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EFFECTS OF STIMULUS DURATION AND INTER-STIMULUS INTERACTION ON VOWEL INTELLIGIBILITY FOR NORMAL AND HEARING-IMPAIRED SUBJECTS

Akiko Hayashi, Satoshi Imaizumi, Takehiko Harada*,
and Hiroshi Hosoi**

Introduction

The deterioration in speech intelligibility observed for sensori-neural hearing-impaired listeners seems unpredictable only from an elevation of the auditory threshold for pure-tones, since speech perception may be affected by other factors, such as the spectral and temporal properties of speech sounds, the speaking rate and the presence of background noise.

Plomp(1978)[1] has suggested that a hearing loss for speech in everyday situations can be described by using two parameters, "attenuation" and "distortion". The value of the "distortion" parameter, which correlates with the reduced speech intelligibility in noise, is larger for the sensori-neural hearing-impaired than normals, and it aggravates of speech perception handicaps and limits the benefit of hearing aids.

It seems that the deterioration of basic auditory functions, such as frequency selectivity and temporal resolution, corresponds to "distortion" in Plomp's model. It is possible to presume that the discrimination of the spectral speech pattern in noisy situations becomes more difficult if frequency selectivity is poorer, and that the perception of consonants which have rapid and dynamic changes in their acoustic characteristics becomes more difficult if the temporal resolution of the hearing system is poor.

Although several groups of researchers have investigated the relationships between speech perception and psychoacoustic temporal acuity observed for non-speech stimuli[2)3)4)], there have not necessarily been consistent conclusions. Moreover, it has not been sufficiently elucidated how the speech perception of hearing-impaired subjects is affected by the temporal factors of speech sounds.

To get a clue toward explaining these problems, in this paper we examined the effects of temporal factors on the vowel perception of the hearing-impaired. In the experiments reported here, the controlled parameters were 1) the length of vowel segments, and 2) the length of inter-vowel silent intervals. We examined how vowel length and inter-vowel silent intervals affect vowel perception through listening tests using isolated vowels and two-vowel sequences.

* Department of Otolaryngology, Faculty of Medicine, University of Tokyo; ** Departmant of Otolaryngology, School of Medicine, Kinki University

Method

Stimuli

Five Japanese vowels spoken clearly by a professional female announcer were digitized through a 12-bit A/D converter at a sampling rate of 20KHz and stored in a micro computer. From the steady part of each vowel waveform, one glottal cycle was extracted. The glottal cycle was repeated continuously to make a vowel segment of a certain duration without any fluctuation in its formant and pitch values.

1) Isolated vowels

The length of the isolated vowels were set at 20, 40, 60, 100, 140 and 180ms. Accordingly, 30 stimuli were made from the five vowels. The initial and final 10ms portions of each stimulus were linearly tapered, as shown Fig. 1.

2) Two-vowel sequences

The stimulus configurations are illustrated in Fig.2. Two vowels with different lengths (40ms or 100ms) were put into sequences with various silent inter-vowel intervals. The length of the inter-vowel intervals was set at 0, 40, 80 and 120ms. Accordingly, 160 stimuli were made, omitting sequences of the same vowel.

