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AN EXPERIMENTAL STUDY ON TIME ORDER EFFECTS

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In comparison of a pair of durations presented successively, the effects of the second duration on the first duration (e-function) and on ISI (p-function) were examined by the method of reproduction. The time order effect (TOE) changed from positive to negative as the duration was increased (0.5 to 8 s) and the positive TOE increased and the negative TOE decreased with increasing ISI (0 to 9 s). These results differ markedly from those found in other perceptual modalities.

From the results obtained when each of two durations was individually reproduced, it was suggested that the mutual effect, i.e., the compression effect of the second duration on the first one and the expansion effect of the first on the second, would take an important role in operation of the TOE.

In any psychological measurements by means of successive comparison of stimuli, especially in comparison of two or more temporal intervals or durations no one can avoid a difficulty due to time-order effect (TOE) because of a self-evident fact that these durations can not be compared with each other simultaneously, and no discussion of time perception would be complete without due consideration of TOE. The letter "E" of TOE originally means an "error" which refers to the fact that the judgements are distorted owing to the temporal succession of stimuli. As Frankenhaeuser (1959, p. 21) stated, however, "in respect of subjective time, *succession is in itself an inherent characteristic of the experience.* Thus the discrepancy between immediate perception and retention of time is not an error caused by methodological inadequacies which we want to eliminate, but rather a typical expression of the phenomenon we want to study."

Her claim is definitely true and hence we would like to regard "E" of TOE as "E" of effect. Although there are plenty of studies on TOE in several sensory modalities since Fechner discovered the presentation-order effects in the comparative judgments of a pair of lifted weights, few established empirical data to guide elucidating mechanism to generate TOE, especially in time estimation and duration discrimination, has been obtained.

The TOE observed in temporal interval or duration shows the changes in two directions, positive and negative, in common with other sensory modalities. Suppose two physically equal stimuli are presented successively. When the first stimulus in the pair is judged shorter than the second, the TOE is negative, whereas when the first stimulus is judged longer, the TOE is positive. It depends mainly on two factors whether TOE is positive or negative. One of them is the time interval between a standars duration and a variable (reproduced duration), and another one a standard duration. The former refers to the *p-function* which has been introduced to express the variation of the interstimulus interval (ISI) or pause (Needham, 1934) while the latter refers to variation of TOE with varying a standard duration and has been termed as the *e-function* (Nakajima, 1951).

Let us survey the findings connected with e-function and p-function.

The e-fuction. Since Vierordt (1968) stated first that short intervals were overestimated and long intervals underestimated, many researchers have paid much attention to the

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relations between the objective duration and subjective one, and also to the relation between the standard duration and TOE. Their attention, however, has been concerned upon the time-order indifference interval or duration (TOID) which is defined as the point where the comparison of two successive durations or intervals is not affected by the order of presentation or as the point in which a standard duration is identical with the reproduced duration (for a review of TOID, see Fraisse, 1963; Woodrow, 1951). In the strict sense there are few studies on the functitional relationship between the standardard duration and TOE.

The early investigations of duration discrimination (e.g., Quasebarth, 1924; Stott, 1933, 1935; Woodrow and Scott, 1936) have showed that if the subjective factors such as attitude and experiences were ignored, for the shorter than TOID, P(RvlTvTs) tended to be greater than P(RvlTsTv), P(RvlTvTs)> P(RvlTsTv), where TsTv indicates the order of the presentation of a standard (Ts) and variable duration (Tv), and Rv denotes a "variable longer" response in Tv>Ts. And the difference in magnitude between the two conditional probabilities decreased as the duration got near the value of TOID. For duration longer than TOID, P(RvlTvTs) was less than P(RvlTsTv), P(RvlTvTs)<P(RvlTsTv), and the difference tended to increase as the duration increase. However, Closer inspection revealed a fact that these results has not clearly elucidated the relation between the standard duration and TOE.

Nakajima (1958) tried to make the characteristics of e-function clearer, using the percentage of the difference between the standard duration and PSE to the standard as a measure of the amount of TOE (D=100×(PSE −TS)/TS, where TS is a standard duration). Based on the results obtained under conditions of the standard durations ranging from 1/8 to 2 s, he found that e-function was divided into three phases, i.e., for shorter TSs the amount of TOE varied largely, though being always negative (Phase I), for moderate TSs the negative TOE decreased with increasing TS (Phase II), and for longer TSs the TOE descended to the negative side again as Ts increased (Phase III). Since his experiment was carried out within the range of shorter duration below 2 s and showed considerable inter-individual differences, in order to generalize his findings, further experiments which cover a wide range of TS would be required.

