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ABSTRACT

A study assessed the practical use of the simplified speech pattern approach to teaching lipreading in a tone language by comparing performance using an acoustic hearing-aid and a Sivo-aid in a tone labelling task. After initial assessment, subjects were given training to enhance perception of lexically contrastive tones, then post-tested. The test used was audio-video recorded test material in Cantonese used to assess speech receptive ability, which includes a tonal component. For each subject, visual stimuli were presented, some accompanied by an auditory signal (either speech tone or larynx tone) through either acoustic hearing aids or a Sivo-aid. One treatment used lipreading alone. Subjects in the experimental group were four profoundly deaf children; all of their deaf classmates served as a control group. Results indicated that the auditory signal contributes to tonal reception more effectively using the Sivo-aid, but some variation still occurred. It is concluded that the simplification approach allows a better match to the user's hearing capabilities, making better use of residual hearing, and allows gradual development of perceptual skills relating to suprasegmentals as well as segmentals. (MSE)

TONES FOR PROFOUNDLY DEAF TONE-LANGUAGE SPEAKERS *

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I Significance of tones

The use of tones to signal different meanings is an inherent characteristic of a tone language like Cantonese. Syllable-based tonal contrasts can be realized by one of six tonal contours, namely, the high level tone, the high rising tone, the mid level tone, the low falling tone, the low rising tone, and the low level tone. This may be illustrated by the segmental combination /ji/. The utterance means "clothing", "chair", "meaning", "child", "ears" or "two", according to which of the six tones the speaker has selected in his production of /ji/. This systematic use of pitch variations on the syllable level constitutes lexical tone contrasts. Tonal patterns can also be superimposed on an utterance for discoursal functions, such as interrogative as opposed to declarative; and for affective purposes, for instance, to express attitudes and emotions. This linguistic use of pitch on the sentence level is intonation, and is also characteristic of non-tone languages, such as English (see, for example, O'Connor and Arnold, 1965).

The production of tonal contrasts relates primarily to the speaker's control of the rate of vibration of his vocal folds in phonation. The hearer perceives changes in the fundamental frequency as differences in pitch. When speech communication takes place in a tone language environment, the ability to produce and perceive tonal contrasts is of utmost importance, for lexical distinctions and grammatical meanings are dependent on the systematic use of voice pitch. Figure 1 shows the contrastive tone patterns in Cantonese.

Figure 1 about here

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From a developmental perspective, vocalisation is one component of the auditory-vocal dimension of communication activity (see Bruner, 1975) which the infant uses to express its intentions at a very early stage in life. Learned patterns of prosodic behaviour and language specific prosody tend to emerge during the first year of life (Weir, 1962; Dore,1975; Crystal, 1975). Recent work on the acquisition of tone languages all agree that phonetic accuracy in the production of lexical tones is learned earlier than in the production of segments (Tuaycharoen, 1978; Tse, 1978; Clumeck, 1980). In normal language acquisition, the establishment of efficient phonatory control precedes accurate articulatory control. This normal sequence must be a sure guide for helping the profoundly deaf child to develop speech communicative ability. Not only is the establishment of phonatory skills of pragmatic and social importance, it also underlies subsequent verbal and cognitive development.

II Tones and the profoundly hearing-impaired

With an average hearing loss over the first four frequencies (250Hz, 500Hz, 1kHz and 2kHz) of greater than 100dB, the profoundly hearing-impaired listener often encounters great difficulty in understanding speech. This is especially so in a tone language situation, because tones cannot be lipread (Ching, 1986). In an experimental task in which the lipreadability of Cantonese connected speech is investigated, it was found that the performance, measured as number of words conveyed in a minute, is worse than that of the same task in English (Rosen, Fourcin and Moore, 1981). It is much more difficult to understand speech on the basis of lipreading alone in a tone language environment. The invisible voice pitch contrasts carry an important functional load in the language system, but lexical tones cannot be lipread in isolation or in context for meaning to be conveyed. When information related only to the voice pitch of the speaker is available auditorily, the enhancement of receptive ability in Cantonese is a 200% gain. Much of the lexical ambiguity is resolved, and the benefit is directly related to the provision of tonal information to complement lipread information. A gain of 76% was obtained for the same task in English. Since the larynx activity of the speaker cannot be seen on the face, while certain articulatory movements are visible, lipreading can best be complemented by the availability of clear information relating to the speaker's voice.

The complexity of the acoustic speech signal undermines the ability of the deaf listener to hear speech. While conventional hearing-aids tend to provide amplification across the speech spectrum, this does not always contribute to improving speech reception. It has

been reported that profoundly hearing-impaired listeners are best at discriminating frequency changes at low frequencies, particularly when these are presented as a pure tone rather than a complex tone (Stock and Rosen, 1986). The limited auditory functioning of the impaired ear is not well served by the conventional acoustic hearing-aids used. Lebisch (1989), for instance, commented on the mismatch between the recommendation of the audiologist who fits the hearing-aids and the preference of the experienced user. The latter consistently adjusts for a higher gain in the low frequency end, and a lesser gain above 1kHz than the settings suggested by the professional. As frequency selectivity worsens (widened critical bands) and frequency discriminability degrades at higher frequencies, what can be processed may be masked by other components in the amplified signal. Background noise would also exert influence on the entire auditory spectrum. Not only is the deaf listener unable to use the additional information in the speech signal, he is also deprived of what he can use.

