Intelligibility of Interrupted Japanese Vowels*

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INTRODUCTION

Various kinds of distorted speech sounds, such as filtered speech, interrupted speech, accelerated speech, retarded speech, etc. have been used in the diagnosis of retrocochlear deafness. Interrupted speech was not used diagnostically until Bocca reported its clinical application in 1956. Some investigators, however, had performed experiments on the effect upon intelligibility to normal subjects of periodically interrupted speech (Poirson 1920, Marro 1936, Montani 1946, Miller & Licklider 1950). They concluded that the effect of interruption upon intelligibility depended on the two variables, interruption rate and speech-time fraction.

In the present paper, to clarify the role of the time factor in speech perception, and to apply this knowledge to improve hearing tests in the diagnosis of retrocochlear deafness, the intelligibility of periodically interrupted Japanese vowels was investigated when the interruptions were at the same rate as the fundamental frequency of the vowels and at a repetition rate several times as long as the fundamental period.

EXPERIMENT I: Interruption synchronized with fundamental periodicity of Japanese vowels.

In this experiment we investigated the intelligibility of interrupted Japanese vowels when the same fraction of the fundamental period was repeated in interruptions synchronized with the fundamental periodicity of the vowels.

The intelligibility of this kind of interrupted vowel, stated as a function of the duration of the sound-time or silent-time fraction, should demonstrate the temporal frame of the fundamental wave of the vowel.

Procedure

The five Japanese vowels (/a/, /i/, /u/, /e/ and /o/) were interrupted by an electronic switch synchronized with the fundamental frequency of the vowel. The sound-time and silent-time fractions were varied in two series separately. The patterns of interruption are illustrated in Fig. 1. These interrupted vowels of the two series were produced with the equipment shown in the block diagram in Fig. 2. The electronic switch designed by the author utilized the "tone burst generator"

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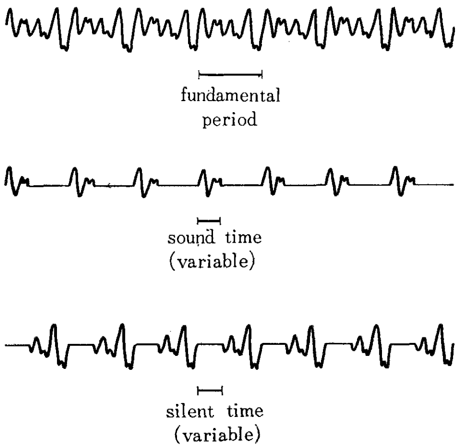


Fig. 1. Patterns of interruption synchronized with fundamental frequency of vowels.

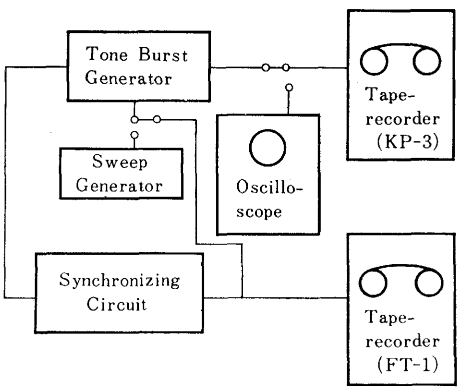
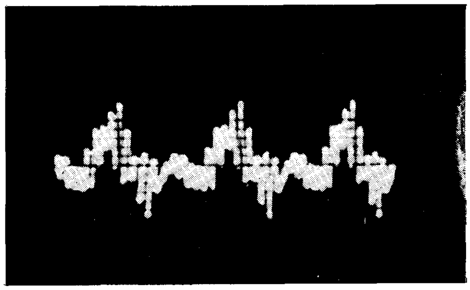
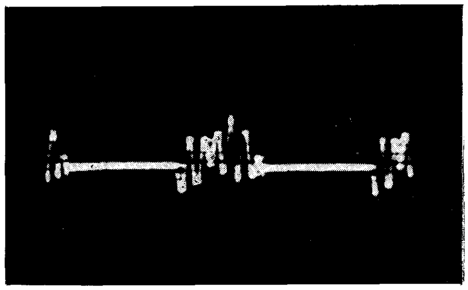


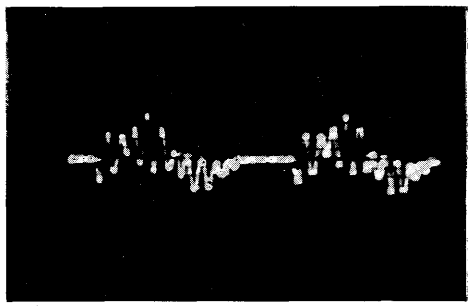
Fig. 2. Block diagram.



Original Wave



Sound-time Fraction : 1.5 msec.



Sound-time Fraction : 3.0 msec.

Fig. 3. The interrupted vowels /i/.

of R.G. Roush (1947). The interruption was performed in synchronization with the negative trigger made from the negative peak of every fundamental wave. The sound-time fraction of each interruption started from the same point of every wave, and its duration was variable. The silent-time could also be produced starting from a certain fixed point of each wave with the use of the same equipment. In this way, a predetermined portion of every fundamental wave of vowel could be sounded or eliminated.

A female voice (pitch: ca. 280 c/s) was utilized, and a steady portion of the vowel, about one second in duration, was used in this experiment. The sound-time fraction of interrupted vowels in Series-I and the silent-time fraction in Series-II were varied by steps of 0.5 msec. from 0.5 msec to 3.0 msec. Thus an interrupted fundamental wave was obtained (Fig. 3).