The p-fuction. The successive comparison in sensory modalities such as loudness and brightness involves the comparison of a present (second) perception with the "image or memory" of an earlier (first) stimulus. Thus Fechner developed the so-called memory-image theory in order to explain the TOE (Needham, 1934). Köhler (1923) and Lauenstein (1932) criticized the "memory-image" theory from viewpoint of Gestalt theory and instead tried to account for the TOE in terms of *physiological trace theory.* In order to verify their claims many experiments on several sensory modalities, in which the inter-stimulus interval (ISI) between two successive stimuli was varied, have been carried out. In Köhler's experiment on loudness the positive TOE occured when ISI was shorter (0.3 s). At ISI of 3 s the TOE was minimal or absent, whereas with the longer ISIs, up to 12 s, the TOE became negative and increased with increasing the ISI. On the other hand, the TOE in duration changed in the opposite direction. In Nakajima's experiment on TOE in which ISI ranged from 0.15 s to 1.6 s, remarkable negative TOE took place under condition of the shorter ISIs and tended to decrease as ISI increased, and even positive TOE was showed by some Ss in longer ISIs (Nakajima, 1958). The tendency toward the decrement of negative TOE with increasing ISI have been confirmed in experiments by Jamison and Petrusic (1975a, b), in which ISI ranged from 0.5 s to 8 s in one experiment and from 1 to 26 s in another one. In general the effect of ISI on the amount of TOE seems to change with varying the duration of TS, but this effect has not sufficiently been established.

The present study was planned to determine more fully the e- and p-function of TOE when measured by means of the reproduction method. In addition, the mechanism generat-

ing TOE will be discussed on the basis of results obtained through the reproduction of each of a pair of successive durations.

EXPERIMENT I

Method

Subjects

Three laboratory staff were tested individually in a sound proof, dark room. They had never participated in any experiment of time perception before, though they had been well trained as *Ss* in psychological experiments.

Apparatus and procedure

A small red or green photo-diode, wired to electronic timing devices, was used to demarcate passages of time. When the experimenter pressed a start key of a preset-timer (T.K.K. Co.), a standard stimulus lighted for pre-defined duration (standard duration: TS). After a given interval (ISI) the second stimulus lighted and a digital timer (T.K.K. Co.) started. The standard light and the second light were almost the same in luminance but different in color. Thus the red standard was followed by the green second, and *vice versa*. The *S* switched off the second light (reproduced duration: TR), when the second duration was judged to be equal to the TS. The *S* was told to go about the task in whatever way seemed to the most natural for her and never to count.

The experimental conditions consisted of 30 combinations of 5 TSs and 6 ISIs. The TSs were 0.5, 1.0, 2.0, 4.0, and 8.0 s and ISI were 0, 1.0, 2.0, 3.0, 5.0, and 9.0 s. All combinations were randomly presented twice within each session. The red and green standards were used once each for each combination in each session. Each *S* was tested for a total of 6 sessions: twice per day for 3 days and at the same time of the day as closely as scheduling permitted. The results of this experiment were therefore based on 1080 observations (3 *Ss* × 5 TSs × 6 ISIs × 12 repetitions).

Results

The results shown in Figs. 1 and 2 represent, respectively, p-function and e-function. As a suitable measure of the amount of TOE, D% (Differenz-Prozent) was calculated as follows: D=(TR−TS)/TS. The negative value of D, therefore, means the negative TOE which indicates overestimation of the second stimulus in the reproduction; likewise the positive value means the positive TOE. Since the results obtained from three *Ss* coincided with each other in the trend of change in D% with varying ISI in p-function and TS in e-fuction, though their absolute values of TR made a little difference between one *S* and the other two, the mean D values over three *Ss* were plotted.