Even in the case of profound impairment, there is usually some residual hearing abilities. For example, Rosen et al (1987) reported for their profoundly deaf listeners the ability to distinguish periodic from aperiodic sounds, and to discriminate changes in frequency in the low frequency range (below 500Hz). These capabilities are of practical importance in speech perception.

The range within which there is residual hearing corresponds to the larynx frequency range of the speaker. Figure 2 shows a typical left-hand corner audiogram of a profoundly deaf listener, and the corresponding larynx frequency range of two Cantonese speakers.

Figure 2 about here

Variations in tone and intonation are conveyed by systematic changes in the fundamental frequency patterns in the speaker's voice, and these occur below 500Hz in normal speech. If the varying voice pitch could be clearly conveyed to the profoundly deaf listener, he would be able to discriminate changes in frequency in this range and use the tonal information for understanding speech.

III Speech pattern approach to enhancing tonal perception

Tone patterns are most useful to the impaired listener who has to depend on lipreading for understanding speech. For these patterns to be presented in a way matched to the limited auditory abilities, simplification is necessary. Speech pattern features can be extracted from the complex speech signal and presented in a simplified form.

The extraction of tonal patterns from speech can be carried out by the use of a laryngograph, which senses vocal fold closure by two electrodes externally placed on the speaker's neck (Fourcin, 1974). Moore et al (1985) reported extensive work using the speech pattern extraction approach. Fourcin (1986a) described the possibility of presenting simplified tonal information by means of a specially designed hearing-aid. A profoundly deaf listener using the Sivo-aid, which provides him only with a sinusoidal representation of voice fundamental frequency variation, performs consistently better at lipreading connected speech than when he uses his own high quality acoustic hearing-aid, which provides him with the entire speech signal. Rosen et al (1987) also provided evidence showing that for some impaired listeners, simplifying the speech signal to a sinusoid is advantageous to speech reception.

The presentation of tonal and prosodic information in a simplified form can be implemented in the use of the Sivo-aid. The device basically receives a speech input, extracts the voice fundamental frequency from the signal, and generates an acoustic sinusoid at the appropriate frequency and amplitude level. The implementation is detailed in Rosen et al, 1987.

IV Video-recorded tests of tone perception

Since visual information is of crucial importance to speech perception, particularly for hearing-aid users, voice pitch information must be evaluated as an aid to lipreading. The relative usefulness of presenting a simplified speech pattern for enhancing speech perception is assessed using video-recorded lipreading tests. It is profitable to start with simple patterns of contrasts and to gradually build up in complexity on the basis of increasing speech processing abilities.

The present work aims at assessing the practical use of the simplified speech pattern approach by comparing the performance using an acoustic hearing-aid and the Sivo-aid in a tone labelling task. The initial assessment is complemented by a related programme of training to enhance perception of lexically contrastive

tones. Subsequent assessment provides an objective measure of progress.

1 Method

A battery of audio-video recorded test material in Cantonese has been developed to assess speech receptive ability. This includes a tonal component and a consonantal component.

Of primary concern here is the tests on tonal contrasts. These are graded, from two tone discrimination involving the High Level and the Low Falling; to three tone contrasts involving the High Level vs. High Rising vs. Low Falling; to the entire system of six tone contrast, namely High Level, High Rising, Mid Level, Low Falling, Low Rising, and Low Level tones. These tonal contrasts are all based on /ji/, which gives readily available lexical labels corresponding to the six tonal patterns (see Figure 1 for the larynx frequency patterns).

A female native speaker of Cantonese was recorded. Figure 3 shows the voice characteristics of the speaker.

Figure 3 about here

The frequency of vocal fold vibration was derived from a long term sample of the larynx waveform, determined on a period by period basis. The second order probability histogram shows the distribution of laryngeal periods at different frequencies. The modal frequency is 243Hz, with a wide range of vibratory activity in the dominant range of 170 - 329Hz. This range within which varied tonal and intonational patterns are realized can be illustrated in the digram distribution, derived by plotting successive periods against each other. (For a detailed explanation of this laryngograph-based micro-computer analysis of vocal fold function, see Fourcin, 1986b).

The recordings were made on a Sony U-matic high band video-cassette-recorder. Speech was recorded on one channel and simultaneously derived laryngograph signal on the other.

Each of the test items was embedded in a frame /ˉni-ko _hai _____ / (this is _____), the inter-stimuli interval was 7 seconds. Each test consisted of

ten tokens of each stimulus, making a total of twenty in the two-tone tests, and thirty in the three-tone tests. A practice session preceded each test session, giving the fundamental frequency patterns of the contrastive tones and the corresponding lexical items.

Response sheets were used, on which the subjects were required to circle the appropriate lexical item after each stimulus was presented.

2 Conditions

All conditions used visual stimuli, and four of them presented auditory signal either via sound field when the subjects used their own hearing-aids or through the Sivo-aid. The auditory signal can be one of two types, speech tones or larynx tones. A fifth condition was lipreading alone.

The tests aimed at assessing the relative contribution of the conventional hearing-aid and the Sivo-aid; and the use of speech tones and larynx tones for lexical tone reception. The Sivo-aid presents information related only to the voice fundamental frequency of the speaker, with practically no spectral information; while the conventional hearing-aid presents the complex speech signal. The speech tones contain vocal tract information, while the larynx tones contain basically tonal information.

Before the testing session, each subject adjusted for the most comfortable listening level for all conditions with auditory signal. The individual settings for each subject when listening to recorded speech and recorded larynx tones were also observed for optimal reception using the Sivo-aid.