Six samples were recorded for each vowel in each series, a total of 60 samples, which were then placed in random order and recorded on a test tape. The duration of each sample was ca. 1 sec., and the pause between them was ca. 7 sec. Ten trained listeners with normal hearing were asked to make two responses to each stimulus, an unforced first choice response and a response rating their first choice.

The first response was an attempt to identify the stimulus and write down one of the five vowels. However, when a listener could not identify the stimulus as a particular vowel, he was permitted to write down two of five vowels. In that case, the articulation score was 0.5 for each of the two vowels recorded.

The rating response was designed to indicate the quality of the responses. The listeners assigned a rating of 4, 3, 2, 1 or 0 according to how distinctly they

Fig. 4. Articulation score (%) of the interrupted vowels in Experiment-I.

S \ R	Sound-time Fraction	/a/	/i/	/u/	/e/	/o/	Silent-time Fraction	/a/	/i/	/u/	/e/	/o/
/a/	0.5 msec.	5	20		65	10	0.5 msec.	85				15
	1.0	90			5	5	1.0	90		5	5	
	1.5	95				5	1.5	80		5		15
	2.0	95				5	2.0	90				10
	2.5	90			5	5	2.5	75				25
	3.0	95				5	3.0	50		15		35
/i/	0.5 msec.	5	60		35		0.5 msec.		85	10	5	
	1.0	5	45	10	40		1.0		35	35	25	5
	1.5		60	10	25	5	1.5	5	55	20	15	5
	2.0		100				2.0		45	35	20	
	2.5		95	5			2.5	10	50	40		
	3.0		90	10			3.0	5	30	20	40	5
/u/	0.5 msec.	10		15	70	5	0.5 msec.		25	50	15	10
	1.0	55		15		30	1.0	10	5	60	15	10
	1.5	20	5	50	15	10	1.5	15	5	65	10	5
	2.0	30		55		15	2.0	5		75	5	15
	2.5	15	15	30	15	25	2.5	10	15	70	5	
	3.0	25		45	15	15	3.0	5	5	40	35	15
/e/	0.5 msec.		5	15	75	5	0.5 msec.	5			95	
	1.0		5	10	80	5	1.0	10	5	5	70	10
	1.5				100		1.5	35			50	15
	2.0				100		2.0	15			45	40
	2.5		5		95		2.5	40	5		45	10
	3.0				100		3.0	10		30	15	45
/o/	0.5 msec.	55		5	5	35	0.5 msec.	60				40
	1.0	25		25	5	45	1.0	40		10		50
	1.5	40			25	35	1.5	20		10	20	50
	2.0	50		10	10	30	2.0			55	15	30
	2.5	45		5	15	35	2.5		15	40	30	15
	3.0	30			20	50	3.0	35		35	25	5

could identify the stimulus as a particular vowel. A rating of 4 was given a particular vowel could be identified with complete confidence, and a rating of 0 when the stimulus could not be recognized as a vowel at all. The intermediate rating indicated the degree of uncertainty in identification. The rating score were calculated mathematically, and the total rating score of correct responses divided by the number of listeners was termed the "mean rating score" (MRS).

The samples were also analysed by sound-spectrography.

Results

1) Results of the first choice response:

Fig. 4 shows the results of unforced first choice responses. The articulation score was calculated as a function of the duration of the sound-time or silent-time fraction.

The articulation score for /a/, /i/ and /e/ rapidly reached close to 100% with the increase in duration of the sound-time fraction in Series-I, while the articulation score of these three vowels was not so great in Series-II, and /a/ was often confused with /o/; /i/ was confused with /u/ or /o/; and /e/ with /a/ or /o/. The score for /u/ and /o/ remained low in both series.

2) Results of the rating response:

The function of MRS vs. the duration of the sound- or silent-time fraction for each vowel is illustrated in Fig. 5. The results of Series-I are represented by a solid curve, and those of Series-II by a dotted curve. The MRS-function for /a/,

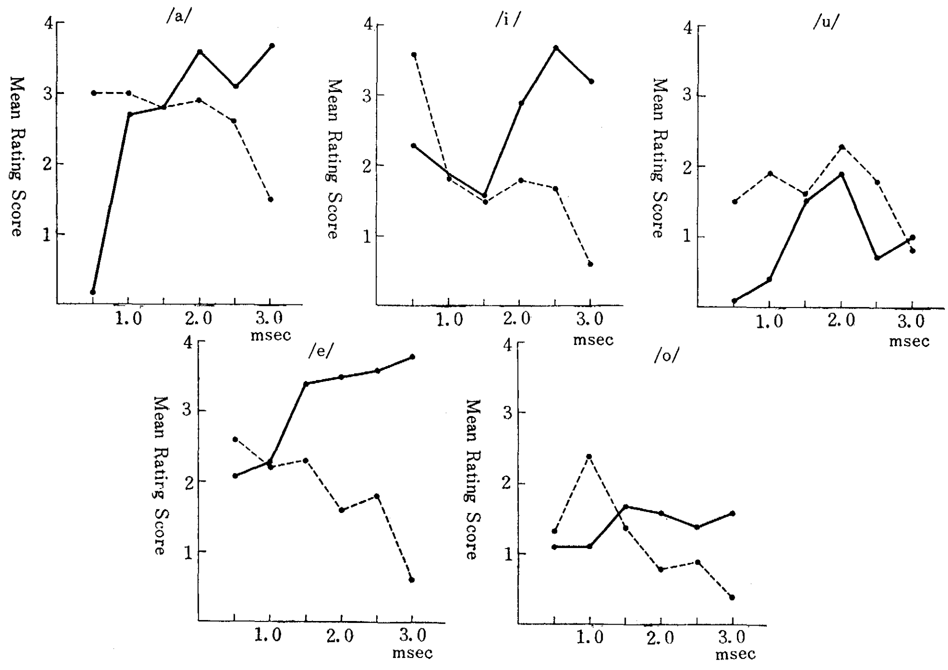


Fig. 5. The MRS-function vs. the duration of the sound- or silent-time fraction for each vowel.

