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Plant, G.

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B. THE USE OF VIBROTACTILE AIDS WITH PROFOUNDLY DEAF CHILDREN

Geoff Plant

Abstract

Three profoundly deaf children were fitted with vibrotactile aids and provided with weekly training sessions over periods ranging from 18 months to 3 years. The aids used for training were a high powered auditory trainer which delivered the unprocessed speech signal via an audiometric bone-conductor, plus a commercially available vibrotactile aid - the Sentiphone - which provides some frequency information. Testing at the completion of training revealed that the children were able to perceive a number of speech features with the aids. The prosodic features, syllable number and type in words, and syllabic patterns in sentences, were identified at a level well above chance. Analysis of the children's responses at this level revealed that their performance was equal to, and in some cases better than, the results obtained by adventitiously deaf adults tested using the same material. Testing of the segmental features vowel length and the presence/absence of /s/ in the initial and/or final position in words yielded scores which were well above that which could be attributed to chance. The significance of these results for speech training with congenitally deaf children is discussed and suggestions made as to the development of a vibrotactile aid which would provide optimal information for speech training.

Introduction

Many profoundly deaf children appear to derive little benefit from conventional hearing aids. A study of hearing impaired students in a Swedish high school programme (Lind, 1973; cited in Risberg, 1976) found that 40% of those with a hearing loss greater than 90 dB reported receiving little or no help from their hearing aids. This figure rose to 60% for those students with an average loss greater than 105 dB.

Until comparatively recently it was generally accepted that there were few cases of total deafness (Dale, 1962) but a number of researchers (Nober, 1970; Ericson and Risberg, 1978; Erber, 1978; Risberg, 1976) now believe that many profoundly deaf children do not have true hearing, but rather perceive amplified sound via tactile receptors in their ears. The information available via these receptors is limited to time and intensity patterns, for "frequency discrimination by the tactile sense is very poor compared with that of the auditory sense" (Erber, 1979; p. 257). Goff (1967), for example, found tactile difference limens for frequency of around 45% at 125 Hz, compared with the 0.4% reported for audition.

Risberg (1973) believes that those children who receive only tactile information through their hearing aids would be better served by a
visual or tactile speech perception aid. A few visual aids have been
developed (Upton, 1968; Traummüller, 1980) but at this time tactile aids
seem to have a number of advantages. Single channel vibrotactile aids
are portable, enabling them to be worn at all times, and because of
their simple design they are readily available for use by deaf children.
Mértory (1974) has also speculated that visual aids may have the disad-
vantage of presenting information as to connected discourse in a form
which cannot be decoded by the human brain.

The use of vibrotactile aids with deaf children dates from the
pioneering research undertaken by Gault in the 1920s. Although his
original aim of using the sense of "touch as a substitute for hearing in
the interpretation and control of speech" (Gault, 1926; p. 121) was
never realised, his research highlighted the great potential of vibro-
tactile aids. In a study of 22 experienced users of his aid, Gault
(1930) found that when lipreading was supplemented by the tactile aid,
the scores obtained were from 10-15% better than those obtained by
lipreading alone. Goodfellow, (1934) reporting on the use of the Gault
vibrator with congenitally deaf children at the Illinois School for the
Deaf, stated that lipreading improved by 20% and that the aid enabled
the children "to locate the emphasized words and phrases in speech more
successfully, to perceive the inflections and the natural phrasing of
spoken language and to identify many homophenous words" (Goodfellow,
1934; p. 45). He also reported that the teaching of speech was greatly
facilitated by the vibrotactile aid which provided the children with
feedback of their own vocalisations, and enabled them to compare their
own vocalisations with those of their teachers. Despite these findings,
interest in tactile aids waned due in a large part to the introduction
of wearable hearing aids following the Second World War. Although a
number of research studies were conducted into the use of vibrotactile
 vocoders during this period (Pickett, 1963; Kringlebotn, 1968) the
generally held conviction that all deaf children had at least some
residual hearing meant that the use of such devices was confined to
research facilities. Interest in tactile aids was rekindled in the
1970's as it became increasingly obvious that many hearing impaired
persons did not receive sufficient benefit from conventional hearing
aids. Single channel vibrotactile aids have been fitted to both deaf
children (Neate, 1972; Boothroyd, 1974; Schulte, 1974; Erber, 1978) and
adults (Rosenberg, 1973; Decker and Folsom, 1978; Plant, 1979) with
encouraging results. Reported studies with adults have emphasised the
importance of vibrotactile aids as supplements to lipreading while those with children have concentrated on their use in the teaching of speech.