3 Subjects

Four profoundly deaf children served as subjects (Figure 4 gives the pure tone audiograms of the children). After the initial assessment, the children were placed in weekly training sessions using the Sivo-aid and a visual display (a Visi-pitch display). The subjects were tested again after a four-week programme.

Figure 4 about here

A control group, which comprised all students in the same class as the subjects, was also tested. They all

used their own hearing-aids and lipread speech tones, larynx tones, and finally lipread with no auditory signal. All children were in the age range of 10-12 years.

All subjects were tested individually in a sound-treated room. The video signal was presented on a 12in. colour monitor and the audio signal via a loudspeaker for the sound field conditions. As for the Sivo-aid conditions, the audio signal was fed directly into the hearing-aid.

4 Results

The two-tone labelling tests were used. This involves labelling a stimulus as meaning either "clothing" (for the high level tone) or "child" (for the low falling tone). The orthographic representations of these lexical labels are well within the knowledge of even the youngest child tested.

Table 1 gives the labelling results of all children. Responses were generally random (50% or below), showing no discrimination between the two tones. Either the subjects did not understand the task completely, or they lack the ability to classify the simple stimuli accurately. It is apparent that tonal contrasts cannot be lipread, even in a closed class of two oppositions.

Table 1 about here

Four of the twenty-three children tested attained a criterion level of 75% correct in the two-tone tests when lipreading speech tones with their own hearing-aids. These are severely hearing-impaired children with an average hearing loss in the region 75 - 90dB over the first four frequencies. They are making better use of their residual hearing than their profoundly deaf peer group. They are also getting additional information from the speech tones than from the larynx tones.

Further assessment using a three-tone test and subsequent tests of the entire tonal system would reveal limitations in their linguistic capabilities, which could then be complemented by a rehabilitative programme to improve their prosodic skills. Normally hearing children performing the same task can confidently label the two tone contrasts accurately by five, and the three tone contrasts by six. Ching (1984) reported that children made confident judgments on the entire system of tonal

contrasts in Cantonese by about ten years of age.

As the present work is concerned with using a simplified approach to enhance tone receptive ability in the profoundly deaf, the performance of the profoundly deaf subjects is of primary interest.

Comparing the four subjects' performance across conditions of presentation, it can be seen that the auditory signal contributes to tonal reception via the Sivo-aid more effectively (see Table 2). Subject 1 and subject 2 performed better when using the Sivo-aid than when using their own aid. Subject 3 responded best to the larynx tones received via the Sivo-aid. Subject 4 was not able to identify the high level and low falling tones at all.

Table 2 about here

The Sivo-aid presented an auditory signal corresponding to the fundamental frequency of the utterance in the form of a sinusoid. The signal is well defined in periodicity, and frequency changes can be clearly conveyed. This accounts for the significantly higher scores in the Sivo-aid conditions as compared with those in the Own aid conditions for subject 1. He makes no use of the spectral information presented through his own hearing-aid. It is likely that the complex signal precludes the effective use of the available fundamental frequency information. The loss of acoustic information in the sinusoidal presentations is not associated with a potential loss in labelling efficiency. The scores for the Sivo-aid conditions are not significantly different from those in the Own aid conditions for the other three subjects. In fact, the scores are all slightly higher.

The general inability in lexical tone labelling can thus be attributed not so much to the loss of auditory information, but rather to the lack of listening experience to classify the auditory information meaningfully and accurately.

5 Training

Extensive training can make a lot of difference in speech perceptual tasks. White et al (1982), for instance, used a question/statement test to assess the perception of fundamental frequency contours of a patient using different speech coding schemes. Higher scores were obtained with the scheme which presented fundamental

frequency of the utterance only, but the score was not significantly different from chance. Fourcin et al (1979), however, reported significant improvement on the same task for their four patients using an auditory stimulation which presented only fundamental frequency. The patients reported in the latter study had had considerable training in labelling prosodic contrasts before they were tested.

While sinusoidal presentations can simplify the acoustic signal so that it is better matched to the limited sensory capability of the profoundly deaf listener, appropriate training can help in the development of the perception of tonal contrasts, so that it can be an important source of information for the lipreader.

The four subjects were given extensive training specifically on the tonal contrasts in Cantonese. They used the Sivo-aid for each training session so that the larynx frequency patterns of the speaker could be clearly presented auditorily. There was also a visual display to help them monitor their own production. Live training in perceiving and producing the tonal contrasts lasted fifteen minutes per session, and three sessions were given per week to each individual subject. The training programme initially went on for four weeks, after which the subjects were tested again.

Figure 5 compares the scores before and after training for the four subjects using the video-recorded lipreading tests, showing overall improvement with training. Table 2 shows the relative enhancement of labelling ability for each individual subject.

Figure 5 about here

Subject 1 showed confident labelling and performed perfectly when the larynx tones were presented via the Sivo-aid. He also scored 75% correct when using his own aid. There is learning effect for all lipreading conditions on the same task. Subject 2 demonstrated significant improvement, scoring 85% correct labelling when using her own aid and 90% correct using the Sivo-aid after training. Obviously she was not only gaining from the simplified signal but the increased listening experience also enabled her to make better use of the acoustic signal presented via her own aid. The results of subject 3 before and after training were not very much different. Although he was able to attend to the

differences between the two tones in live training, his labelling was not very confident. Further training is necessary so that he can better identify the perceived differences. Subject 4 is probably poorest in frequency resolution ability, although the pure tone audiogram does not give information relating to this aspect. His labelling score was 90% correct when larynx tones were presented via the Sivo-aid. The speech tones, which contain more spectral information possibly interferes with his effective use of the acoustic signal for identifying the contrasts between a high level tone and a low falling tone. While he was completely unable to classify the stimuli before training, he scored 60% correct when lipreading with auditory speech tones after training.

