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PERCEPTION OF TONE-GLIDES IN HEARING-IMPAIRED PERSONS

Tatsuo Nakagawa,* Shuzo Saito and Tomoyoshi Yoshino**

Introduction

The perception of speech is a highly-skilled task which requires considerable acuity to be able to resolve the slight acoustical differences among speech sounds. In order to illuminate the speech perception process, psychoacoustical investigations of speech-like sounds and/or synthesized speech sounds have been performed so far.

The place of articulation information for stop consonants is conveyed by formant transitions and by noise bursts.1,2) These temporally varying acoustic stimuli may be modeled by short duration signals in which the frequency component varies across time, such as tone-glides. Psychoacoustical studies of the perception of tone-glides have been performed by many investigators.3-9)

It is generally understood that sensorineural hearing-impaired persons have difficulty in understanding speech. Such deterioration in speech perception can not be fully explained by their pure-tone audiograms and mean hearing losses.10-13) Other auditory properties must be involved.

To find these properties, we have assumed the following model. Speech perception, particularly, stop consonant perception, involves several acoustical perception stages. First, listeners may be able to detect the consonant portion in speech sounds. Second, even in vowel contexts, it seems necessary to be able to detect it. Third, it seems necessary that the listeners be able to discriminate frequency differences in consonant portions and also in vowel contexts.

The present investigation was designed to measure the detection threshold of tone-glides with and without a succeeding vowel. We also assessed the frequency difference limens of tone-glides with and without succeeding vowel.

Method

1. Subjects

Four hearing-impaired subjects between the ages of 17 and 24 participated in the expeiments. Pure tone audiograms for these subjects are shown in Fig. 1. All of the subjects had bilateral congenital sensorineural hearing loss. The test ear for each

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* The National Institute of Special Education.
** Tsukuba University