/e/ and /i/ increased with the sound-time fraction in Series-I, and decreased roughly with the duration of the silent-time in Series-II. However, the MRS-value of /u/ and /o/ remained low in both series. These results were similar to the results of the first choice response. It is concluded that the MRS-value reflects rather accurately the quality of the stimulus.

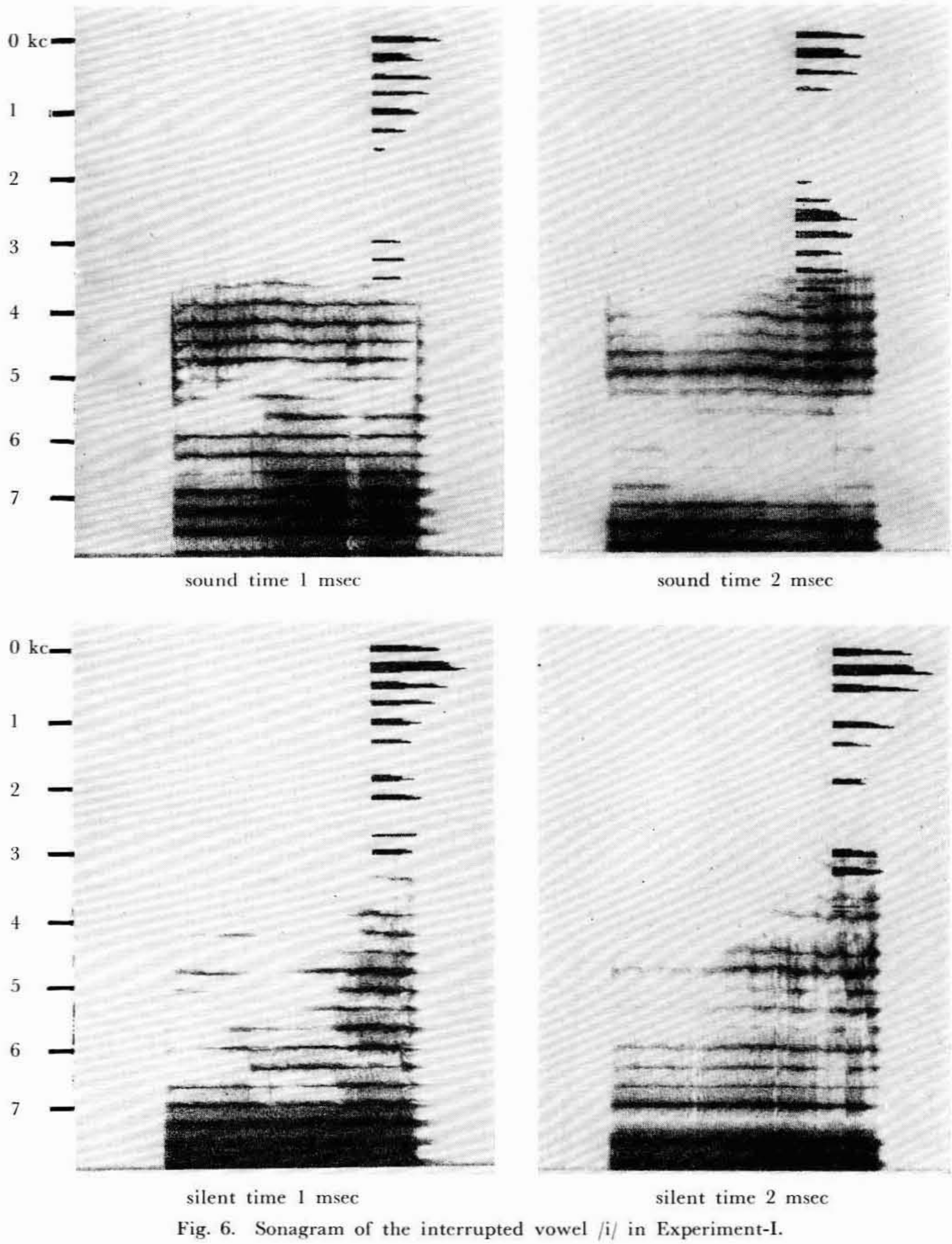


Fig. 6. Sonagram of the interrupted vowel /i/ in Experiment-I.