Since 1977 the Australian National Acoustic Laboratories have fitted simple, single channel vibrotactile aids to a number of adventitiously deaf adults. A study by Plant (1982a) of four deafened adults who had been fitted with the aid for periods ranging from 6 months to 3 years found that the subjects performed well on all tasks where time/intensity cues provided sufficient information to enable identification. The subjects were able to accurately identify word and sentence patterns, syllable number in sentences, vowel length and a number of environmental sounds. The subject’s lipreading performance with the vibrotactile aid was significantly better than their unaided performance, and an analysis of one subject’s visual identification of CV syllables revealed that the vibrotactile aid provided cues to consonant voicing, nasality and manner. Conversely, in tasks where time/intensity patterns provide weak cues to identification, the subjects scored relatively poorly but still above chance level. These included the tactual identification of consonants, tactual word discrimination and the perception of word stress in sentences. These results encouraged the fitting of vibrotactile aids to a group of deaf children who appeared to derive little benefit from conventional hearing aid usage.

Method
Subjects and Equipment

The children chosen for the trial ranged in age from 7 - 11 years at the time of fitting and all attend a school for deaf children which uses Cued Speech as the principal means of communication. The children were fitted with single channel vibrotactile aids consisting of a hand-held bone vibrator driven by a high powered body worn hearing aid. The aid was used in conjunction with binaural, high powered post-auricular hearing aids. It was hoped that the vibrotactile aid would serve to highlight the less prominent signal provided by the hearing aid, and thus lead to improved hearing aid usage.

A training programme was also introduced in an attempt to optimize the children’s use of the available vibratory information. This has been conducted on an individual basis for approximately 15 minutes a week over a period of 3 years. The training programme (Plant, 1982b) concentrated on the use of the tactile aid as a supplement to visual speech perception, the identification of speech features, and as a means
of monitoring speech production. During training 2 vibrotactile aids were used simultaneously in an attempt to provide both segmental and suprasegmental information. The aids used were a hand-held bone vibrator (Radio-Ear B70A) driven by a Phillips ST-70 Auditory Trainer plus a commercially available vibrotactile aid - the Sentiphone (Traummüller, 1980). In most cases the children held one aid in each hand, although on some occasions both were held in the one hand. Prior to each training session the children were asked to adjust the gain of the two aids to their preferred level. The microphones for the two aids were taped together and held approximately 2 cm from the speaker's lips. The signal provided by the bone vibrator has no processing and is limited to time/intensity information while the Sentiphone "maps the centre of gravity of the speech spectrum of the speech signal" (Spens, 1980; p. 25) and presents it within the frequency range 30-350 Hz. Informal testing suggested that the latter signal was especially beneficial in enabling the children to detect the presence of the high frequency fricatives.

The children were encouraged to wear their vibrotactile aids at all times during the school day. In most cases, however, the children have rejected the use of the aid during normal class-room activities. The reasons for this rejection include the inconvenience of using a hand-held aid, a general reluctance to use an aid which is different from that used by other children in the school, and the masking of the speech signal by classroom noise.

This paper reports on the use of vibrotactile aids by three children who had been using the aids for periods ranging from 18 months to 3 years. These children represent relatively experienced deaf users of vibrotactile aids. This is an important factor as many studies of vibrotactile aids have been conducted using hearing subjects artificially deafened for the duration of the experiment, and having only minimal training prior to testing. Consequently the results obtained with such subjects may not show the full potential of the aid under study.

Details of the three subjects taking part in the testing programme are given in Table 1. Two of the subjects are congenitally deaf while the other was deafened at age 18 months by meningitis. The audiometric thresholds obtained with the children probably reflect tactile rather than auditory responses.