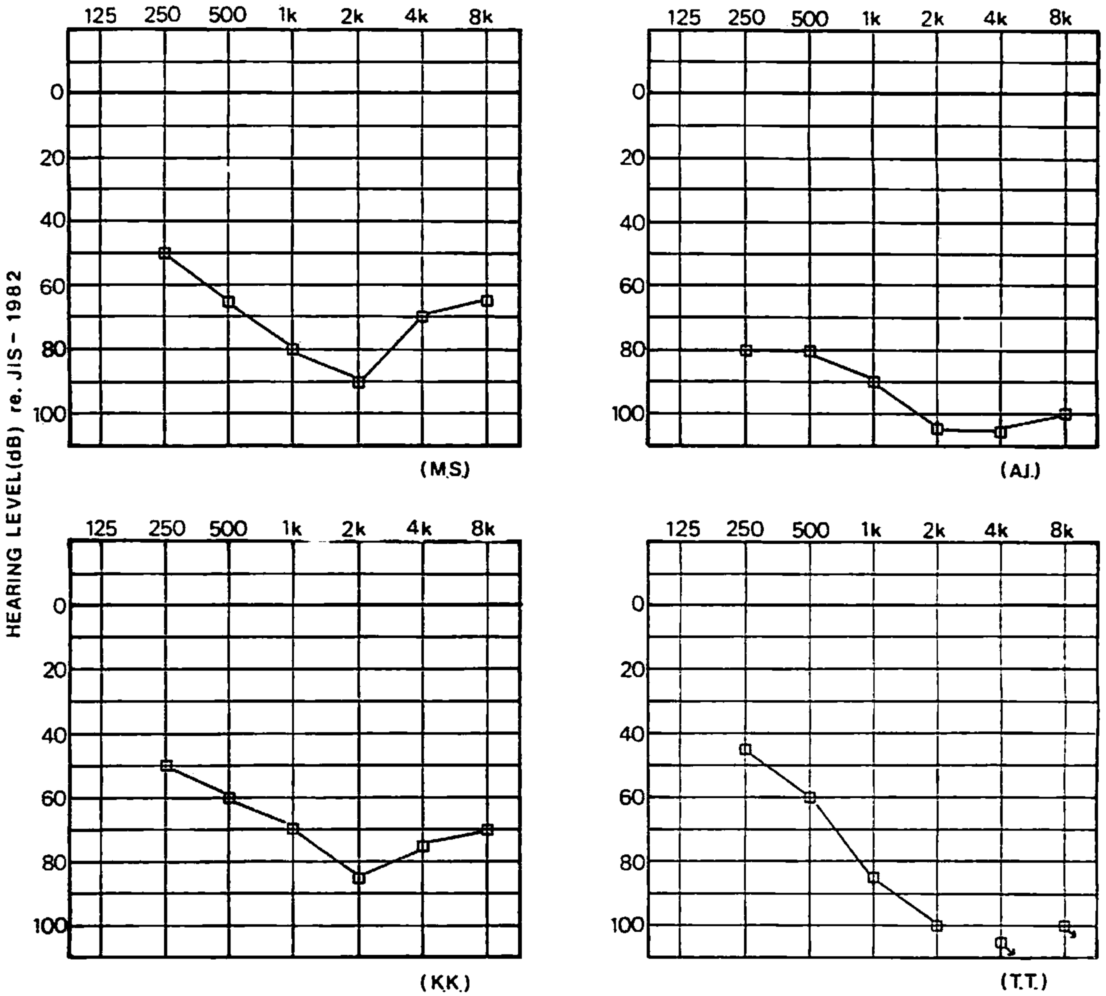

Fig. 1 Audiograms for each of the four hearing-impaired subjects used in the experiment. Thresholds for the test ear(□) are plotted.

subject was the ear on which he or she wore the monaural hearing aid. Some relevant audiometric data for the subjects are presented in Table 1.

2. Stimuli

All stimuli were generated by a micro-computer(NEC PC-8001) and stored in the disk memory. The sampling rate was 10kHz, and all stimuli were low-pass filtered at 5kHz.

Table 1 Audiometric data available for each hearing-impaired subject. The speech discrimnation scores were determined by the use of 50 Japanese syllables.

Subject	Sex	Age	Test Ear	Average Hearing Level (dB, JIS-1982)	Max.Speech Discrimination Score(%)
MS	M	24	R	78	78
AI	F	17	L	91	12
KK	M	19	R	71	66
TT	M	20	L	83	22

The masker was the vowel /a/ synthesized using a computer-programed, cascade-connected formant synthesizer on the basis of data analyzed by the linear prediction method. The five formant frequencies were 690, 1100, 2750, 3750, and 4050Hz. The temporal fluctuation in both the fundamental frequency and the overall amplitude was simulated based on an analysis of natural utterance data.

A stimulus in which the frequency component was linearly changed over its duration was used as the test signal. The signal duration was 10, 25, and 50ms, and the rise and decay time were fixed at 5ms. Two directions of frequency change were used; one was positive(from 500Hz to 1000Hz) and the other was negative(from 1500Hz to 1000Hz).

3. Procedure

A three-intervals, two-alternative forced-choice procedure[10)] was employed for all test conditions. A warning light accompanied the three paired stimuli. The target stimulus was presented at random during the three intervals, and the standard stimulus was presented during the other two intervals. Each interval was separated by about 500ms of silence. Subjects were required to press the one of three buttons corresponding to the interval that they thought contained the target. Feedback was provided by illuminating the correct interval light. An up-down adaptive testing strategy[14)] was used to estimate the 70.7% threshold value on a psychometric function.

In this experiment, we obtained detection thresholds for the test signals in a temporal integration paradigm. After that, the detection thresholds for the signals with the succeeding vowel masker were measured in a backward masking paradigm. After the detection data were collected, the subjects were tested for frequency discrimination of the signals in two conditions. In one condition, the signals were presented separately. In the other condition, the signals were followed by the vowel(backward recognition paradigm). Detection and discrimination performance were assessed after a roughly 20-minute practice period.

In the temporal integration paradigm, the subjects were required to select which of three intervals contained the signal, whereas the other two intervals contained only silence.

In the backward masking paradigm, the subjects were required to select which of three intervals contained both the signal and masker whereas the other intervals contained only the masker. The time interval between the offset of the signal and the onset of the masker was fixed at 10ms. The vowel was presented at a comfortable listening level for each subject.

In the frequency discrimination paradigm, the target stimulus was paired with the standard stimulus in one of three intervals, in each of the other two intervals the standard stimulus was presented. In the positive frequency change condition, the target stimulus onset at a frequency more than the standard but had an identical final frequency to the standard. In the negative frequency change condition, the target stimulus onset at a frequency less than the standard but had an identical final frequency to the standard. The signal level was 15 or 20 dB higher than the threshold determined by the temporal integration experiments.