6 Further work

On the basis of the improved labelling ability of subjects 1 and 2, a third tone, the high rising tone was introduced. The subjects were first assessed using the video-recorded three tone lipreading tests. Subject 1 labelled the high level and low falling tones confidently, but was completely unable to identify the new tone. Subject 2 showed degraded performance and overall inability to classify the stimuli. The subjects were then given appropriate training on the three tone contrasts in Cantonese, using the Sivo-aid and the visual display. The subjects were re-assessed after ten training sessions.

Figure 6 compares the subjects' performance before and after training. Subject 1 showed overall improvement, and perfect identification when lipreading with larynx tones presented via the Sivo-aid. He also scored 83% correct using his own aid when listening to speech tones. Subject 2 scored 60% correct for the Sivo-aid condition, but her overall performance using her own aid was not better than chance.

Figure 6 about here

V Summary and Discussion

The present work uses a simplified speech pattern approach to enhance perception of tonal contrasts in Cantonese. The speech pattern is directly related to the larynx frequency of the speaker, which is known to aid lipreading most; and the simplification is implemented in the use of the Sivo-aid. Lipreading tests designed on the basis of speech patterns and graded in terms of

complexity are useful for identifying the difficulties, guiding specific training, and measuring learning effects. Appropriate training has led profoundly deaf subjects from a complete inability to discriminate tones to confident labelling and identification of lexical tones.

As speech pattern features may gradually increase in complexity to encompass more contrastive information, it would be possible to help profoundly deaf listeners to develop perceptual skills relating to suprasegmental as well as segmental contrasts in speech.

The simplification approach makes it possible to provide a better match to the hearing capabilities of the user, so that he could make better use of his residual hearing. While speech pattern features relating to periodicity can be better carried by sinusoidal presentations, the range of frequency variation can also be transposed to a region at which there is optimal discriminative ability. So long as the essential patterns are preserved, the information thus presented can be usefully employed for speech perception.

Especially when working in a tone language environment, hearing-aid design or stimulation techniques need to take into consideration the potential benefits obtainable with the profoundly deaf listener using a speech pattern extraction and simplification approach. Assessment and rehabilitation work guided by this knowledge would speed up learning process and ensure meaningful results, both with regard to the development of perceptual skills as well as adequate expressive skills.

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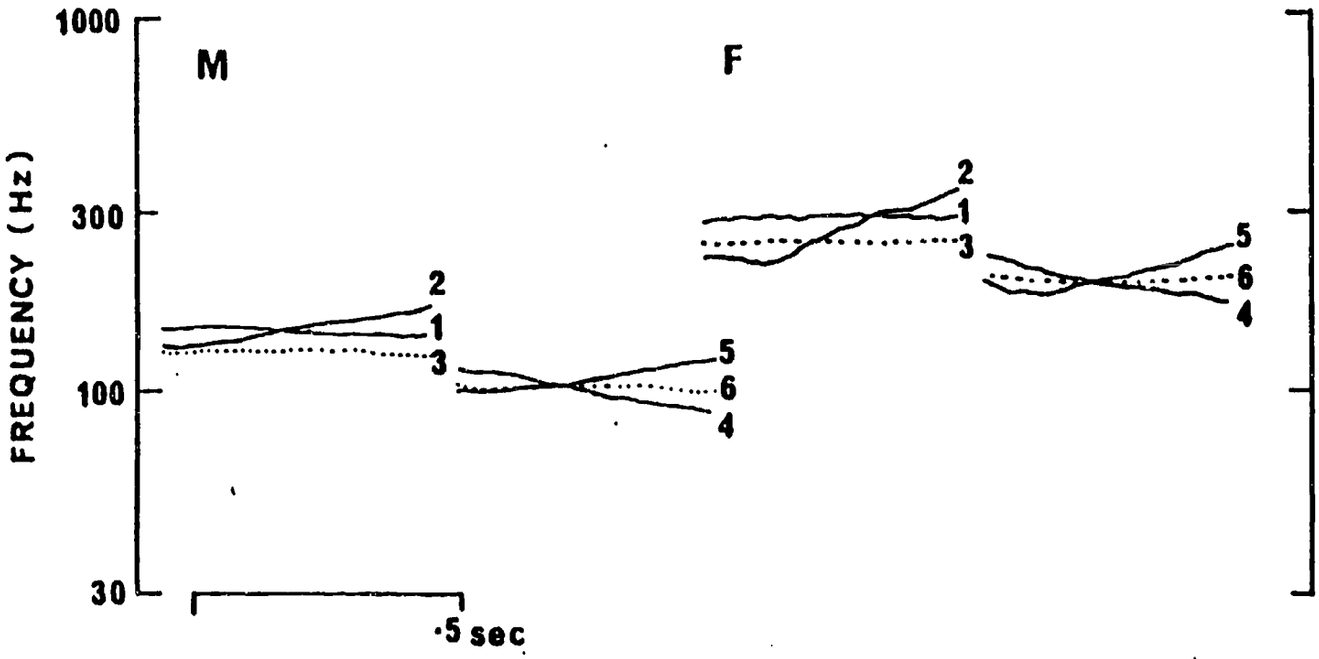
Fx PATTERNS OF TONES



CANTONESE TONES

1 HIGH LEVEL 4 LOW FALLING

2 HIGH RISING 5 LOW RISING

3 MID LEVEL 6 LOW LEVEL

Figure 1 gives the fundamental frequency patterns (measured on a period-by-period basis) of the Cantonese tones produced by a male and a female speaker. The relative patterning of the tonal contours is the same, although there are absolute differences in frequency.