3) Results of sound-spectrography:

A sound-spectrogram of test materials is presented in Fig. 6; the upper two are of Series-I, and the lower two of Series-II. The section pattern of the sound-spectrogram is diagramed in Fig. 7. It is estimated that the original vowel can be reproduced, if interrupted vowels with a silent-time fraction of 1 msec. and a sound-time fraction of 1 msec. are added. So an attempt is made to sum up the corresponding section patterns of the two series graphically. The results are shown

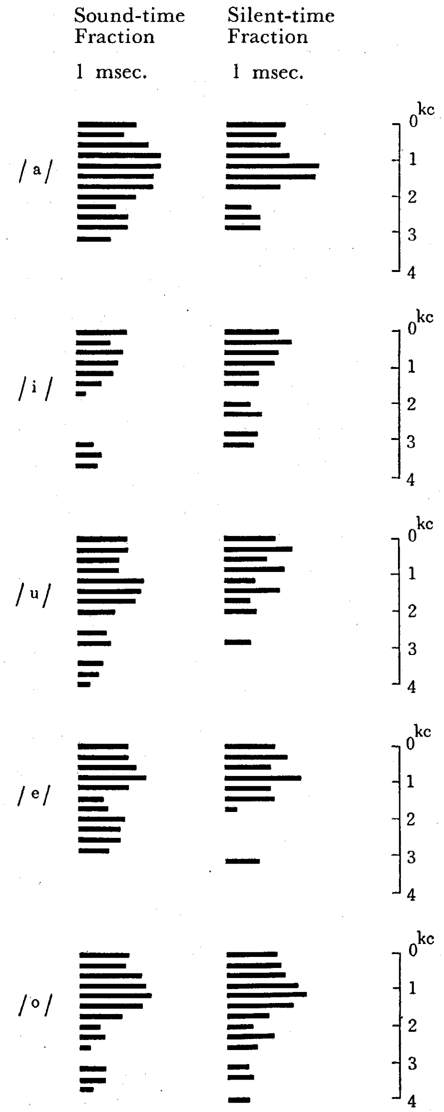


Fig. 7. Diagrammatic representation of the section pattern of sonagram of Series-I and the corresponding Series-II.

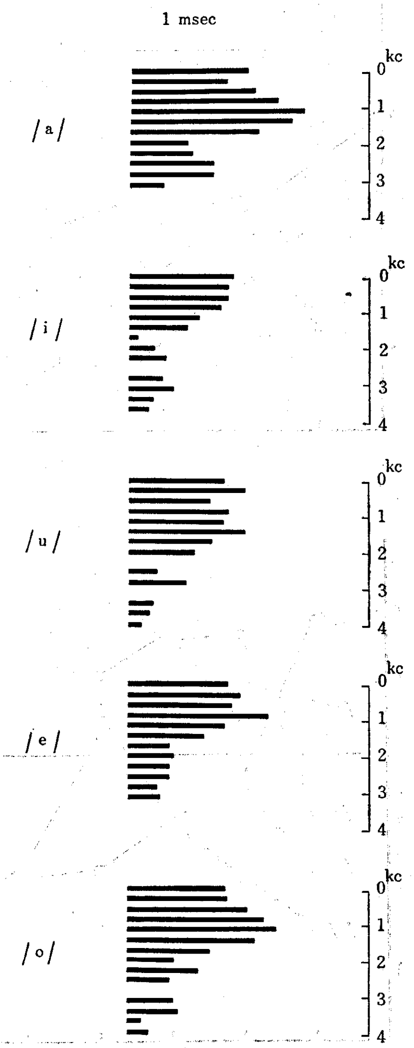


Fig. 8. Summed up section patterns of the interrupted vowels with a sound-time fraction of 1 msec and a silent-time fraction of 1 msec.

in Fig. 8. These summed up patterns are similar to the original section patterns of Japanese vowels in general.

These results indicate that the two series of test stimuli were produced as expected.

Conclusion

The intelligibility of the interrupted vowels, except /u/ and /o/, increased with the increase of the sound-time fraction in both series, while the intelligibility of /u/ and /o/ was significantly low.

If the "information" of a vowel exists uniformly in the fundamental period, then the MRS-function would increase linearly from 0 to 4 in Series-I, and would decrease in the same manner in Series-II (Fig. 9). If this assumption is true, the summed up MRS-value of Series-I and the corresponding Series-II would always score 4 or 100% (Fig. 10). But actually the MRS-function did not show a linear proportion, and so the summed up MRS-value rose and fell irregularly. The summed up MRS-functions of /a/, /e/ and /i/ were generally above, and those of /o/ and /u/ were below the line of 4.

The assumption of uniform distribution of the "information" cannot be accepted. The distribution of the "information" is not similar for every vowel. Individually speaking, if the stimulus of /a/ in a duration of 1 msec. or more is presented repeatedly, the sound may be heard correctly as /a/. Repetition of the first 1 or 1.5 msec. portion of a stimulus may be neces-

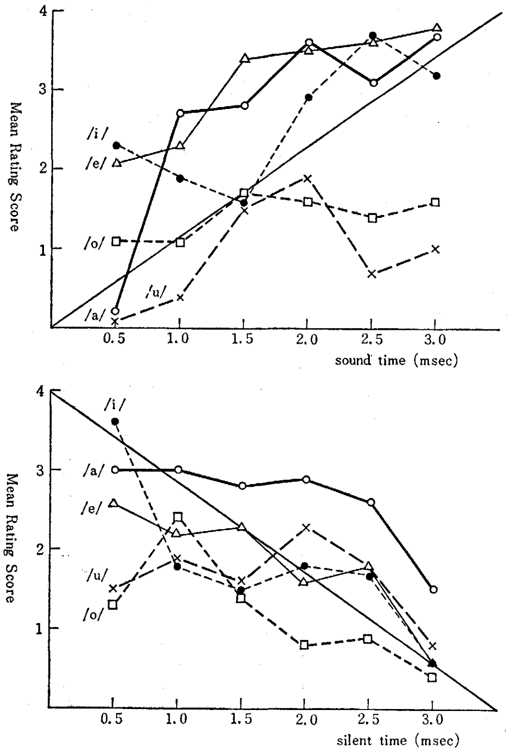


Fig. 9. MRS-function of Series-I and Series-II.