In the backward recognition masking paradigm, the subjects discriminated frequency differences in the signal accompanied by the vowel masker. The signal level was 15 or 20dB higher than the threshold determined by the backward masking experiments.

The stimuli were presented monaurally to the listeners through a TDH-49 earphone.

Results and Discussion

The thresholds for the signals are shown separately for each of the subjects in Fig. 2. There is a general tendency for threshold values to increase a little as stimulus duration decreases.

Until the same measurements are performed for normal subjects, some of the atypical temporal integration functions found for the hearing-impaired should be interpreted cautiously. However, we think our data suggests a reduced ability for integration over time of acoustic power in frequency varying signals as shown in the frequency fixed signals.15,16)

The thresholds for the signals with a negative frequency change were generally higher than those for the signals with a positive frequency change. For the subjects AI and TT, a shallower integration function was observed for frequency where

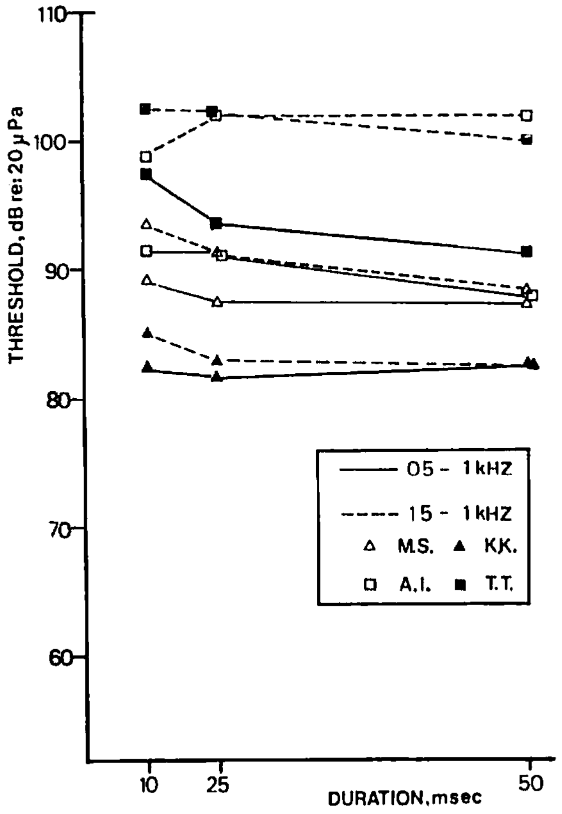

Fig. 2 Temporal integration functions of the four subjects with sensorineural hearing loss.

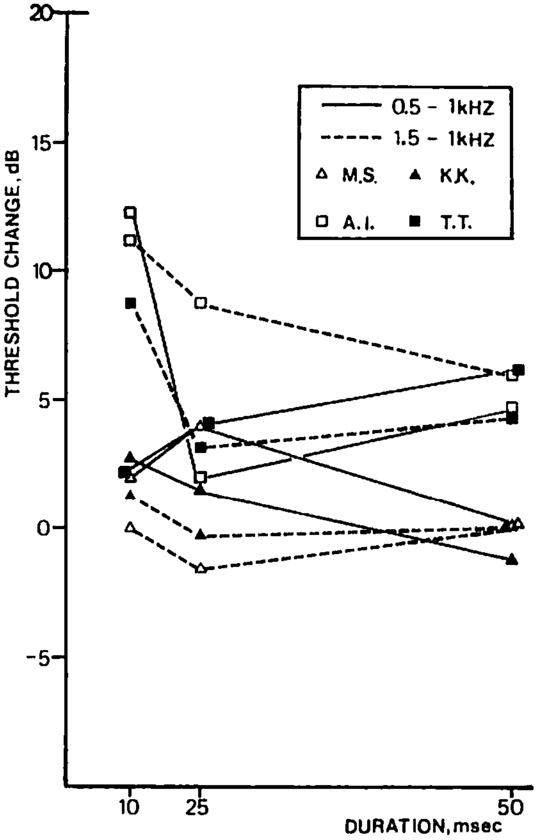

Fig. 3 Threshold changes for the subjects for the backward masking of the signals by the synthetic vowel.

they showed more hearing loss. But this relation was not apparent for the other two subjects. From these results we could not conclude whether the temporal integration is sensitivity specific.