From these data it is apparent that the TOE depends on ISI and TS, and also the interaction between them. These effects were born out by analysis of variance; ISI and TS

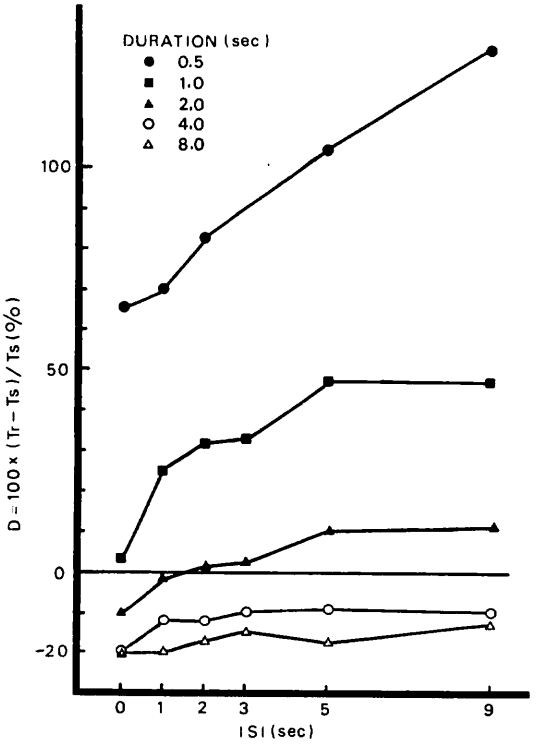

Figure 1. P-function, representing D% as a function of ISI.

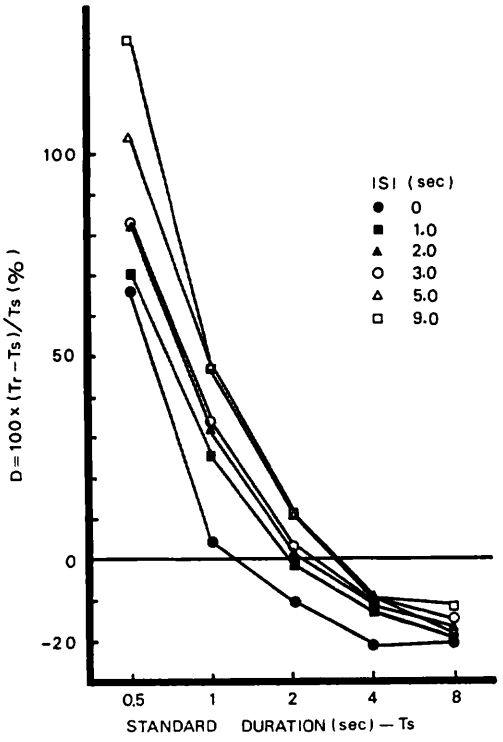

Figure 2. E-function, representing D% as a function of TS.

were both highly significant [$F(5, 10)=11.11$, $p<.01$ and $F(4, 8)=30.26$, $p<.005$, respectively] and ISI×TS interaction also was significant [$F(20, 40)=2.07$, $p<.05$].

As shown in Fig. 1, the D values increased with increasing ISI, but the rate of increment decreased with increasing TS. When TS was 0.5 and 1.0 s, the D values were positive in the whole range of ISI and tended to increased up to 9 s of ISI. On the other hand, the D values for 2 s of TS changed its sign from negative to positive with increasing ISI and for 4 and 8 s of TS the Ds showed negative values in all ISI conditions. In the case of negative TOE the tendency to decrement of TOE with increasing ISI has been shown in the results obtained by Jamieson and Petrusic (1975a) and Nakajima (1958), whereas so far the increase of positive TOE for shorter TSs with increase of ISI has not been found. This is not due to a delay in *Ss'* response. In fact the reaction time tends to increase as the fore-period increases, but its fluctuation is less than 50 ms between 0.3 and 10.0 s of the fore-period (Kozaki and Wake, 1974), while the difference of reproduced duration between 0 and 9 s of ISI is about 300 ms in average.

In discrimination tasks involving the sequential presentation of two stimuli to be compared, the ISI is one of most important variables and generally the discriminability decreases with increasing ISI. This effect is shown for various perceptual dimensions, e.g., loudness (Kinchla and Smyzer, 1967), pitch (Moss, Myers, and Filmore, 1970), and visual movement (Kinchla and Allan, 1970). As Allan and Kristofferson (1974) summarized, however, in discrimination of duration such effect has not been found. Since several studies were done under condition of durations or temporal intervals less than 2 s, however, these results will not furnish with much information.

With respect to the e-function shown in Fig. 2, D values for each ISI described a negatively decelerated curve on semi-logarithmic plot with increasing TS and changed their signs from positive to negative. For 0.5 and 1 s and for 4.0 and 8.0 s of TS the data showed positive and negative TOEs regardless of ISI, respectively, while for 2.0 s of TS both positive and negative TOEs occured, depending on the ISI. In addition, the TS×ISI interaction reflects a fact that the gradient of curves varied with ISI and became steeper as ISI increased. Thus the time-order indifference duration (TOID) also shifted to some point between about 1 s and 4 s and lengthened with increasing ISI. These finding are in part consistent with the results reported by Scott (1935) and Nakajima (1951).