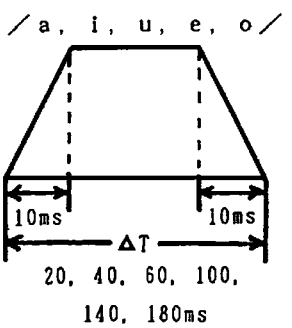

Fig.1 Stimulus configuration of isolated vowels

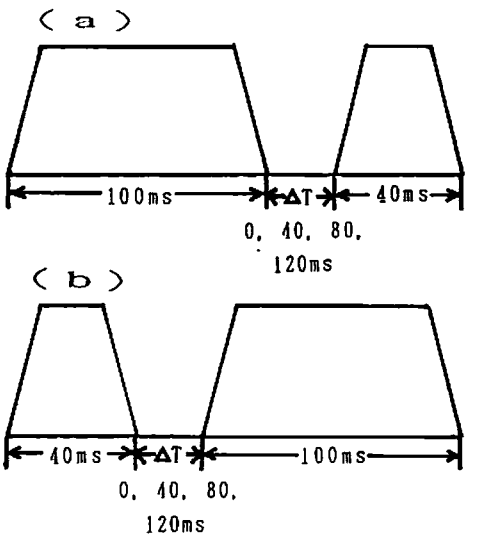

Fig.2 Stimulus configuration of two-vowel sequences

Procedure

The listening tests were performed for 6 normal hearing subjects (average hearing level range for the tested ears: 4-8dB HTL; age range : 21-37 years), and for 53 sensori-neural hearing-impaired subjects (11-80dB HTL; 13-75 years).

The stimuli were presented monaurally at 3-second intervals using an earphone at the most clearly perceived level for each subject. The subjects were instructed to assign one or two (for two-vowel sequences) Japanese character(s) representing vowels to each stimulus.

Results

General tendencies

1)Isolated vowels

Fig. 3 shows the relationship between the intelligibility of the isolated vowels (medians and quartile ranges) and the duration of the vowels for the normal and the hearing-impaired subjects.

The normal subjects showed approximately 100% intelligibility regardless of the length of the stimuli. For the hearing-impaired subjects, on the other hand, the intelligibility are lower than that for the normal subjects for every length. Particularly, the intelligibility of short vowels (20 and 40ms) decreased remarkably.

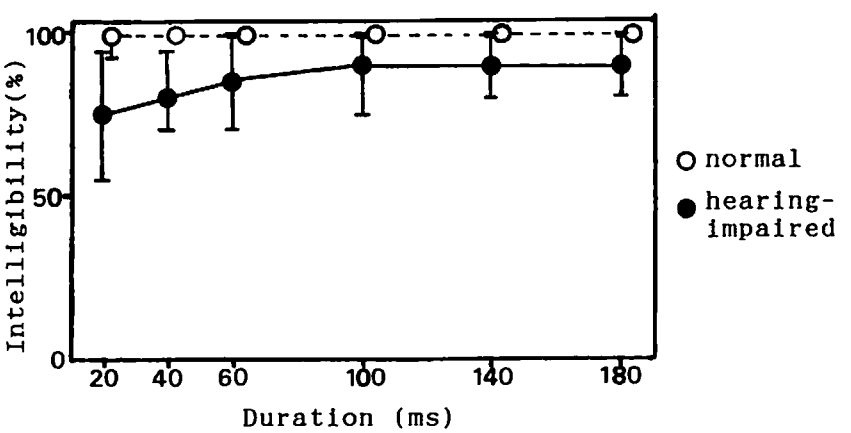

Fig. 3. Intelligibility of isolated vowels for the normal and hearing-impaired. The symbols indicate the medians. the vertical bars represent the quartile ranges.

2)Two-vowel sequences

The relationship between the intelligibility and the length of the silent intervals are shown in Fig. 4 for the normal subjects and Figures 5(a)-(d) for the hearing-impaired subjects. In these Figures, the intelligibility is presented separately according to the vowel length (40 or 100ms) and to the vowels' position (first or second)in the two-vowel sequence. The medians of the intelligibility for the 40 and 100ms isolated vowels are also presented in these figures.

For the normal subjects, the intelligibility was almost 100% for all cases except when the first vowel was 40ms long and immediately followed by a second vowel of 100ms long with a 0ms silent interval. Except this case, the intelligibility for two-vowel sequences was almost the same as that for the isolated vowels of the same length.

For the hearing-impaired subjects, on the other hand, the intelligibility of the individual vowel segments of the two-vowel sequences was lower than that for the isolated vowels of the same length, especially when the silent interval was short. The intelligibility increases when the length of silent interval increased, and approached; but did not necessarily reach, the intelligibility for the isolated vowels.

