, all but a couple were produced as *single breath groups*.

By contrast, not one of the hearing-impaired children was able to produce all ten test sentences as single breath groups. While some of the better speakers read the very short sentences as single breath groups, several of these children took as many as eight breaths in the longer sentences. The typical *Type* II pattern then, consisted of one or two preliminary inspirations; two or more breath groups which were separated by intakes of air and non-phonatory exhalations not part of the articulatory process; and a further non-phonatory expiration following speech. In addition, the words and syllables within the several breath groups were frequently separated by non-phonatory expiratory airflow. Thus in the airflow pattern produced by these children there was considerable wastage of inspired air. The pauses for breath, often at linguistically inappropriate points in the sentence and the short non-phonatory exhalations, also indisscriminately placed, severely interrupted the flow of speech. At best, the effect of these pauses on the children's utterance was a staccato-like rhythm and, at worst, linguistically inappropriate grouping.

Comparison of the two types of airflow can be seen in Figures 1 and 2.

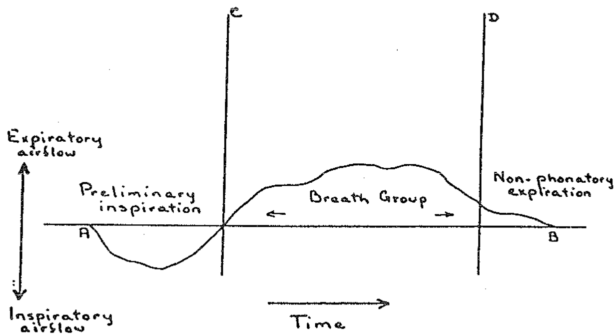

Figure 1: Trace Type I - the normal volume airflow pattern, showing (i) preliminary inspiration; (ii) single breath group; (iii) non-phonatory expiration.

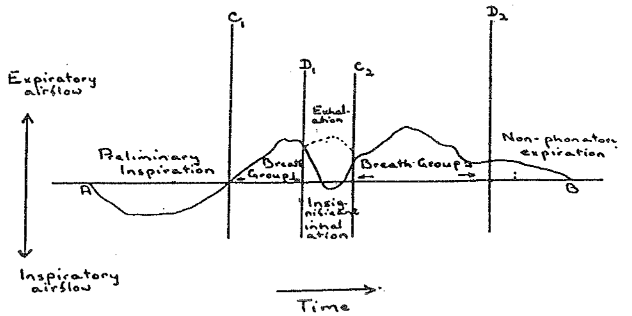

Figure 2: Trace Type II - the typical volume airflow pattern produced by the deaf subjects. Instead of the single uninterrupted breath group, non-phonatory exhalation is indicated between phonation groups and insignificant inhalation is shown to occur between them.

Whereas the records of the normal-hearing children showed only minimal difference in volume between the preliminary inspiration and their total intake in a given sentence, those of the hearing-impaired children were characterised by considerable dissimilarity. Failing to regulate their initial intake of air adequately to produce the test items as single breath groups, the hearing-impaired children replenished their air supply as they progressed through the sentence and expended a great deal more air than was actually necessary to sustain its production. As a result of inefficient programming of their initially inspired air, much of which was lost in non-phonatory expiration, the deaf children on the whole expended two to two-and-a-half times as much air as did their normal-hearing counterparts. However, they also used a great deal more than the normal-hearing children in their production of the individual syllables of the items, the difference between the two groups being highly significant.

FUNDAMENTAL FREQUENCY AND AMPLITUDE

The deviance in the acoustical characteristics of the deaf children's utterance was equally striking. Of the several dimensions of fundamental frequency and amplitude analysed, in only one, the terminal fall in F_o at the end of each of the test sentences, was there accord between the two groups. It was found, for example, that average F_o of the deaf subjects (286 Hz) very considerably exceeded that of the normal-hearing subjects (235 Hz), a difference which was highly significant.

Likewise, the F_o range of the deaf children was significantly greater than that of the normal-hearing boys and girls. The wide range was due mainly to the high peak F_o recorded by the hearing-impaired children, although comparison of the two groups revealed that the younger children in the hearing-impaired group also recorded a lower minimum F_o than their normal-hearing counterparts.

Although the terminal fall was correctly used in practical all sentences by both groups a significant difference between them on this dimension was found in the much greater mean fall recorded by the deaf children. This fall was associated with their consistent rise in F_o on the last syllable of the sentence. This rise is illustrated in Figure 3 which shows the mean peak F_o for each of the syllables in the longest test item, as spoken by the 10-13 year-old children of both groups. The F_o contours seen in this figure also illustrate the difference between the two groups in declination effect.

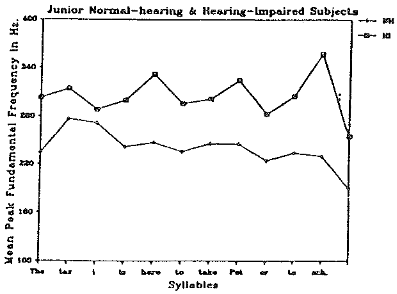

Figure 3. Mean peak fundamental frequency (in Hz) of the several syllables of a test sentence.