Subject 1 was fitted with a vibrotactile aid three years before the testing programme described in this paper. Prior to fitting the Mono-
Table I. Characteristics of the experimental subjects. (NR = No response within the limits of the audiometer).

<table>
<thead>
<tr>
<th>No</th>
<th>Sex</th>
<th>Age</th>
<th>Age of Onset</th>
<th>Vibrotactile Aid Experience</th>
<th>Hearing 250 Hz</th>
<th>Threshold 500 Hz</th>
<th>Levels 1-8.000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>1</td>
<td>F</td>
<td>12</td>
<td>Birth</td>
<td>3 years</td>
<td>95</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>13</td>
<td>18 mths</td>
<td>3 years</td>
<td>NR</td>
<td>NR</td>
<td>110</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>13</td>
<td>Birth</td>
<td>18 mths</td>
<td>75</td>
<td>85</td>
<td>100</td>
</tr>
</tbody>
</table>

Table II. Scores obtained by the individual subjects for the sub-tests

<table>
<thead>
<tr>
<th>Prosodic features</th>
<th>Guessing</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Words</td>
<td>25%</td>
<td>33.3%</td>
<td>41.7%</td>
<td>33.3%</td>
</tr>
<tr>
<td>MST Identification</td>
<td>33%</td>
<td>91.7%</td>
<td>87.5%</td>
<td>87.5%</td>
</tr>
<tr>
<td>MST Categorization</td>
<td>33%</td>
<td>80.8%</td>
<td>86.7%</td>
<td>96.7%</td>
</tr>
<tr>
<td>Syllables in Words</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentences Number Patterns</td>
<td>10%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Nonsense Patterns</td>
<td>10%</td>
<td>100%</td>
<td>100%</td>
<td>90.0%</td>
</tr>
<tr>
<td>Sentences (i)</td>
<td>20%</td>
<td>60.0%</td>
<td>72.0%</td>
<td>68.0%</td>
</tr>
<tr>
<td>Sentences (ii)</td>
<td>10%</td>
<td>35.0%</td>
<td>35.0%</td>
<td>35.0%</td>
</tr>
</tbody>
</table>

| Segmental features       |          |           |           |           |
| Vowel length             | 50%      | 70.0%     | 80.0%     | 80.0%     |
| Final voicing            | 50%      | 90.0%     | 95.0%     | 55.0%     |
| Initial /s/              | 50%      | 75.0%     | 90.0%     | 65.0%     |
| Final /s/                | 50%      | 95.0%     | 80.0%     | 100%      |
| Initial/Final /s/        | 25%      | 80.0%     | 50.0%     | 30.0%     |
| Mean                     | 76.5%    | 76.5%     | 70.0%     |           |
syllable, Spondee and Trochee (MST) Test (Erber and Alencewicz, 1976) was presented using the child's individual hearing aids. In this test the child is asked to discriminate between a set of words consisting of 4 monosyllables, 4 spondees and 4 trochees. The children's responses are scored for the correct identification of the words, and also the ability to categorize the words according to their syllabic structure. The scores obtained by Subject 1 using conventional hearing aids were: Identification 1/12 and Categorisation 2/12. These represent chance level performance and indicate that the child was receiving little usable information from her hearing aids. Testing with the single channel vibrotactile aid on the same day yielded a categorisation score of 9/12 although no words were correctly identified. Subject 2 was also fitted 3 years prior to this study. The scores for the MST using his hearing aids were 1/12 for identification and 4/12 for categorisation. The scores obtained with the vibrotactile aid on this occasion were 0/12 for identification and 6/12 for categorisation. Subject 3 was fitted with a vibrotactile aid 18 months prior to this study. Initial results on the MST Test using his hearing aids yielded an identification score of 0/12 and a categorisation score of 3/12. Testing with the vibrotactile aid was not carried out with this child.

Evaluation

Test Materials

The aim of the testing programme was to evaluate the children's ability to identify a number of prosodic features at both the word and sentence level, plus their ability to discriminate selected segmental features.