In regard to the TOID, it has been suggested by many authors that its value changes depending on conditions under which perception occurs, and one of the most important facts which cause its variation is a central tendency related to the range of duration presented in a given situation (e.g., Hollingworth, 1909; Fraisse, 1963). Fraise (1948) measured TOID in condition of two different ranges of stimuli by the reproduction method and found that the TOID were 1.14 s and

3.64 s for series stimuli ranging from 0.2 to 1.5 s and 0.3 to 12 s, respectively. An application of adaptation-level theory (Helson, 1964) to the determination of TOE and TOID is based on such contextual effect. From the viewpoint of frame of reference, ISI as well as standard duration should be taken into consideration in any experiments on time perception.

In the mutual effects found in comparison of a pair of durations, the questions often arise whether the direction of effects is forward or backward, i.e., the first duration affects the second one *or vice versa*, and also whether TOE is a perceptual phenomenon or a response bias. In the reproduction method the latter problem should be carefully considered because *Ss* is requied more active operation for reproducing a duration appeared equal to a given TS while they perceive TS passively. The next experiment was planned to examine these problems.

EXPERIMENT II

Method

Subjects

Three laboratory staff and the present author served as *Ss*. Two (Tk and Tm) of them participated in Exp. I.

Apparatus and procedure

The apparatus was identical to that used in the previous experiment. Each *S* was tested individually under the following conditions. Three light stimuli were presented: There was no interval between the first light and the second one; the third lighted with an interval of 1 s after the second light terminated. Color of lights was either red or green, and the color of second light was different from the first one. *Ss* were asked to reproduce either the first duraton (TS_1) or the second duration (TS_2) by switching off the third light when judged the third duration to be equal to the first or the second (see Fig. 3). That is, out of two durations, TS_1 and TS_2, the duration of the same light in color as the third light was to be reproduced. Since *Ss* were not told about which color appeared in the third in advance, they could not anticipate a duration to be reproduced, TS_1 or TS_2. This may be useful for preventing *Ss* from using any cues for the estimation of duration such as counting breathing, and so forth.

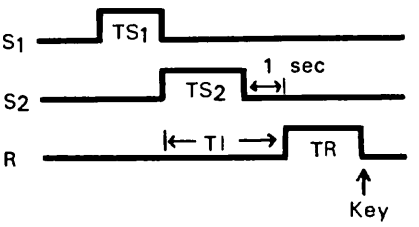

Figure 3. Sequence of the three stimuli, TS_1, TS_2 and reproduction (TR_1 or TR_2).

In this experiment five durations were presented as TS_1 and TS_2: 0.5, 1.0, 2.0, 4.0, and 8.0 s. TS_1 and TS_2 were varied independently of each other. The red and green lights were used one for each of TS_1 and TS_2 in every session. Hence the combination of 25 TS conditions ($TS_1 \times TS_2$), 2 colors (red and green), and 2 reproduction conditions (TR_1 for TS_1 and TR_2 for TS_2) yielded 100 types of trial. The experimental trials consisted of four 1/2 hrs sessions, two sessions per two days, for each *S*. During each session, each of 100 trial types was presented in random order.

The control experiment was carried out before the experimental trials stated above. The conditions of the control were the same in all aspects as Exp. I except the ISI conditions. There was an empty interval instead of TS_2 between TS_1 and TR, and empty interval (=ISI) was either 1.0, 1.5, 2.0, 3.0, 5.0, or 9.0 s, which was equal to each (TS_2 +1) s. The standard durations (TS_0) were the same as TS_1 s. Each of the 60 combinations of 5 TS_0 s, 6 ISIs, and 2 colors of light (red and green) was presented randomly in each session. Each *S* was run for a total of 4 sessions, two per day for two days.

