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ON THE DISCRIMINABILITY OF DURATION, INTENSITY AND FREQUENCY OF TONE STIMULI: A PRELIMINARY REPORT

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The results of our recent study [1] concerning the effect of aphasia on the perception of speech and non-speech sounds showed that (1) aphasic patients as a group were significantly inferior to the normal group in both identification of segmental duration of speech sounds and discrimination of tone duration, and that (2) there was a great variability in performance among aphasic patients.

These findings led us to suspect that at least some of these patients might have defects in processing auditory stimuli even at a stage preceding speech comprehension. In order to confirm this observation, however, it is necessary to investigate their performance on other acoustic cues as well, such as tone intensity and tonal frequency, and to analyze the results individually for each patient. This problem is being pursued in a separate study at present.

Another piece of information of relevance in this respect would be the relative abilities of a single individual in processing different acoustic stimuli. This type of information is extremely scarce as of now, however, not only for aphasic patients but also for normal subjects. In the present experiment, therefore, we investigated the auditory perception of three different acoustic cues, i. e., duration, intensity and frequency of pure tone stimuli, in normal subjects so as to obtain the baseline data against which performances of pathological cases can be evaluated later.

Procedures

Discriminability of duration, intensity and frequency of pure tones was measured in the following tests:

1. Temporal discrimination test (TD-test). Stimuli of 500 Hz pure tones, presented at 50 dB above threshold (50 dBSL), were used to measure discriminability of durations of 50, 100, 200 and 300 msec each.
2. Intensity discrimination test (ID-test). 500 Hz pure tones with a duration of 200 msec were used to measure the discriminability of intensity at the intensity levels of 10, 20, 30, 50 and 70 dBSL.
3. Frequency discrimination test (FD-test). Pure tones of 200 msec were employed to measure discriminability of frequencies at 125, 250, 500 and 1000 Hz, and the intensity level was set to 50 dBSL for the purpose of comparison with the performances in the other two tests.

Table I summarizes the specification of differences in the magnitude of stimuli in which T, I and F represent duration, intensity and frequency, respectively, and the first and the second tones are denoted by the suffixes S_1 and S_2 . The duration in this case indicates the total duration including rise and decay times. The interval between a pair of stimuli was kept at 1 sec., while successive pairs were separated by 3. 5 or 4 sec.

The synthesis of the stimuli and their compilation were performed on the YHP-2100A computer, and the output was fed, through a digital-to-analog converter at a rate of 12 kHz with an accuracy of 10 bit/sample, to

TD-test	T(msec)	50	100	200	300	—	$Ts_1 - Ts_2 = \pm n \cdot \Delta T$ (n= 0,1,2,3)
	Δ T(msec)	4	5	10	15	—	
ID-test	I(dBSL)	10	20	30	50	70	$2\frac{Is_1 - Is_2}{Is_1 + Is_2} = \pm n \cdot \Delta I$ (n= 0,1,2,3)
	Δ I(%)	5 or 10					
FD-test	F(Hz)	125	250	500	1000	—	$Fs_1 - Fs_2 = \pm n \cdot \Delta F$ (n= 0,1,2,3)
	Δ F(Hz)	1	1	1	2	—	

Table 1. Specification of differences in magnitudes of the first and the second stimuli, where $T=(Ts_1 + Ts_2)/2$, $I= (Is_1 + Is_2)/2$ and $F=(Fs_1 + Fs_2)/2$.

an analog tape recorder for off-line experiments.

Subjects were three normal adults whose ages ranged from 26 to 29. They sat for three to five sessions in each test so as to make the number of judgments of each diad 60 to 100. The measurement was based on the two-alternative, forced-choice paradigm, in which two stimuli were presented to the subjects in successive temporal order and the subject was required to select the one which he judged to be longer in duration, louder in intensity or higher in frequency.

Because of individual differences in performance, the test results of individual subjects had to be analyzed separately. If the discriminal process is assumed to be disturbed by internal noise, it may be appropriate to consider that the experimental data can be best approximated by a normal distribution. The approximation did hold quite well for all the individual data. Two parameters, the mean μ and the standard deviation σ, were derived from the measured data on the basis of the least-mean-squared error weighted by Müller-Urban coefficients.

The mean and the standard deviation of the distribution, which are considered mutually independent, indicate the time-order error and an index of accuracy of comparative judgment necessary for discrimination, respectively. Since the conventional difference limen (DL: 75% correct judgment) and the index of signal detectability d' are based upon the correct/incorrect responses, and depend on the time-order error, they are generally inappropriate as an index of accuracy of discrimination.[2, 3] In the absence of the time-order error, however, the standard deviation σ can be converted into 75% DL by the following relation: DL = $0.675\,\sigma$.

Results and Remarks

In Fig. 1, the mean values of absolute DL's (converted from the σ 's) for three subjects in the TD-test, as well as DL's measured by Abel [4], are plotted against tone duration. According to Abel's results, it appears that DL within the indicated range increases with duration T, while our results indicate that DL is almost constant for smaller values of T and tends to increase with T for larger values. The discrepancy may be due to differences in the methods of analysis employed in the two investigations.