Prosodic Features

Tests at this level evaluated the children's ability to perceive:

i. Syllable number and type in words.

ii. Syllable patterns in sentences.

i. Syllable number and type in words

The MST Test was used to evaluate the children's ability to identify and categorize words from a known list of 12 words consisting of 4 monosyllables, 4 trochees and 4 spondees. Each of the words was presented twice in a random order. The Syllables in Words Test (Plant, 1982a) consists of 30 words (10 monosyllables, 10 spondees and 10 trochee, Spondee and Trochee (MST) Test (Erber and Alencewicz, 1976) was presented using the child's individual hearing aids. In this test the child is asked to discriminate between a set of words consisting of 4 monosyllables, 4 spondees and 4 trochees. The children's responses are scored for the correct identification of the words, and also the ability to categorize the words according to their syllabic structure. The scores obtained by Subject 1 using conventional hearing aids were: Identification 1/12 and Categorisation 2/12. These represent chance level performance and indicate that the child was receiving little usable information from her hearing aids. Testing with the single channel vibrotactile aid on the same day yielded a categorisation score of 9/12 although no words were correctly identified. Subject 2 was also fitted 3 years prior to this study. The scores for the MST using his hearing aids were 1/12 for identification and 4/12 for categorisation. The scores obtained with the vibrotactile aid on this occasion were 0/12 for identification and 6/12 for categorisation. Subject 3 was fitted with a vibrotactile aid 18 months prior to this study. Initial results on the MST Test using his hearing aids yielded an identification score of 0/12 and a categorisation score of 3/12. Testing with the vibrotactile aid was not carried out with this child.

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ees) presented in a random order. The children were asked to indicate whether the stimulus word was a monosyllable, spondeo or trochee.

ii. Syllable patterns in sentences

Four separate tasks of increasing difficulty were used at this level. The first task evaluated the children’s ability to identify number patterns up to 10. The patterns 1, 12, 123 etc. were presented in a random order and the children were asked to indicate the last number in each pattern. The second task examined the ability of the children to identify patterns of the nonsense syllable /ba/ from a closed set of 10 alternatives differing in either syllable number and/or stress type. Each of the alternatives was presented twice in a random order. In the third test each of the children was presented with a set of 5 sentences which were of a personal nature and differed for each child. Each set included at least one pair of sentences with the same number of syllables. An example of one child’s set of sentences with the number of syllables in parenthesis was: "My name is Wendy" (5), "I’m twelve" (2), "I come to see Geoff every Friday" (9), "My little brother’s name is Daniel" (9), "Snoopy is my dog" (5). Each of the sentences was presented 5 times in a random order, with the children asked to point to the sentence they thought had been said. The final test in this section consisted of a closed set of 10 sentences ranging from 2-11 syllables in length. Prior to testing, the sentences were read to the child to ensure familiarity. The sentences in the list were presented in a random order with a criterion level of 5 correct responses in 1 presentation of the list set as the level of acceptable performance. It was intended that the list of 10 sentences would be repeated until this level was attained. A second measure was also taken. This was the children’s score for the first 2 presentations of the list. After each response the children were informed as to its correctness and if an error was made the children were shown the correct response and the sentence was read again.

Segmental features

The areas examined in this section were:

i. Vowel length.

ii. Final consonant voicing.

iii. Presence or absence of initial /s/.

iv. Presence or absence of final /s/.

v. Presence or absence of initial and/or final /a/.
i. Vowel length

The children's ability to detect vowel length differences was tested using a set of 10 meaningful word pairs differing only in the length of their medial vowels. The vowel pairs /i/ /I, a/ʌ, o/ɔ were contrasted as Bernard (1967) has shown that length is a critical factor in their discrimination in Australian English. Each of the word pairs was presented twice to form a list of 20 contrasts. The children were given a score sheet showing the 2 possible responses for each test item. The 2 contrasts were spoken and the stimulus word was then presented. The children were asked to indicate whether the stimulus was the same as the first or second word in the contrasting pair.

ii. Final consonant voicing

This contrast was used to see if the children were able to perceive the vowel length cues which signal final consonant voicing. Five word pairs - pick/pig, hat/had, feet/feed, back/bag, bat/bad - which differed only in the voicing of their final consonant - were presented 4 times each to form a list of 20 contrasts. The procedure adopted was again the presentation of the 2 alternatives followed by the stimulus, with the child asked to indicate which of the 2 had been said.