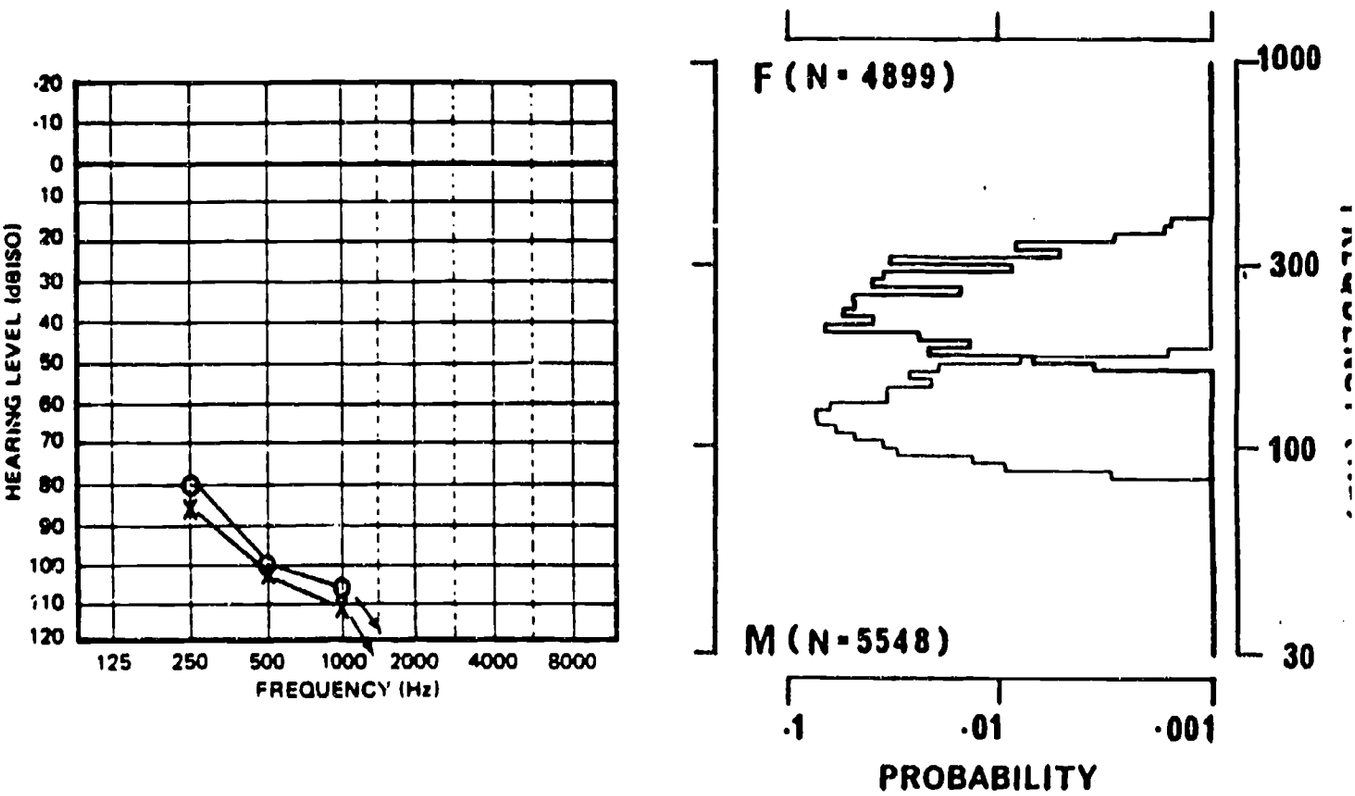


Figure 2 shows a typical left-hand-corner pure tone audiogram and the fundamental frequency distribution of two adult Cantonese speakers, a male and a female. The frequency range at which there is measurable hearing coincides with that of voice pitch variations in speech.