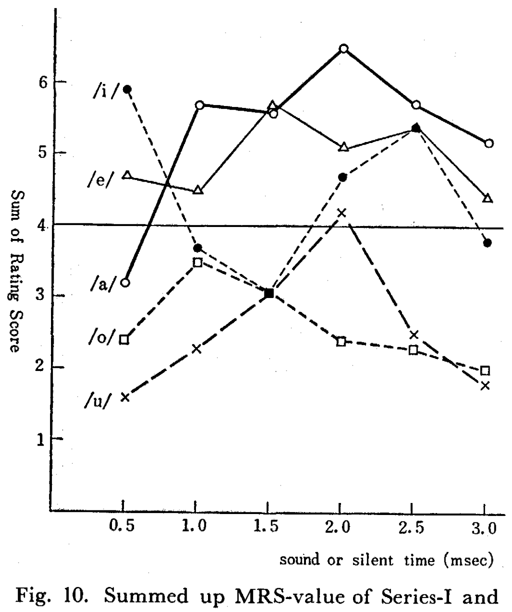


Fig. 10. Summed up MRS-value of Series-I and the corresponding Series-II.

sary for the recognition of /i/ and /e/. To identify the stimuli of /u/ and /o/, a whole wave may be required. It is supposed that /u/ and /o/ have little redundancy, so they are readily confused although the distortion is slight. On the contrary, /a/, /e/ and /i/ are regarded as vowels of high redundancy, and so they are stable to distortion, interruption in this case.

EXPERIMENT II: Interruption synchronized with multiples of a fundamental periodicity of Japanese vowels.

In this experiment, the increased intelligibility of periodically interrupted vowels was investigated, when the sound-time fraction was elongated by a step of each fundamental period synchronized with a period several times as long as a fundamental period. The intelligibility of this kind of interrupted vowel will show a minimum length enough to identify the particular vowel and an interruption rate of vowels adequate for use in hearing tests.

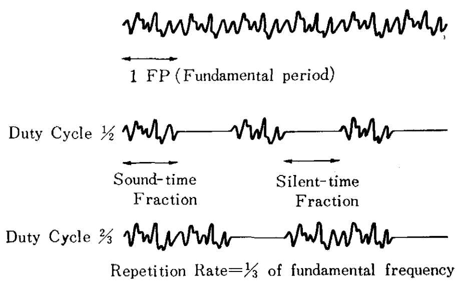
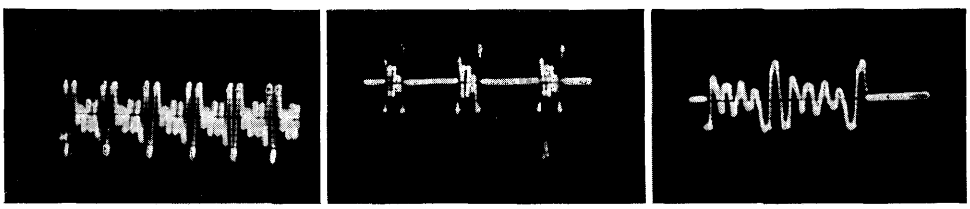


Fig. 11. Patterns of interruption in Experiment-II.

Procedure

The patterns of interruption are illustrated in Fig. 11. The duty cycle of every pattern is indicated frac-



Original Wave | Duty Cycle 1/3 | Duty Cycle 2/3

Fig. 12. Sound wave of vowel /a/.

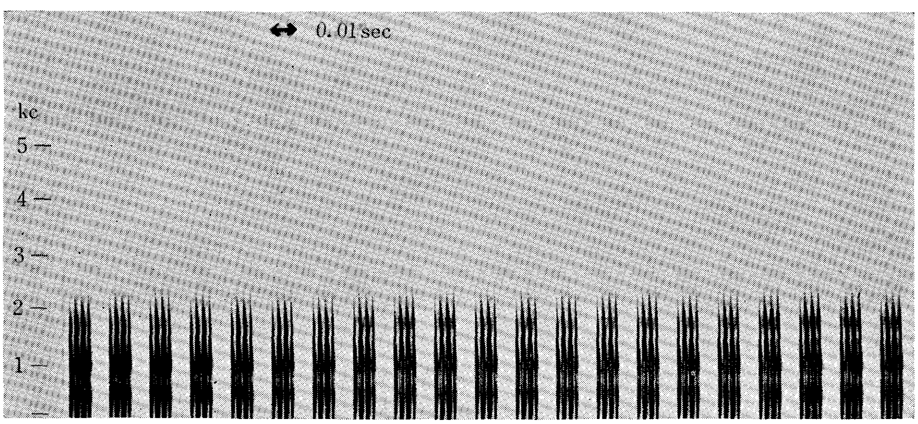


Fig. 13. Sonagram of the interrupted vowel /a/ with the duty cycle of 3/6.

tionally by describing the ratio of the repetition rate to the fundamental frequency as a denominator and the sound-time fraction as a numerator. The difference between the denominator and the numerator represents the silent-time fraction.