iii. Presence/absence of initial /s/

The word pairs at this level differed only in the presence or absence of initial /s/. Examples of this contrast are tar/star, oil/soil and wing/swing. A total of 20 contrasts were presented using the ABX procedure adopted for vowel length and final consonant voicing. This contrast and the following 2 were presented to determine whether the Sentiphone was providing usable information as to the presence or absence of /s/. Such information is not available using a single channel vibrotactile aid with no processing of the speech signal, as the response of the skin is limited to frequencies below approximately 1 kHz.

iv. Presence/absence of final /s/

The 20 contrasts presented at this level evaluated the children's ability to detect the presence or absence of final /s/. Examples of this contrast include sit/sits, kite/kites and stop/stops. The procedure adopted for the previous 3 tasks was again used.
v. Presence/absence of initial and/or final /s/

At this level, the child had to choose the stimulus word from a list of 4 contrasts. The words differed in that 1 had neither an initial nor a final /s/, 1 had an initial /s/, 1 had a final /s/ and 1 had both an initial and a final /s/. An example of this contrast is: talk, talks, stalk, stalks. All 4 words were read to the child prior to the presentation of the stimulus word. The child's task was to indicate which of the four words had been said. There were 10 test items at this level.

Presentation of the Test Materials

The test materials were presented live voice by the examiner with the microphones of the 2 aids held approximately 2 cm from the lips. Instructions were given with lipreading cues available, but the tests were administered with the lips covered by a piece of card. The children held the 2 vibrators in their preferred position and adjusted the gain controls of the aids prior to testing. The children also wore their personal hearing aids during the testing. The tests were administered on an individual basis in 4 weekly sessions of approximately 20 minutes each.

Results

A summary of the results obtained by the 3 subjects is presented in Table II. In almost all cases the scores are well above chance level performance indicating that the aids provide useful information to both segmental and suprasegmental features.

Prosodic features

Words

The identification score for the MST Test (Mean = 36.11%) probably represents chance level performance. An analysis of the data did, however, reveal an interesting trend. It is assumed that if the subject is able to correctly identify the syllable type then s/he has a 1 in 4 chance of correctly guessing the stimulus word. The mean identification scores for the monosyllables (33.3%) and the trochees (25%) are at chance level but the spondee score of 50% is higher than would be expected on the basis of chance. Analysis of the scores obtained for each of the spondaic words revealed that each was correctly identified on 3 of the 6 presentations. Thus the result is not attributable to 1
word being more readily identified, nor is it attributable to exceptional performance by 1 of the subjects. The individual spondee scores for the subjects were 62.5%, 50.00% and 37.5%.

The mean categorization score of 88.7% is well above chance level performance. A confusion matrix showing the response patterns for categorization revealed that the monosyllables were correctly categorized on 95.9% of presentations, spondees 100% and trochees 70.8%. The only confusions made were monosyllables identified as trochees (4%) and trochees as spondees (29.2%). The confusion matrix was then used to calculate the percentage information transmitted (Shannon, 1948). This measure shows how closely each of the various possible responses is associated with each of the various possible inputs. It is a measure of the subject’s ability to discriminate the differing inputs, but does not depend on their ability to label those inputs correctly. The percentage information transmitted was found to be 74.18%.

The scores for the Syllables in Words Test were also well above chance with a mean score for the 3 subjects of 87.8%. A confusion matrix of the subject’s response patterns was again drawn up, and this showed that monosyllables were correctly identified on 96.7% of presentations, spondees on 90% and trochees 76.7%. The error response patterns were monosyllables identified as trochees (3.3%), spondees as trochees (10%), trochees as spondees (11.1%) and trochees as monosyllables (11.7%). The percentage of information transmitted was found to be 64.4%.