Fig. 3 presents the results for the backward masking experiments. The signal-only thresholds determined by the previous temporal integration experiments can be regarded as reference thresholds for determining the amount of threshold change that the succeeding vowel brings about. It can be seen that the threshold changes for the subjects AI and TT are larger than those for the subjects MS and KK.

In Fig. 4 we display the relationship between the threshold change and the percentage correct in the speech discrimination test using the 50 Japanese syllables. It would appear that there is a moderately good relationship between backward masking and speech intelligibility.

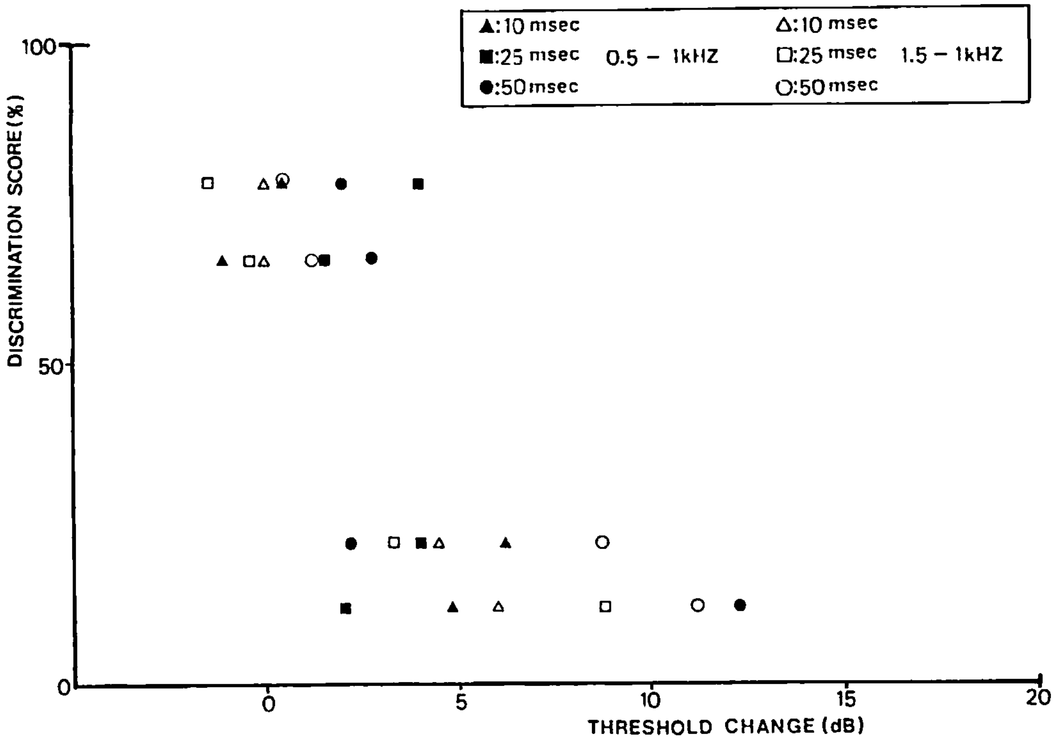

Fig. 4 Speech discrimination scores plotted against threshold changes for the backward masking of the signals.

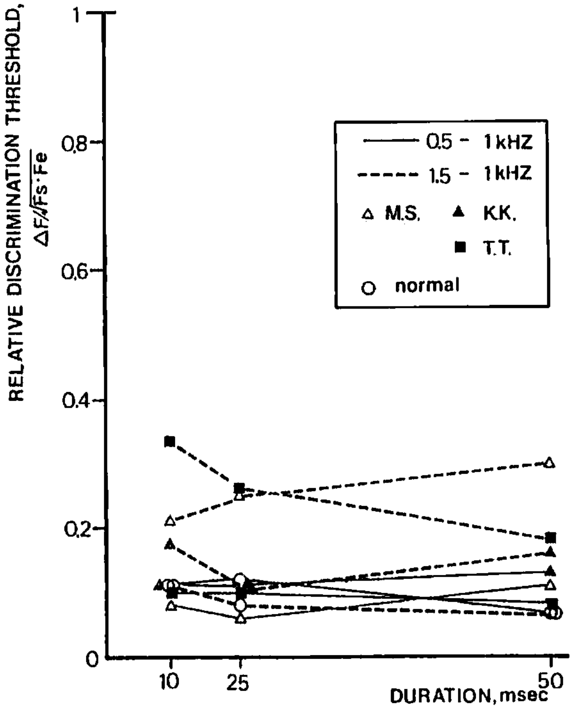

Fig. 5 Relative discrimination thresholds for the signals. The ordinate shows $\Delta F/\sqrt{Fs \cdot Ff}$, where ΔF is the difference limen; Fs is the start frequency of the signal; Ff is the final frequency of the signal.