The voice, equipment and other procedures were the same as in Experiment-I (Fig. 12 and 13).

Three series of experiments were performed; the intelligibility of the interrupted vowels as a function of the sound-time fraction with a fixed silent-time fraction in Series-I, the intelligibility of the interrupted vowels as a function of the silent-time fraction with fixed sound-time fraction in Series-II, and the intelligibility of the interrupted vowels as a function of the sound-time fraction with fixed repetition rate in Series-III.

Results

1) Results of Series-I:

The average MRS-value of the five vowels increased with the increase of the sound-time fraction. The MRS-function of each of the three kinds of silent-time fraction obviously differed from each other, while their articulation score had nearly the same value (Fig. 14). The method of rating response was better than the first choice response in this kind of experiment, as mentioned above.

The MRS-value were little better than the values of the sound-time fractions of three fundamental periods (3 FP), even though the sound-time fraction increased more than 3 FP. This tendency was similar in the case of each vowel (Fig. 15).

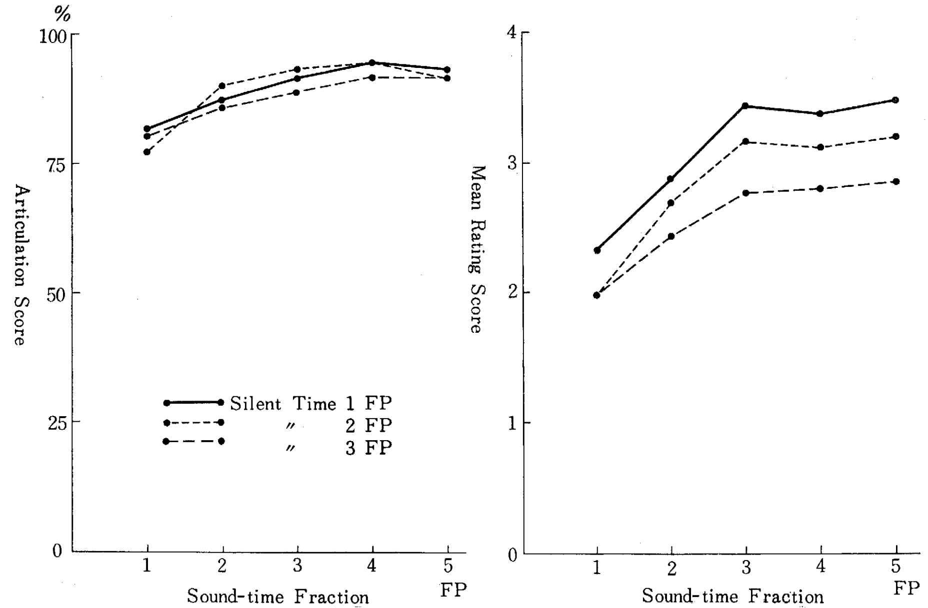


Fig. 14. The left figure shows the correlation between the articulation score and the sound-time fraction with the silent-time fraction fixed at 1, 2 or 3 FP.
The right figure shows the correlation between the MRS and the sound-time fraction under the same condition as above.

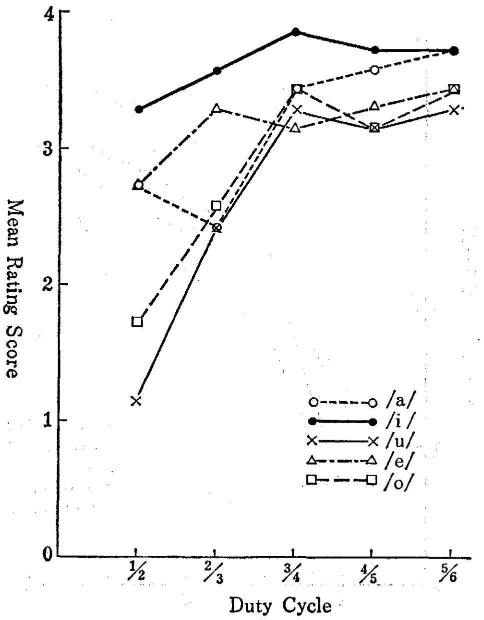


Fig. 15. Correlation between the MRS of each vowel and the duty cycle when the silent-time fraction was fixed at 1 FP.

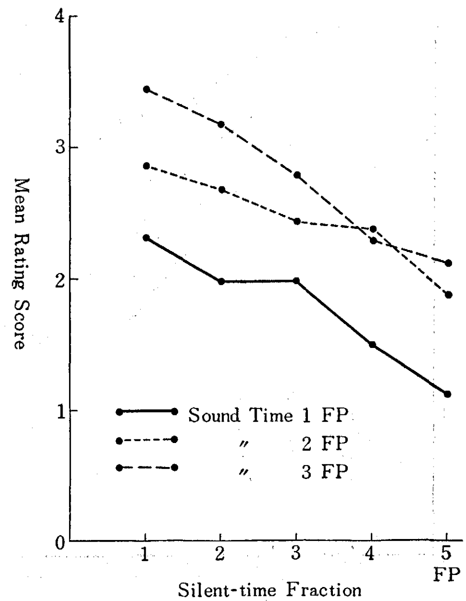


Fig. 16. Correlation between the average MRS and the silent-time fraction when the sound-time fraction was fixed at 1, 2 or 3 FP.