The interaction between the length of the vowel segment and the vowels' position in the two-vowel sequences was clearly shown when the length of the silent interval was short. Although the intelligibility for the vowels of 100ms was slightly higher when the vowels were first in the sequence than when they ware second. On the other hand, the intelligibility for the vowels of 40ms was rather low when they ware the first compared to when they were the second. Furthermore, the difference between the intelligibility of the two-vowel sequences and that of isolated vowels was smaller for sequences in which the first vowel was 100ms long and the second was 40ms long (see Figs. 5a and 5b) than the other sequences (see Figs. 5c and 5d).

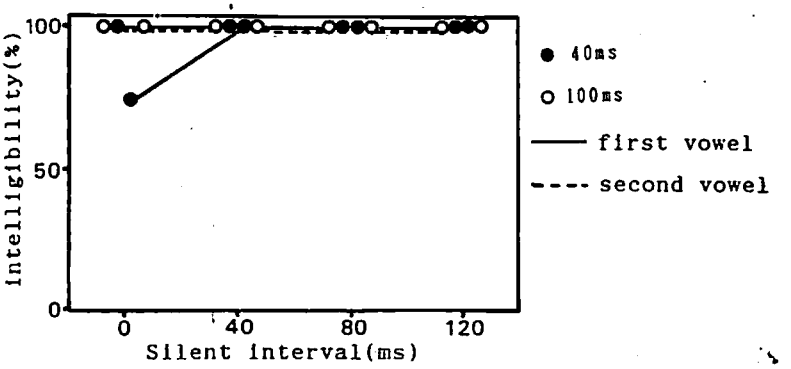

Fig. 4. Intelligibility of individual vowel segments of two-vowel sequences for the normal hearing subjects. The symbols indicate the medians.

3)Patterns of confusions in vowel identification

The differences in intelligibility were not significant among the five vowels for all experimental conditions. The hearing-impaired tended to confuse /u/ and /i/ and /e/ and /o/, and tended to substitute /a/ for /u/. It seems that the confusion was more frequent between vowels whose first and second formant frequencies were close to each other. The hearing-impaired also tended to make no responses when the length of the vowel segment was short.