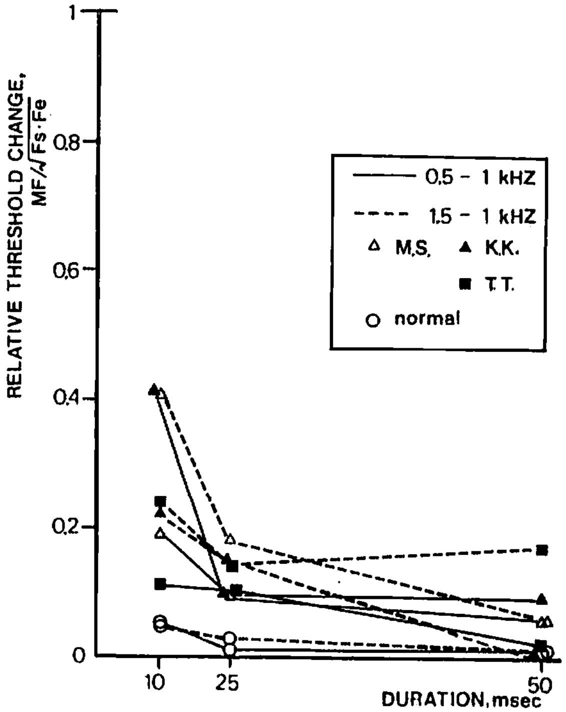

Fig. 6 Relative threshold changes for the frequency discrimination of the signals masked by the synthetic vowels in the backward recognition masking paradigm. The ordinate shows $MF/\sqrt{Fe \cdot Ff}$, where MF is the backward masking in Hz.

The results for the frequency discrimination of the signals are shown in Fig. 5. The ordinate shows the relative discrimination threshold defined as the value of the frequency difference limen divided by the geometrical mean of the start and the final frequencies of the signal. For the sake of comparison, normal data is also included in this figure.

It will be noted that there is no significant difference in relative discrimination threshold for signals with a positive frequency change between the hearing-impaired and normals. But it can be seen from this figure that the relative discrimination threshold for signals with a negative frequency change is higher for the hearing-impaired than that for normals.

Fig. 6 displays the results of the backward recognition masking experiments. The ordinate shows the relative threshold change defined as the amount of backward recognition masking