Results

The mean reproduced duration (TR) of TS_1 and TS_2 collapsed over all combinations of

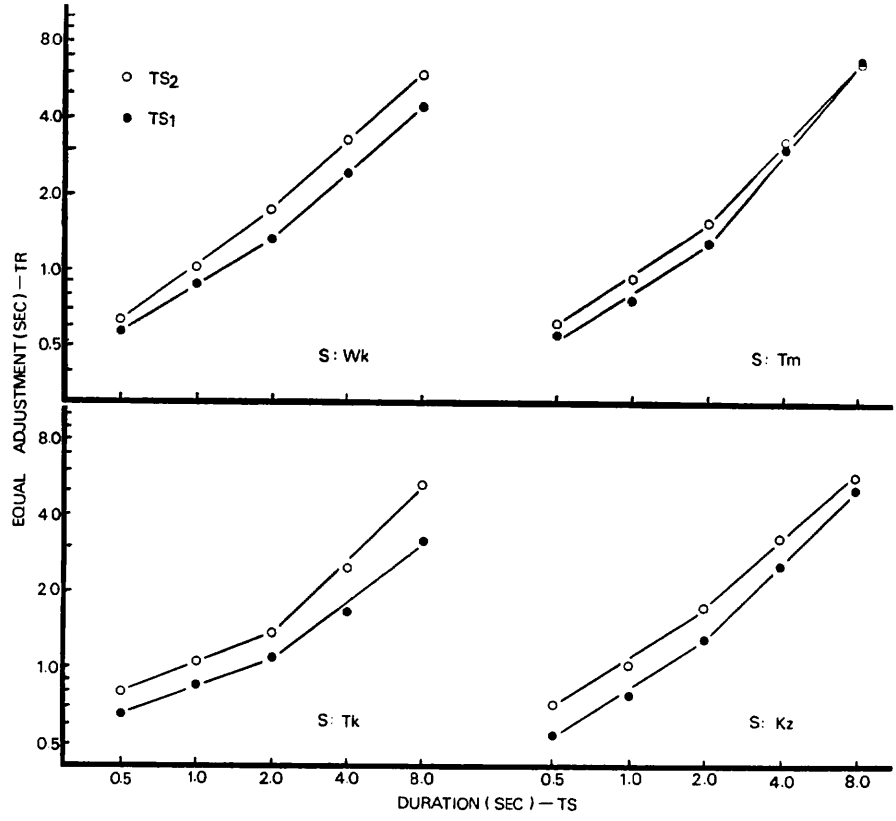

Figure 4. Comparison between TRs for TS_1 and TS_2 for each *S*.

TSs for each *S*s are presented as data points in Fig. 4. Filled and open circles in the figure represent TR_1 for TS_1 and TR_2 for TS_2, respectively. In the same way as the results obtained by the previous experiment (Kozaki and Kozaki, 1976a; 1976b), the curves of TR as a function of TS on log-log plot consisted of two segments, that is, they exhibit a discontinuity in the neighborhood of 2 s of TS.

Making a comparison between the data for TS_1 and TS_2, it is apparent that each TR_2 for TS_2 is greater in magnitude than the corresponding TR_1 over all TS conditions ranging from 0.5 to 8 s. These results reveal a fact that TS_2 had a backward-compression effect on TS_1. Another evidence to warrant this effect is given in Table 1 in which TR_1 for TS_1 followed by TS_2 are compared with the control data (TR_0) without TS_2. Comparison between TR_1 and TR_0 indicates that

Table 1. Comparison between TRs (sec) for TS_1 and TS_0 (=TS_1 without TS_2).

		TS (sec)				
	Ss	0.5	1.0	2.0	4.0	8.0
TR_1	Wk	0.568	0.865	1.343	2.452	4.561
	Tk	0.792	1.085	1.276	1.601	3.081
	Tm	0.551	0.756	1.310	3.093	6.888
	Kz	0.549	0.789	1.307	2.552	5.022
TR_0	Wk	0.694	1.193	2.002	3.344	5.621
(control)	Tk	0.752	1.037	1.540	2.325	3.580
	Tm	0.722	1.057	1.663	3.613	7.535
	Kz	0.574	0.969	1.572	2.664	5.150

the reproduced duration was reduced by 15.6% in average by interpolating TS_2 between TS_1 and the reproduction, though there was no systematic change in percentage of the difference between TR_1 and TR_0 to TR_0 [$P(D)=100\times(TR_1-TR_0)/TR_0$] with varying TS. Mean P(D) was −10.17, −17.72, −22.04,

Table 2. Comparison between TRs for TS_2 and TS_0. Each value was calculated by a formula, $(TR_2-TR_0)/TR_0$.