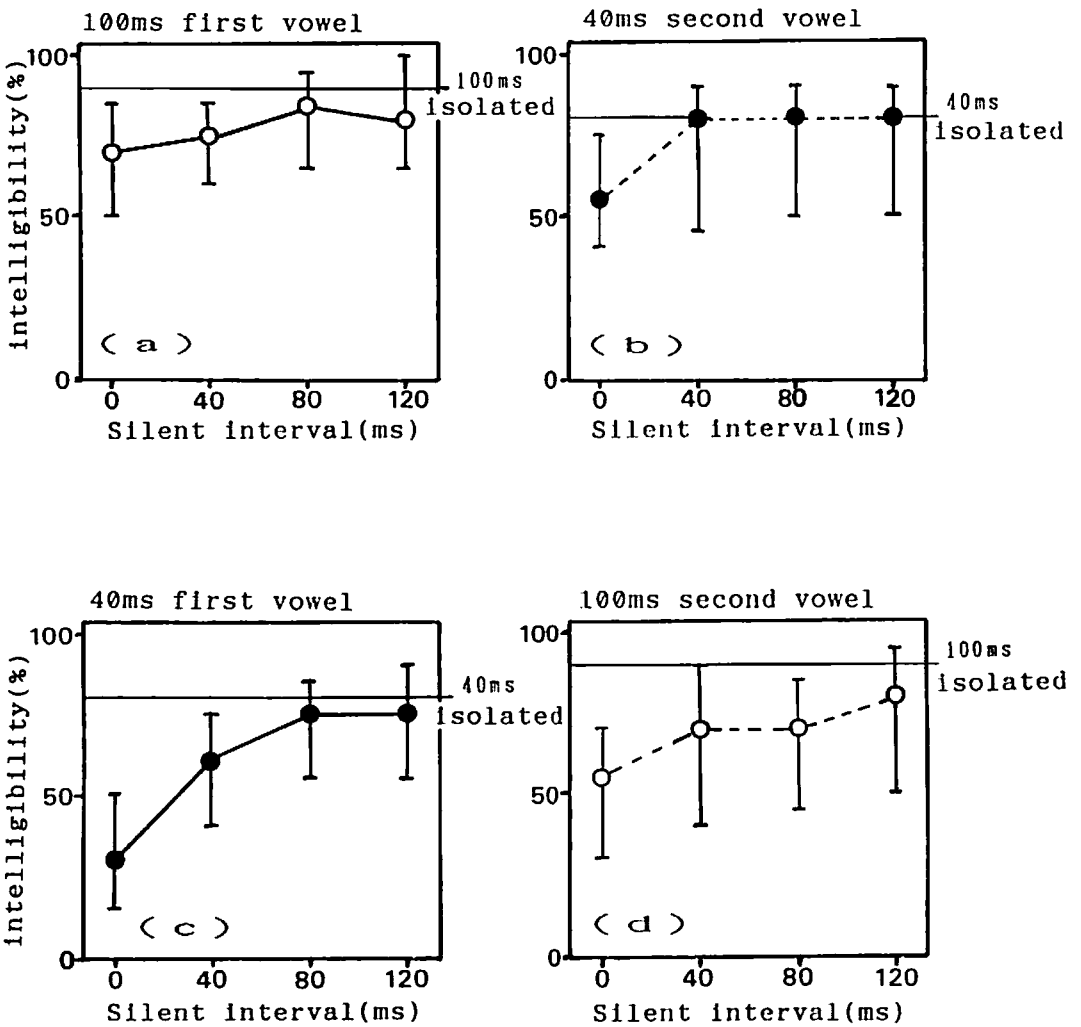

Fig. 5(a)-(d).
Intelligibility of individual vowel segments of two-vowel sequences for the hearing-impaired. The symbols indicate the medians. The vertical bars represent the quartile ranges. The horizontal lines represent the medians of intelligibility for 40ms and 100ms isolated vowels.

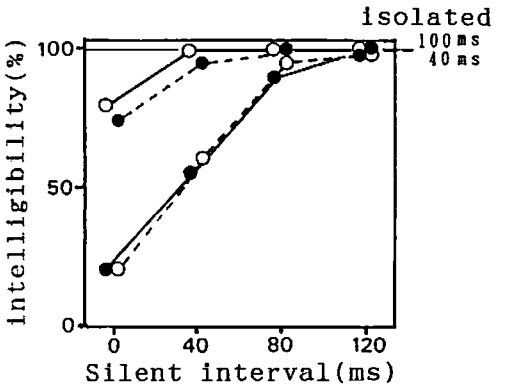

Fig. 6.

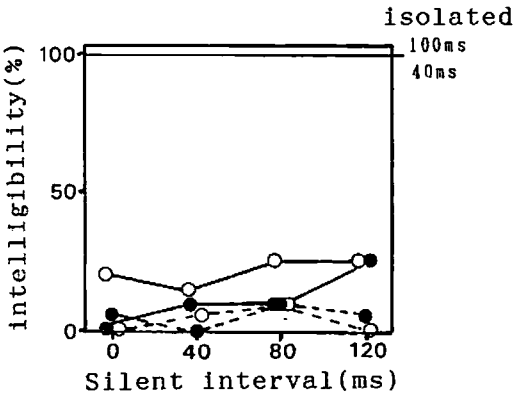

Fig. 7.

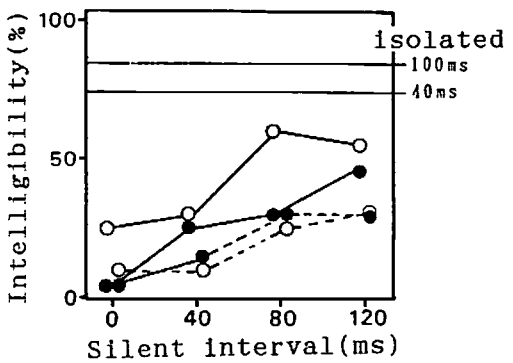

Fig. 8.