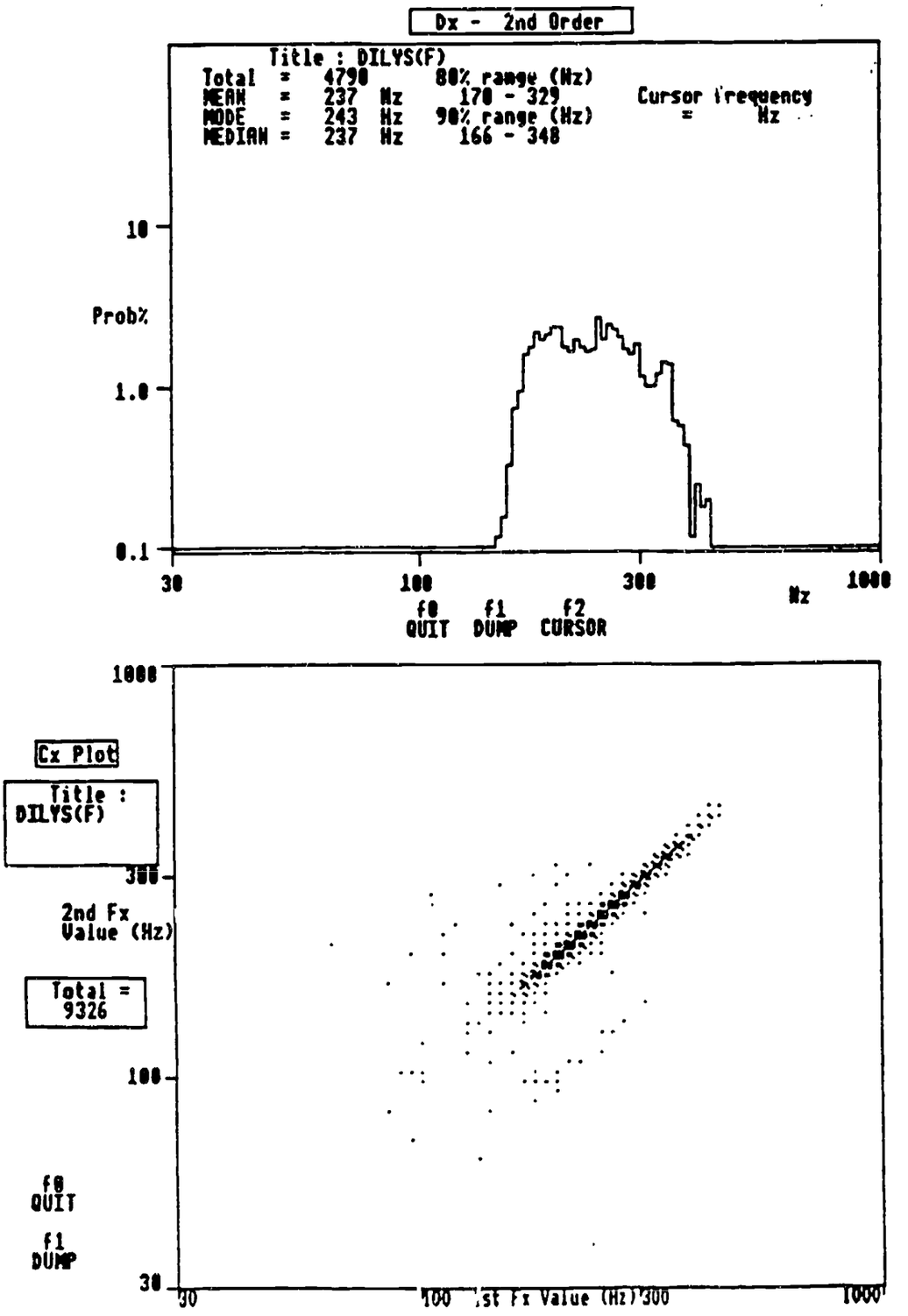


Figure 3 presents the fundamental frequency distribution of the speaker used for producing the tonal stimuli. Her range is indicated by the scatter plot.