The records of the normal-hearing group showed a declination in F_o from the beginning to the end of all test sentences, the decline being gradual from one stress to the next, and the local pitch obtrusions associated with the stressed syllables being subsumed by the global contour. The hearing-impaired children showed no such integration of local and global attributes primarily, it is believed, because they perceived the F_o contour not as a holistic event spanning the sentence, but rather as a sequence of discrete linguistic units. This would account not only for their dramatic F_o obtrusions but also for their indiscriminate increase in the magnitude of other parameters coincident with their production of both stressed and unstressed syllables.

The amplitude contours of the normal-hearing children showed a distinct tendency to decrease in amplitude at the end of the sentence, thus paralleling F_o declination. However, whereas the F_o decrease was very regular, the amplitude decrease was marked by a rather erratic decline. The last syllable did not always show the least amplitude but it was quite consistently among the weakest syllables in the utterance. On the other hand, the greatest amplitude invariably occurred early in the sentence, and usually on the first stressed syllable which also had the highest F_o.

The records of the hearing-impaired children showed remarkable variability both within the utterance of the individual and from subject to subject. Nevertheless, the overall pattern was a *rising* contour which frequently coincided with their rise in F_o on the last syllable of the sentence. It is not known whether amplitude was deliberately used as a cue to stress, since it is uncertain whether these children in fact understood the concept of stress. It is unlikely that most of them did, as the records showed that there was frequently an increase in amplitude on the unstressed syllables also. A more likely explanation is that the rise could have been an indication of abnormal laryngeal management during phonation.

TEMPORAL PHENOMENA

Investigation of timing in the speech of the two groups showed that temporal phenomena, like F_o and amplitude, were very severely distorted in the hearing-impaired group. The duration of the deaf children's utterance of the test items was roughly two-and-a-half times that of the normal-hearing children, increasing linearly with length of sentence. This abnormality resulted from:

(a) inordinately lengthy syllables (caused by abnormally slow segmental production);

(b) increased time intervals between syllables;

(c) introduction of pauses of variable duration into the sentence;

(d) frequent stops for air inhalation;

(e) introduction of adventitious sounds and syllables;

(f) failure to distinguish the timing of stressed and unstressed syllables by reducing the duration of the latter in relation to the fully stressed hub syllable of the rhythm unit.

On the whole, the unstressed syllables were given durations which were closer to those of the stressed syllables in normal speech, while the stressed syllables were disproportionately lengthened. Thus the rhythm was disordered.

As was to be expectged from these results, the average rate of utterance of the hearing-impaired children was less than half that of the normal-hearing children, an average of 1.6 syllables per second being recorded for the hearing-impaired children and 3.9 syllables per second for the normal-hearing children.

The abnormally long time intervals between the several syllables of the utterance which were regularly made by the hearing-impaired children must be regarded as a major cause of their rhythm deviance. These intervals interrupted the flow of speech and produced anomalies ranging from staccato rhythm (when the intersyllable intervals were sometimes as long as the syllables themselves) to linguistically inappropriate grouping of such proportions that the articulatory continuity was disrupted and the utterance was unintelligible.

The effect of the abnormally long and irregular intervals made by the hearing-impaired children was to distort completely the rhythm of their utterance. Whereas the rhythm of the normal-hearing children indicated *analogous timing* of these intervals (that is, the periodicity of the stresses was found to be similar and sufficiently regular to constitute a well-defined stress-timed rhythmic pattern), the utterance of the hearing-impaired children showed no such division into perceptibly regular rhythm units.

RELATIONSHIPS BETWEEN THE PARAMETERS

In view of the observed relationships of the several parameters discussed it was decided to find out whether there was a statistically significant correlation between any two of them. The results of this test showed a significant correlation between expiratory airflow and syllable duration in both groups.

At every stage of this study, the significance of aerodynamic behaviour and temporal phenomena as explanatory variables of deviant speech production was evident. The cycle, which began with the *Type II* pattern of abnormal inspiratory and expiratory airflow, disrupted temporal patterning which in its turn affected the fundamental frequency and amplitude contours associated with linguistic organisation. Thus it seemed that control of airflow was an essential first step to normal speech production.

In lieu of biofeedback techniques designed to teach the deaf children how to manipulate the physiological processes of respiration, however, a method was devised to teach control of aerodynamic behaviour through understanding of the concept and within the context of the breath group.

VISUAL FEEDBACK REMEDIATION

The computer-based visual feedback remediation programme which was developed to assist the deaf children to improve the prosodic and organisational aspects of their speech proved to be very successful.

This experimental programme was trialled with the deaf children who had participated in the aerodynamic/acoustic investigation, another 19 deaf children from the same school acting as the control.

The results of assessment of the children's performance by eighty independent adjudicators before and after this programme showed that there was no significant difference between the two groups on the pre-test, but a highly significant difference was shown between them on the post-test. The improvement of the experimental group from pre-test to post-test was also found to be highly significant. The greatest mean improvement was shown to occur in breath group organisation. Presumably as a result of their learning experiences they became aware of the necessity of maintaining the flow of speech and of organising the linguistic units of their utterance within a specified time span. Thus in the post-test they gave less indication of the inappropriate placement and duration of pauses which so obviously disorganised their utterance in the pre-test.

Analysis of the adjudicators' assessments revealed consistently high correlations between rhythm, duration, and intonation in particular, suggesting that the trading relationships said to exist in the speech of normal-hearing individuals were operating in the speech of these deaf children also.

It was concluded, therefore, that input to these children of several prosodic features synchronously in patterned, integrated models was a very efficient way of improving their control of them.