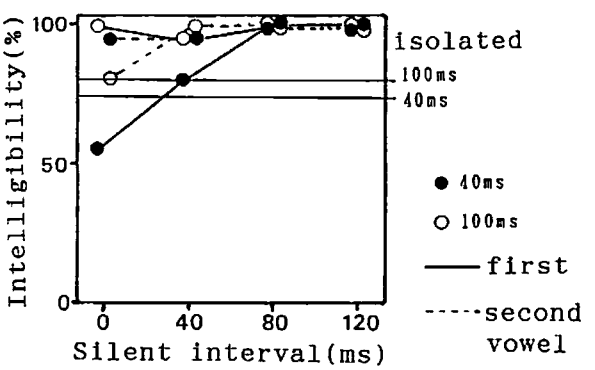

Fig. 9.

Figs. 6,7,8,9 The results for individual subjects.

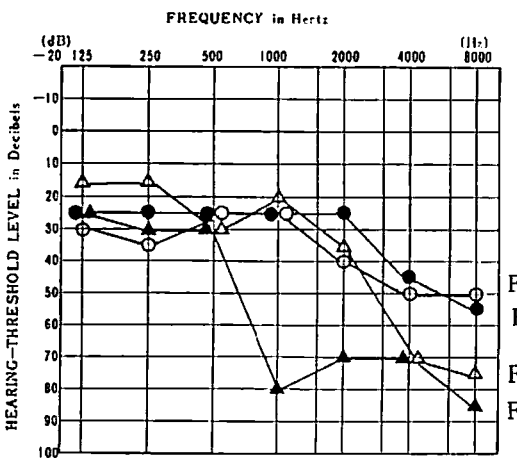

FIg. 7.
FIg. 6.
Fig. 9
Fig. 8.

Fig. 10. Audiograms of the individual subjects represented in Figs. 6,7,8 and 9.

Inter-subject differences among the hearing-impaired subjects

Figures 6, 7, 8, and 9 show some typical results for individual subjects. The pure-tone audiograms of these subjects are shown in Fig. 10. These audiograms have a common characteristic, that is, hearing loss in the high frequency range, although the degree of the loss of the subject shown in Fig. 8 is different from the others.

The results for the hearing-impaired subjects reveal large inter-subject differences as shown in these figures. The subject shown in Fig. 6 shows a typical result representing a strong effect of the silent interval on the vowel perception, and also a significant interaction between the length of vowel segments and the vowels' position in two-vowel sequences. On the other hand, the subject shown in Fig. 7 reveals a remarkably reduced intelligibility for two-vowel sequences when compared to isolated vowels. The subject shown in Fig. 8 tended to wrongly perceive the second rather than the first vowels. The subject shown in Fig. 9 has a higher intelligibility for two-vowel sequences than for isolated vowels. These results do not seem to be predictable from the pure-tone audiograms, which had the common characteristic as mentioned above.

Discussion

Effects of the length of isolated vowels on intelligibility

The results of this experiment indicated that most of the hearing-impaired subjects needed a longer duration of the stimuli than the normal subjects to identify the vowels precisely. Although there were certain individual differences, most of the hearing-impaired subjects showed the highest intelligibility for vowels longer than 100ms. Because this experiment controlled only the length of the vowels, it seems reasonable to concluded that consider the temporal loudness summation in the auditory system affected the intelligibility. In other words, if the vowel was shorter, the loudness was lower and, thus, the intelligibility was lower.

Irwin and Purdy(1982)[5] defined temporal summation as the rising response in auditory sensation for auditory stimulation and measured the minimum detectable duration of signals in the presence of noise. From their results, they concluded that hearing-impaired subjects need a longer signal duration to detect its presence than normal-hearing subjects. Furthermore, Hall and Fernandes(1983)[6] indicate that the minimum duration of signals which is necessary to detect a change in loudness is longer for the hearing-impaired than for normal.