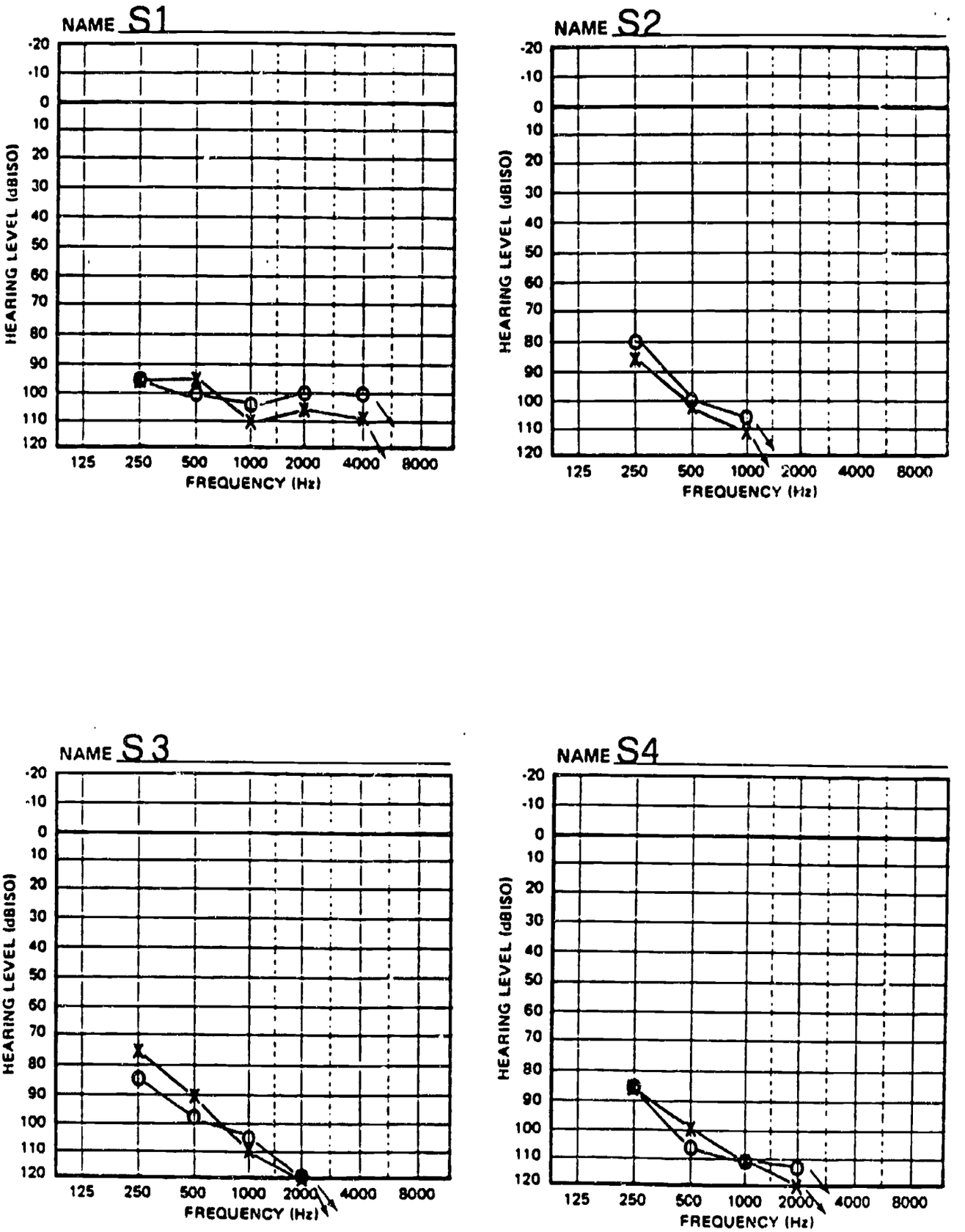


Figure 4 gives the pure tone audiograms of the four profoundly deaf children who served as subjects.

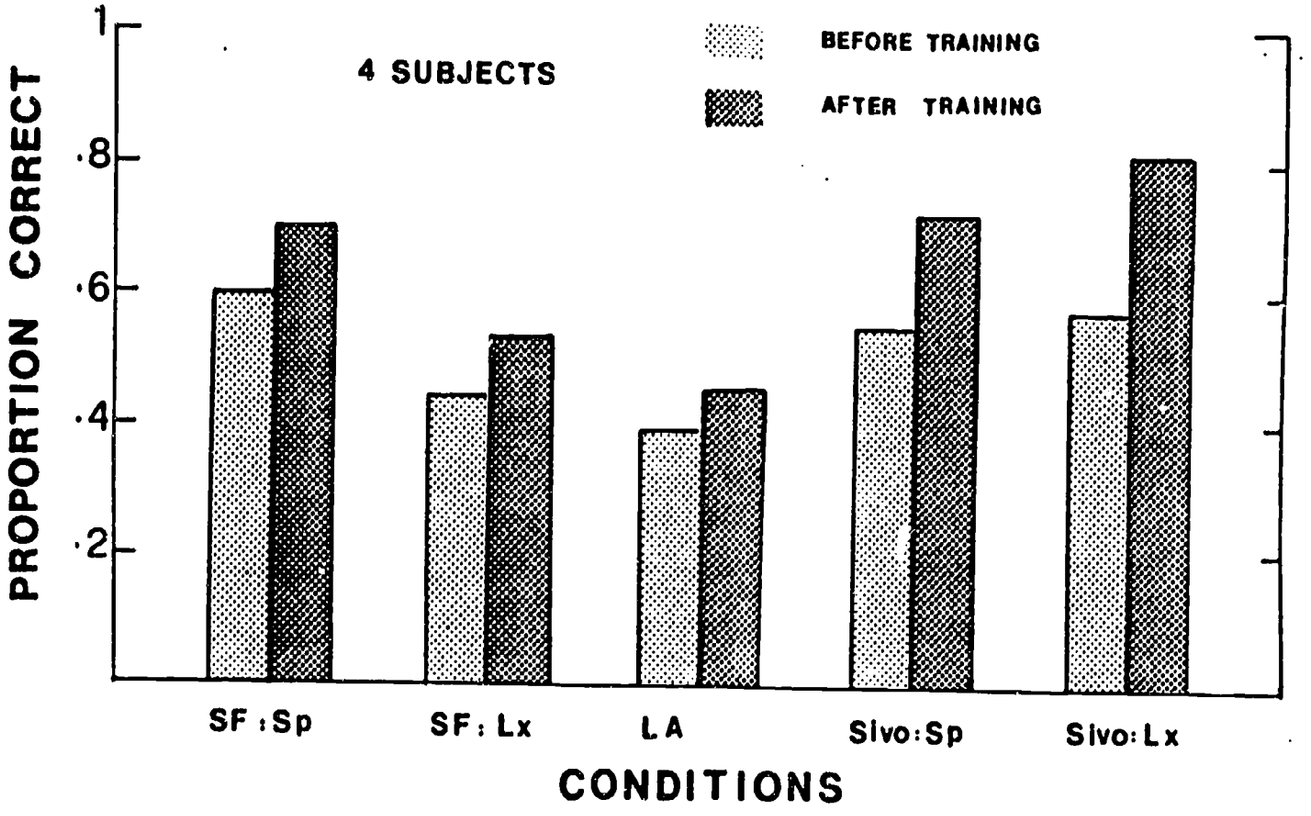


Figure 5 shows the labelling of the four subjects when lipreading with their own aids (SF), lipreading with no auditory stimuli (LA) and lipreading with the Sivo-aid (Sivo). The auditory stimulus, when present, is either speech (Sp) or larynx tones (Lx). Proportion of correct labelling before and after training is compared for the subjects. Two-tone contrasts were used as stimuli.