Fig. 2 illustrates the performances of three subjects on TD, ID and FD-tests. The relative accuracy of discrimination σ(T), σ(I) and σ(F), each in percent, is plotted against duration T, intensity I and frequency F in their respective logarithmic scales. It can be clearly seen that the accuracy of discrimination of frequency is much higher than that for duration and intensity, suggesting that the mechanisms involved in frequency discrimination are inevitably different from those for the other two quantities.[5]

On the other hand, marked similarity can be found between σ(T) and σ(I). In fact, the two curves are almost identical if a 10-to-1 range of I is made to correspond to a 2-to-1 range of T. This implies that there exists a relatively simple correspondence between the mechanism for duration discrimination and that for intensity discrimination.

Based on these results, a model for the mechanisms and processes involved in the discrimination of tone duration can be constructed. The model, shown in Fig. 3, consists of a non-linear (logarithmic) compressor, a short-term-memory and a comparator along with two sources of internal

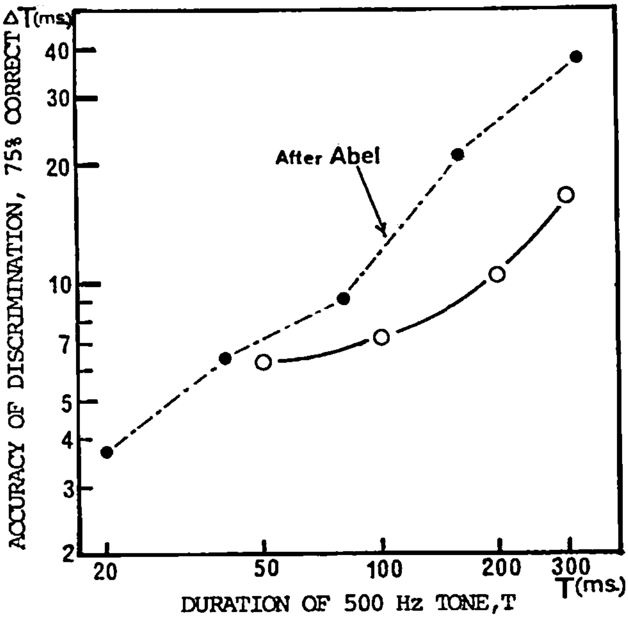

Fig. 1: Discriminability of duration as a function of duration.

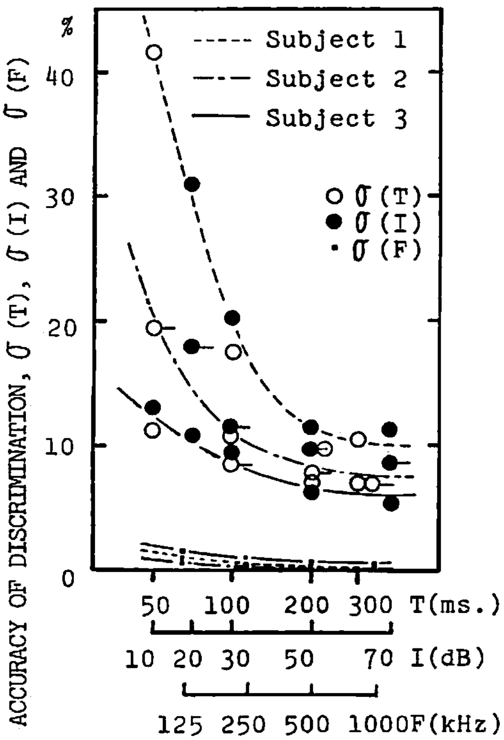

Fig. 2: Accuracy of discrimination obtained in discrimination tests of duration, intensity and frequency.

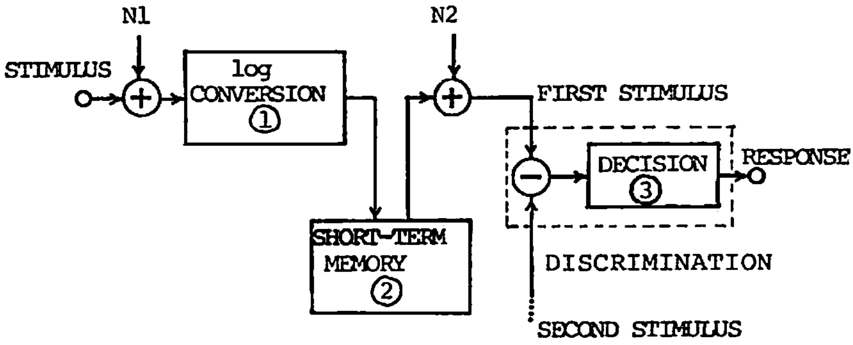

Fig. 3: A model for the mechanisms and processes involved in the discrimination of tone duration.

noise. Information of an input stimulus mixed with the internal noise N1 is compressed logarithmically at ① , and is stored in the short-term-memory ② . After receiving the second stimulus, the information in the memory is conveyed to the comparator ③ together with the internal noise N2, and the discrimination is carried out on the basis of the difference in the magnitudes of the stimuli. Thus the two noise sources N1 and N2 are responsible respectively for absolute and relative errors of discrimination, the former being dominant in the small-signal range, and the latter being dominant in the large-signal range.

The model for intensity discrimination is considered to be similar to the above model, except that the degree of compression is more drastic, judging from the fact that a 2-to-1 difference in duration is found to correspond roughly to a 10-to-1 difference in intensity, as seen from Fig. 2. Further research is now being undertaken for physiological interpretation of these results.

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