In the present results, the hearing-impaired subjects tended to make no response on the identification task when the length of the vowel segments is shortened. It seems that, because of their reduced temporal loudness summation capability, the hearing-

impaired subjects cannot fully perceive or discriminate the critical information required for identification when vowel duration is too short. Therefore, even if the presence of stimuli can be sensed, some hearing-impaired subjects are apt to confuse vowels of short duration. However, because there are some hearing-impaired subjects having a high intelligibility for isolated vowels regardless of the length of the stimuli, we consider that the temporal processing capability may remain undefected for some of sensori-neural hearing-impaired subjects.

Effects of the silent interval and inter-stimulus interaction on the intelligibility of the two-vowel sequences

The normal subjects revealed decreased intelligibility only when the first vowel was 40ms and followed by 100ms vowels with a 0ms silent interval. In this condition, the effect of backward masking, or interaction must be significant. This effect, however, disappears when the silent interval increases to longer than 40ms, and the intelligibility for first vowels of 40 ms in length also reaches at 100%.

For the hearing-impaired, on the other hand, the inter-vowel interaction is present clearly for 40ms vowels regardless of their position in the sequences. Although the intelligibility increased when the silent interval was lengthened, the optimum length of the silent interval, or the length for which the highest intelligibility was gained, was much longer than that for the normal-hearing subjects.

We conclude that the effects of the inter-vowel interaction is related to the auditory temporal acuity, which is sometimes represented by the amount of non-simultaneous masking and the thresholds for the detection of temporal gaps. Several recent studies have shown that temporal acuity is generally decreased for the hearing-impaired, although the inter-individual differences are large[7)8)9)10)11)]. For instance, Glasberg et al. (1987)[12)] measured the gap detection threshold, simultaneous masking and forward masking in normal and impaired ears for unilaterally hearing-impaired subjects. They reported that a longer interval between signal and masker was required for recovery from forward masking in impaired ears compared to normal ears.

Furthermore, it has been thought that the temporal resolution of the auditory system can be modeled using a hypothetical temporal window (a weighting function) analogous to the auditory filter measured in the frequency domain[13)]. We feel that the width of the temporal window is broader for impaired ears than for the normal ears, and that thus, impaired ears need a longer time for sensations to rise and to decay than the normal ears[14)]. The results reported in this paper may be accounted for by assuming that the hearing-impaired subjects tested here had broader temporal windows than normal ears.

Interestingly, there are some results of our experiment which seem to be not fully explainable by assuming only that the width of the temporal window is broader for the hearing impaired than for normals. For example, some of our hearing-impaierd subjects revealed higher intelligibility for the two-vowel sequences than for the isolated vowels when the silent interval was long enough. This result might be a specific phenomenon of speech perception in which the contrast between successive vowels may help to identify both of them.

Conclusions

For the sensori-neural hearing-impaired subjects, the following results were obtained.

1) For the perception of isolated vowels of various length, the shorter the vowel segment was, the lower the intelligibility was.

2) For the perception of two-vowel sequences, the shorter the inter-vowel silent interval was, the lower the intelligibility was. The intelligibility for the short vowels decreased much more significantly than for the long ones when the silent interval became shorter. The intelligibility of individual vowels in two-vowel sequences was lower than for isolated vowels for most of the hearing-impaired subjects.

3) There were large inter-subject differences in the amount and manner of the decrements in intelligibility when the temporal factors were set in severe conditions. The degree of the effect of temporal factors on the intelligibility of vowels seemed unpredictable from only the pure-tone audiograms.

These results indicate that the vowel perception of the sensori-neural hearing-impaired is easily affected by the temporal factors in the stimuli. This suggests that the temporal processing capability in the auditory system of the hearing-impaired is usually reduced.

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