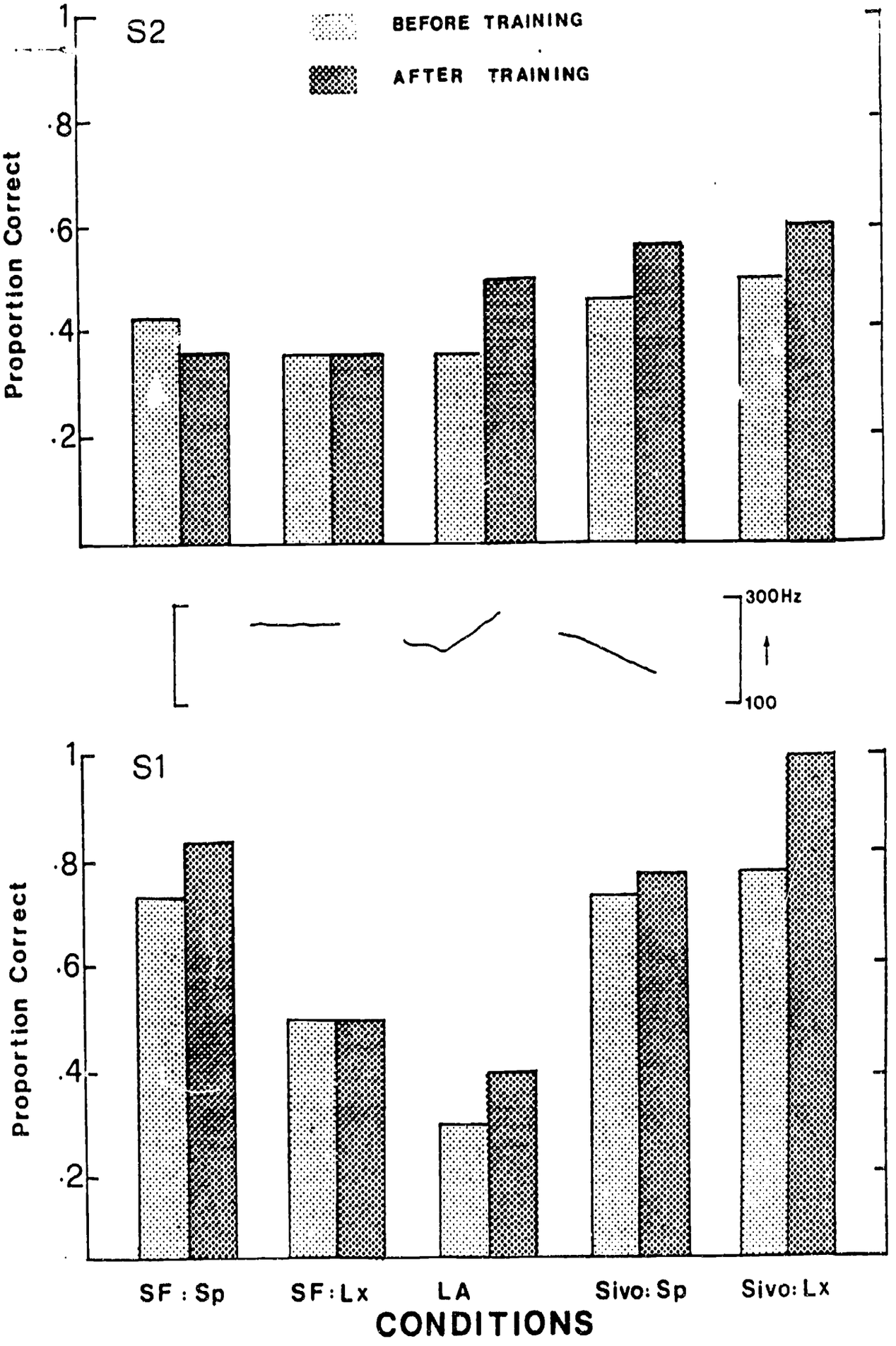


Figure 6 compares the labelling performance of two subjects before and after training for the five conditions.

LIPREADING CANTONESE TONES

HIGH LEVEL : LOW FALLING

Conditions	Lips + Speech	Lips + Larynx tones	Lips Alone
Proportion correct (%)			
Control group:			
P31	50	50	50
P32	55	55	55
P33	60	55	40
P34	75	75	55
P35	55	50	40
P36	50	60	55
P37	100	75	45
P38	50	65	55
P41	60	60	25
P42	45	60	40
P43	60	50	40
P44	55	65	45
P45	70	50	45
P46	85	70	50
P51	50	45	50
P52	75	50	60
P53	55	60	45
P54	70	60	40
P55	45	65	25
Subjects			
S1	70	45	45
S2	60	30	35
S3	60	40	25
S4	50	50	50

Table 1 gives the results of the two tone labelling tests. Twenty-three children took the tests, and they lipread under three conditions: lipreading with speech tones, lipreading with larynx tones, and lipreading alone. The children used their own aids in conditions with auditory stimuli.

LIPREADING CANTONESE TONES

HIGH LEVEL : LOW FALLING

Conditions	Own aid + Speech	Own aid + Larynx tones	Lips Alone	Sivo aid + Speech	Sivo aid + Larynx tones
Proportion correct					
S1 (Before Training)	14/20	9/20	9/20	16/20	15/20
(After Training)	15/20	12/20	12/20	17/20	20/20
S2 (Before Training)	12/20	6/20	7/20	13/20	8/20
(After Training)	17/20	13/20	7/20	18/20	14/20
S3 (Before Training)	12/20	11/20	5/20	6/20	13/20
(After Training)	12/20	11/20	8/20	10/20	13/20
S4 (Before Training)	10/20	10/20	10/20	9/20	10/20
(After Training)	12/20	7/20	10/20	12/20	18/20

Table 2 Individual labelling scores of four subjects before and after training for the five conditions in a two-tone lipreading test.

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