The MRS-values of /u/ and /o/ with sound-time fractions of 1 or 2 FP were lower than the average curve, and the MRS-value of /i/ was situated above 3 in all five test points. This shows that the identification of /o/ and /u/ requires the succeeding two or more fundamental waves when the silent-time fraction is 1 FP, while /i/ is identifiable with only one fundamental wave.

2) Results of Series-II:

The average MRS-value decreased with the increase of the silent-time fraction, and with the decrease of the sound-time fraction (Fig. 16). When the sound-time fraction was fixed at 3 FP, that of /i/ was the highest among the five vowels (Fig. 17).

When the duty cycle of interrupted vowels was 0.5, that is, a pattern of 3/6, /i/ seemed to be clearly identifiable, but the listeners were still very uncertain about the other vowels, especially /u/ and /o/. When the duty cycle was decreased below 0.5, no vowel was heard with certainty.

3) Results of Series-III;

The results of Series-III are shown in Fig. 18, with the repetition rate fixed at 1/6 of the fundamental frequency.

The intelligibility increased with the increase of the sound-time fraction. These data suggest that /i/ is identifiable with three succeeding fundamental waves, /e/ and /a/ with four succeeding fundamental waves and /u/ and /o/ with five.

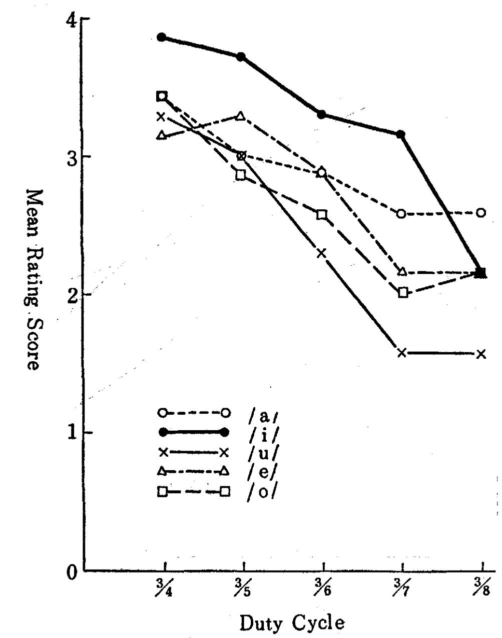


Fig. 17. Correlation between the MRS of each vowel and the duty cycle when the sound-time was fixed at 3 FP.

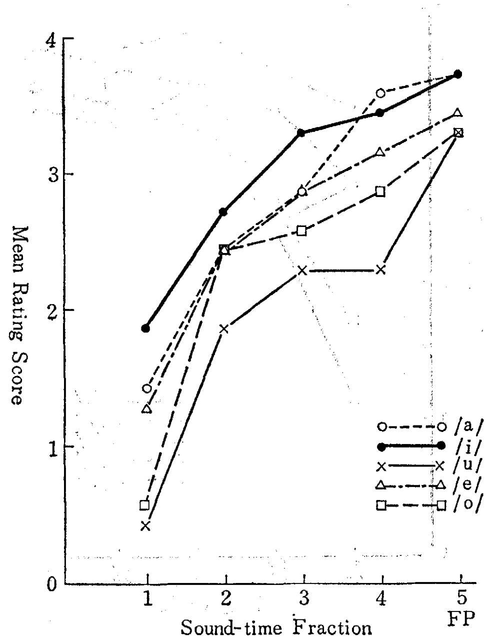


Fig. 18. Correlation between MRS and sound-time fraction with the repetition rate fixed at 1/6 of the fundamental frequency.

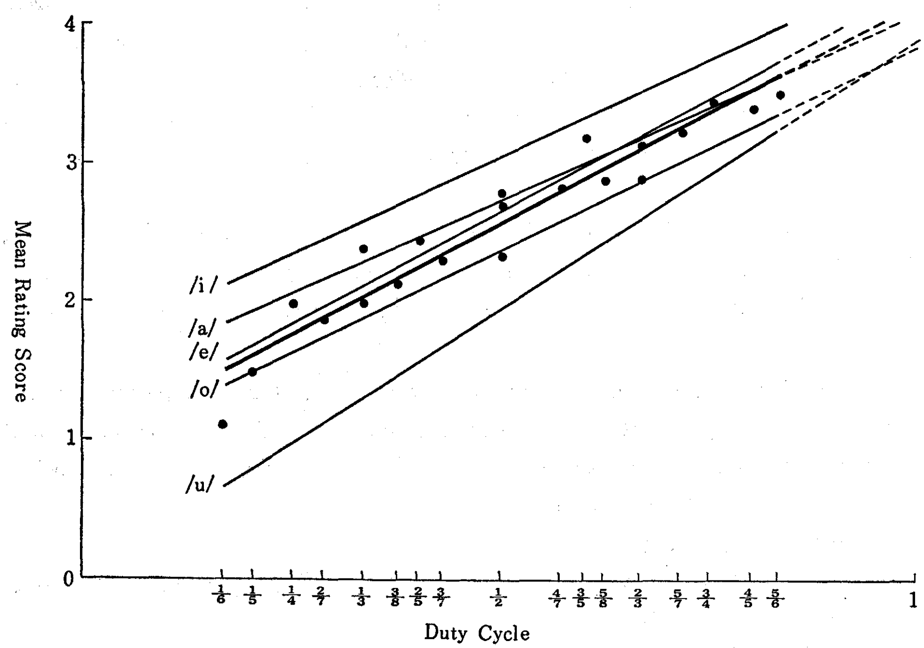


Fig. 19. Correlation between MRS and duty cycle.