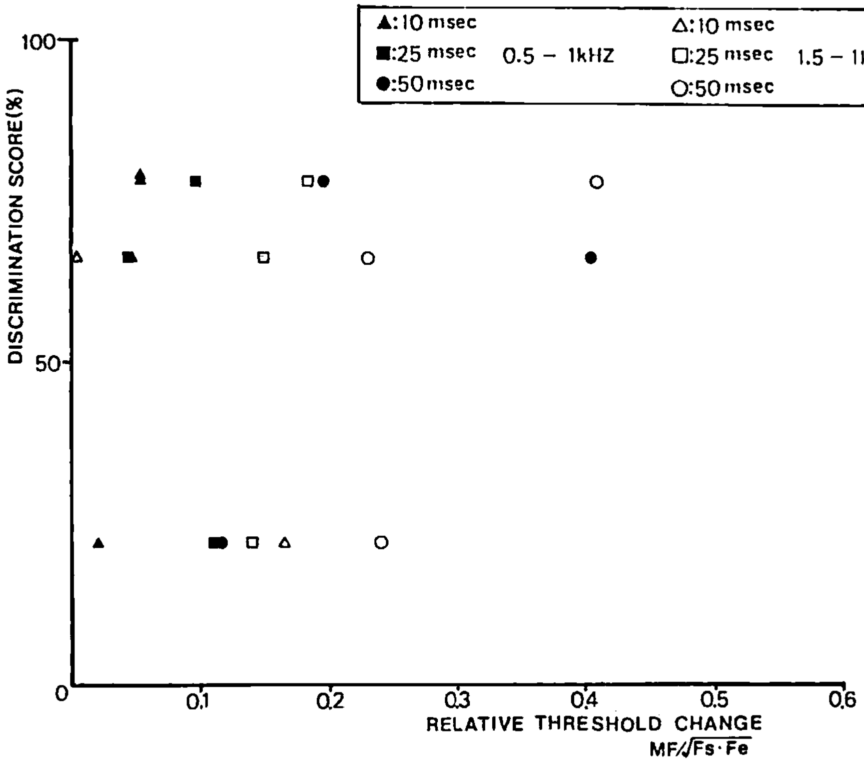

Fig. 7 Speech discrimination scores plotted against relative threshold changes, $MF/\sqrt{Fs\ Fe}$, for the backward recognition masking.

divided by the geometrical mean of the start and final frequencies of the signal. Compared with the normal data, it can be seen that in the sensorineural group the masking effects were generally greater. Particularly, the backward recognition masking effects were greatest in signals with a duration of 10ms.

The relationship between the articulation scores and the relative threshold changes is shown in Fig. 7. From this figure we could find no significant relationship between these.

Summary

The present study assessed the hearing thresholds and frequency discrimination thresholds for signals with frequency changes with and without a succeeding vowel masker. The major findings of this study are as follows.

1. The temporal integration of the signals was reduced in hearing-impaired persons.
2. There was a negative correlation between backward masking and speech intelligibility.
3. In the frequency discrimination experiments, the signals with a positive frequency change were well discriminated in both normal-hearing and hearing-impaired persons. But there were differences in the discrimination performance for the signals with a negative frequency change.
4. We could not find any significant relationship between backward recognition masking and speech intelligibility.

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References

1. Liberman, A.M., F.S. Cooper, D.P. Shankweiler and M. Studdert-Kennedy (1967); Percption of the speech code, Psychol. Rev., 74, 431-461.
2. Cooper, F.S., P.C. Delattre, A.M. Liberman, J.M. Borst and L.J. Gerstman (1952); Some experiments on the perception of synthetic speech sounds, J. Acoust. Soc. Am., 24, 597-606.
3. Pollack, I. (1968); Detection of rate of change of auditory frequency, J. Exp. Psychol., 77, 535-541.
4. Nabelek, I. and I.J. Hirsh (1969); On the discrimination of frequency transitions, J. Acoust. Soc. Am., 45, 1510-1519.
5. Nabelek, I.V., A.K. Nabelek and I.J. Hirsh (1970); Pitch of tone bursts of changing frequency, J. Acoust. Soc. Am., 48, 536-553.
6. Cullen, J.K. and M.J. Collins (1978); Temporal integration of two-component tone glides, J. Acoust. Soc. Am., 64, 1526-1527.

7. Collins, M.J. and J.K. Cullen (1978); Temporal intergation of tone glides, J. Acoust. Soc. Am., 63, 469-473.
8. Nabelek, I.V. (1987); Temporal summation of constant and gliding tones at masked auditory threshold, J. Acoust. Soc. Am., 64, 751-763.
9. Cullen, J.K. and M.J. Collins (1982); Audibility of short-duration tone-glides as a function of rate of frequency change, Hear. Res. 7, 115-125.
10. Tyler, R.S., Q. Summerfield, E.J. Wood and M.A. Fernandes (1982); Psychoaoustic and Phonetic temporal processing in normal and hearing-impaired listeners, J. Acoust. Soc. Am., 72, 740-752.
11. Tyler, R.S., E.J. Wood and M. Fernandes (1983); Frequency resolution and discrimination of constant and dynamic tones in normal and hearing-impaired listeners, J. Acoust. Soc. Am., 74, 1190-1199.
12. Carney, A.E. and D.A. Nelson (1983),An analysis of psychophysical tuning curves in normal and pathological ears, J. Acoust. Soc. Am., 73, 268-278.
13. Nakagawa, T., S. Saito and T. Yoshino (1983); Discriminability of second formant frequencies in hearing-impaired children, Ann. Bull. RILP, 17, 201-209.
14. Gengel, R.W. and C.S. Watson (1971); Temporal integration. I. Clinical implications of a laboratory study. II. Additional data from hearing-impaired subjects, J. Speech Hear. Res., 36, 213-224.
15. Elliott, L. (1975); Temporal and masking phenomena in persons with sensorineural hearing loss, Audiology, 14, 336-353.