Sentences

The first 2 subtests at this level revealed almost perfect performance for both number patterns and nonsense syllable patterns with only one subject failing to score 100% for both tasks. The scores for the tests using meaningful sentences were much lower but still well above chance. For the set of personal sentences (Sentences 1) the mean score obtained by the subjects was 66.6%. With these sentences, however, there was a possibility of confusing sentences with the same number of syllables. A confusion matrix was drawn up comparing the number of syllables in the stimulus sentence with the number of syllables in the sentence given as a response. It was found that on 94% of presentations the children either correctly identified the sentence or gave as a response a sentence with the same number of syllables as the stimulus sentence. The percentage information transmitted for this task was
76.09%. The second sentence task (Sentences ii) represented a far more
difficult task as is evidenced by the mean score obtained of only 38.33%
for the first 2 presentations of the sentence set. It should be em-
phasized that this score is still well above chance. An analysis of the
error patterns found that on 66% of presentations the response given was
either correct or within 1 syllable of the stimulus sentence. The
percentage information transmitted was found to be 51.76%. The cri-
terion level of 50% was reached by Subject 1 on the first presentation
of the sentence set, on the second presentation by Subject 3 but was not
attained within 4 presentations by Subject 2. In this latter case it
was decided to stop testing as the child was becoming increasingly
frustrated by the task.

SEGMEN TAL FEATURES
Vowel length

The mean score obtained by the 3 subjects at this level was 76.7%.
Analysis of the error responses revealed some difference in the scores
for the 3 vowel pairs with i/ı being correctly differentiated on 77.6% of
presentations, ı/ʌ 83.3% and a/ʌ 94.4%.

Final consonant voicing

Although the mean score of 80.0% is well above chance this is attrib-
utable to the scores obtained by Subjects 1 (90%) and 2 (95%). Subject
3's score of 55% represents chance level performance.

Initial /s/

The mean score obtained for this task was 76.7% but again the scores
for the individual subjects differed greatly. Subject 3's score of 66%
is around chance level while Subjects 1 and 2 scored 75% and 90%,
respectively.

Final /s/

All 3 subjects scored well above chance in this test as is indicated
by the mean score of 91.7%.

Initial/final /s/

This task (Mean = 53.3%) involving 4 contrasts proved more difficult
for both Subjects 2 and 3 with Subject 3's score again being attribut-
able to chance. Subject 1, however, was able to complete the task with
a high degree of proficiency scoring 80% correct.
Discussion

The results of the testing programme indicate that the vibrotactile aids used provide useful information to assist in the identification of prosodic and segmental speech features. The scores obtained with the prosodic level tasks show that the aids enabled the children to recognize both word and sentence patterns. The categorization scores for the MST Test and the Syllables in Words Test can be compared with those obtained by a group of deafened adults using single channel vibrotactile aids (Plant, 1982a). The mean score obtained for the MST Test by the adult subjects was 77% (Range 66.6% - 83.3%) while the children in the present study scored 88.9% (Range 87.5% - 91.67%). The adult subjects scored 77.5% (Range 73.5% - 80.0%) for the Syllables in Words Test compared to the children's score of 87.8% (Range 80% - 96.7%). Although the children's scores for both tests were superior to the adults' performance a t-test showed that only the scores for the MST Test were significantly different at the .05 level of confidence. The percentage information transmitted obtained by the adults for the MST Test was 46.25% compared with the children's 74.18%. For the Syllables in Words Test the percentage information transmitted for the adult subjects was 50.00% compared to the children's 64.04%. In both cases the higher percentage information transmitted for the children reflects the fact that the errors made by the children were usually towards items with the same number of syllables as the stimulus. The difference in scores for the two groups of subjects may result from the extended period of training to the children which emphasized the perception of syllabic patterns at both the word and sentence level, the children's use of a dual channel system or a combination of these and other factors.

Sentence level performance is also encouraging, with almost perfect performance for both number strings and nonsense syllable patterns. The latter score indicates that nonsense syllable patterns may be used to provide deaf children with word and sentence patterns in situations where the presence of voiced continuant consonants results in a tactile representation which differs from that available through audition (Zeiser and Erber, 1977). Although the scores obtained for the final two sentence tasks were not as high, they again provide a good indication of the information provided by the aids. The ability to perceive sentence patterns has been shown to assist lipreading skills (Gault, 1930) and it
can also be used to provide deaf children with a model of normal speech patterns on which to base their own productions (Erber, 1979). The importance of using the prosodic information provided by vibrotactile aids to assist in speech teaching should not be underestimated. The speech of the profoundly deaf is "characterized by greater overall duration, greater duration and undifferentiated stress among the syllables and elongated pauses" (Erber, 1979; p. 262). All of these features are transmitted by vibrotactile aids and this information should be used in an attempt to provide more effective speech teaching (Schulte, 1972).