4) The MRS-value of every measured point was plotted in Fig. 19. The thick line shows the linear regression of the average MRS of the five vowels, and the five fine lines show the regression line of each vowel. Strictly speaking, the values of the same duty cycle (i.e. 1/2, 2/4, and 3/6) differ from each other, but the values show a significant regression of the first grade. Experimental formulae were calculated as follows:

Average MRS-function: $y=3.19x+0.96$
MRS-function of /a/: $y=2.69x+1.39$
/i/: $y=2.80x+1.66$
/u/: $y=3.88x+0.00$
/e/: $y=3.25x+1.03$
/o/: $y=2.95x+0.89$

If an extrapolation is applicable, the average line reaches the full scale of MRS at the point of the duty cycle 0.95; those of /a/,, /i/ and /e/ reach the full scale at duty cycles of 0.97, 0.84 and 0.91, respectively; while those of /u/ and /o/ do not completely reach the full scale even at a duty cycle of 1.0, or a continuous tone. The MRS-value of /u/ and /o/ is 3.88 and 3.84, respectively, when the duty cycle is 1.0.

The duty cycle sufficient to identify a particular vowel is given by the point at which each of these regression lines crosses the MRS line of 3. The answers obtained by solving these formulae are 0.60 for /a/, 0.48 for /i/, 0.77 for /u/, 0.61 for /e/, and 0.72 for /o/. These results show that the duty cycle necessary for the identification of a particular vowel increases with the increase in the number of succeeding waves.

Conclusion

It is concluded that /i/ can be identified by the repetition of only one fundamental wave when the duty cycle is above 0.5. The other vowels, however, require a duty cycle of above 0.6. From the data shown in Fig. 19, /a/, /i/ and /e/ have a sufficient redundancy but /u/ and /o/ have little redundancy for distortion of interruption.

Discussion

In Experiment-I, a research was made for the significant fraction of each vowel by auditory impressions with the use of repeated similar partial fundamental waves. It was found that /i/, /e/ and /a/ may have significant fractions by which they can be identified, but that /u/ and /o/ do not.

In general, the intelligibility of interrupted vowel sounds of such a pattern is low even for normal subjects. It appears that a interrupted vowel synchronous with its fundamental frequency is least intelligible, because only a part of the vowel wave is presented. If a pattern in Series-I is presented to one ear and the corresponding pattern in Series-II is presented to the other ear simultaneously, one would expect the intelligibility to be increased by the binaural fusion phenomenon.

In Experiment-II, we found that the intterrupted /i/ is identifiable when the repetition of only one fundamental wave is presented under duty cycles above 0.5, but that duty cycles above 0.6 are necessary for the identification of the other vowels. These materials may be applied in a binaural switched speech test which presents each half portion alternately to each ear.

In a previous paper "The Intelligibility of Short Japanese Vowels as a Function of Duration", the author concluded that the shortest duration for /i/ to be identifiable was 19.6 msec. Those for /e/, /a/ and /o/ were calculated as 21.8 msec., 34.9 msec. and 35.8 msec., respectively, and /u/ could not be identified even at 50 msec.

In comparison with the shortest duration for these vowels to be identifiable, the repetition of succeeding fundamental waves shows the same tendency: /i/ is the most redundant vowel, followed in order by /a/, /e/, /o/ and /u/.

These facts must be considered when interrupted speech is used in the diagnosis of deafness. It is apparent that the redundancy of speech sounds is important, and that a certain amount of redundancy is helpful in correct identification. In cases of retrocochlear deafness, especially central deafness, however, extra redundancy is probably wasted.

Japanese monosyllables are ordinarily used in hearing tests, for purposes of simplification. The Japanese language has only five vowel sounds, so if there is uncertainty as to their identity, the articulation score of Japanese monosyllables may not be reliable, because the chance response given from probability is 20%. It is well known, however, that words or sentences have more redundancy than monosyllables, and are rarely confused by persons with normal hearing even when slightly distorted. Therefore, monosyllables do not appear to be suitable stimuli for use in the differential diagnosis of deafness.

In conclusion, interrupted Japanese vowels may be utilized in the binaural switched speech test, but they are unsuitable for the interrupted speech test presented monaurally. And it is expected that words or sentences may be better than vowels or monosyllables for use in hearing tests with interrupted speech.

At present, unfortunately, we have no reliable lists of words or sentences for hearing tests in Japan. A fundamental study should be done to make such a list and to define its clinical applicability by audiologists in cooperation with experts in phonology, phonetics, acoustics and psychology.

SUMMARY

In order to determine the role of the time factor in speech perception, and to apply this knowledge to the diagnosis of retrocochlear deafness, the intelligibility of periodically interrupted Japanese vowels was investigated.

Interrupted speech sounds were produced by interruption synchronized with

the fundamental frequency. Sound-time and silent-time fractions were controlled by an electronic switch.

The results of two experiments showed that /a/, /e/ and /i/ are vowels of high redundancy, and /u/ and /o/ have low redundancy. No significant portion of the fundamental period needed to identify each vowel was found, but a duty cycle of above 0.5 was necessary for the identification of interrupted vowel sounds.

The question of whether monosyllables or words are better test materials in the diagnosis of deafness is discussed with regard to their respective degrees of redundancy.

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