Performance at the segmental level again shows that the aids provide information which can be used to assist in both speech production and perception. The ability to perceive vowel length is an important cue in both vowel identification and the perception of final consonant voicing. All three subjects were able to differentiate long and short vowels, with Subjects 1 and 2 also able to perceive the vowel length cues signalling final consonant voicing. It may be that with more training Subject 3 would also be able to complete this task successfully. Again the ability to perceive vowel length differences should be used in the teaching of speech. Monsen (1974) reported that deaf children tend to produce the long/short pair /i, I/ with "much more restricted durational ranges" (Monsen, 1974; p. 386) than normal hearing subjects. He also found that deaf speakers failed to produce those vowel length differences which signal the voicing characteristics of the following consonant. Simple vibrotactile aids offer teachers the opportunity to model these differences for deaf children as a prerequisite to correct production.

The tasks involving the detection of the presence or absence of /s/ in various positions highlighted the great value of the Sentiphone in providing information regarding high frequency fricatives. Such information is not available via a single channel vibrator with no processing of the speech signal, for the majority of energy for /s/ is located above 3 kHz and is, thus, not detectable via the tactile sense. The Sentiphone signals the presence of /s/ by presenting a signal around 350 Hz. This is subjectively different from the signal produced by the single channel aid and is easily detected. Practical experience using the aid for speech teaching with the experimental subjects has shown that the use of the Sentiphone leads to more consistent production of both /s/ and /ʃ/. This is especially significant when it is considered
that Hudgins and Numbers (1942) reported that /s/ is among the most frequently omitted consonants for deaf speakers. Given that very many deaf children do not possess usable hearing for the high frequencies this is perhaps not surprising. Observations of the speech of the adventitiously hard-of-hearing also show that /s/ is one of the first speech sounds to be disrupted following the acquisition of a high frequency hearing loss. It would appear that the maintenance of an acceptable production of /s/ is dependent upon the ability to perceive this sound.

The aid combination used in this study does appear to offer much useful information to the children but it does appear to have at least two major disadvantages. The first is the size of the system which confines its use to class-room activities. The second is that the output transducers are hand-held which makes the system difficult to use in situations where manual systems are being used to supplement lipreading. It is apparent that a wearable system needs to be designed to overcome these two factors. It is probable that a simple two-channel aid can be designed to meet these demands. If such an aid is designed consideration should be given to providing information as to pitch change via one of the channels. Studies by Risberg and Lubker (1978) and Risberg and Agelfors (1978) have shown the great value of such information. Evaluation of a system which is designed to transmit pitch change information via the tactile sense is currently being undertaken. The second channel of the device should signal the presence or absence of high frequency speech energy. This should be a relatively simple task using a high pass filter at around 5 kHz (see for example Ling and Sofin, 1975). The detection of speech energy in this frequency area can then trigger a signal which is detectable via the tactile sense. In the design of such a system, consideration should also be given to the use of radio input to overcome the problems of environmental noise and distance. Finally the placement of the output transducers needs to be also carefully considered. Spens (1980) in a study of a number of vibrotactile and electrocutaneous aids found that stimulating the fingertips yielded the most information. The use of a hand-held device is, unfortunately, not feasible in many educational settings. It would appear that at this time the use of the wrist/lower fore-arm may represent an acceptable compromise solution. Although some information may be lost with this placement the advantage of portability and user acceptability may be of more importance. Given the results of this study it would
appear that the use of a dual channel vibrotactile system offers great benefit to those hearing impaired children who receive little assistance from conventional hearing aid usage. Such benefits should be maximized if the children have the opportunity to wear such an aid at all times rather than have its use confined to specific training sessions.

References