	TS (sec)				
Ss	0.5	1.0	2.0	4.0	8.0
Wk	−0.125	−0.120	−0.131	0.178	0.082
Tk	0.025	−0.104	0.036	0.073	0.832
Tm	−0.039	−0.038	0.069	−0.082	−0.117
Kz	0.303	0.060	0.136	0.391	0.172

−17.00, and −10.97 for TS of 0.5, 1.0, 2.0, 4.0, and, 8.0 s, respectively. These values of P(D) are consistent with the e-function obtained in Exp. I. Especially for 0.5 s and 1.0 s of TS, Ds in Exp. I represented the positive TOE, while P(D) values were negative. Thus if it is presumed that a simple subtractive relation between TR_1 and TR_2 corresponds to the magnitude of TOE and its sign, positive or negative, not only the effect of TS_2 on TS_1 but also the reversed effect, TS_1 on TS_2 should be expected.

Actually the TS_1 showed a tendency to bring about an increment in the TS_2 reproduction. Since the interval between TS_2 and the reproduction was held at 1 s, the data of TR_2 were compared with the TR_0 at ISI of 1 s. Each value for each S in Table 2 was obtained by dividing the difference between TR_2 and TR_0 at 1 s in ISI by TR_0, i.e., $(TR_2-TR_0)/TR_0$. Although the relative differences between TR_2 and TR_0 are not necessarily coincident between Ss, inspection of Table 2 reveals a fact that the TS_2 s longer than 2 s tended to be overestimated relatively to TS_0, while the TS_2 s shorter than 1 s, if remotely compared, tended to be underestimated. Jamieson and Petrusic (1975) also have observed the same effect in their experiment in which the effect of pairing 4-sec-duration stimuli were examined in six ISIs ranging from 1 to 26 s. Both the first duration and the second one of the pair were affected by each other, i.e., TS_1 was underestimated and TS_2 was overestimated relatively to unpaired durations (TS_0), and hence these mutual effects have been *termed pairing effects* by them. They further suggested that an appropriate measure describing the difference between TR_1 and TR_2 might correctly predict the negative TOE observed in the comparison of duration. Since their experiments were limited to the p-function with constant TS, 4 s, whether the prediction of TOE from the difference between TR_1 and TR_2 hold good with the e-function, especially with the positive TOE found for shorter durations in the present experiment, would be left to further studies.

General Discussion

The present experiments confirmed some facts which have previously been found and found a few new facts.

Within the limits of the present experimental conditions it seems that the duration of 2 s may be of deep significance. In the psychophysical function obtained by means of the reproduction, the transition or break point is in the neighborhood of 2 s. The time-order indifference duration centers on 2 s even though the TOID tends to lengthen as ISI increases. As regards ISI, if ISI is shorter than 2 s, the discriminability does not change, whereas it shows a tendency to increase its value with increasing ISI when the ISI is longer than 2 s. These findings suggest that the experimental task and its underlying perceptual processes may vary, depending upon whether the duration to be estimated or reproduced is shorter or longer than a critical duration of 2 s. How the critical duration is determined may be made clear through the experiments under way, in which the range of durations, method of estimation, experimental tasks, and so forth are varied.

The TOE obsereved in estimation and reproduction of duration is characteristically different from the TOE found in other perceptual modalities. In p-function of duration, D value as a measure of TOE increases with increasing ISI regardless of its sign, positive or negative, whereas the TOE obtained in other modalities tends to change its sign from positive to negative with ISI. As well, e-function in duration differs from the one observed in other modalities, e.g., in comparative judgments of loudness the increase of

stimulus duration resulted in the increase of the positive TOE (Wada, 1937). In psychophysical discrimination tasks, Allan and Kristofferson (1974) concluded that duration discrimination differs from discrimination along other stimulus dimensions. It is unreasonable from these reasons, therefore, that theories or hypotheses which account for TOE on the basis of data in stimulus dimensions other than duration apply to the TOE in comparison of durations.

As a matter of fact, the successive comparison in durations as well as other modalities involves the comparison of a present (second) stimulation with the image or trace of the first stimulation. In other words, it is related to both perception and retention. Since Fechner first proposed the memory-image theory, most of theories in explanation of TOE are closely related to memory processes. For example, Köhler (1923), Frankenhaueuser (1959), and Björkman and Holkvist (1960) enunciated fading-trace theory or model in duration, which assumes that the second stimulus compares with the sinking or fading trace of the first stimulus. Their models may apply to negative TOE but not adequately to positive TOE observed in short duration. Even if inconsistent parts of their models are made up by other assumptions such as the concept of assimilation, the influence of frame of reference, and so on, it is difficult to give an inclusive explanation to the present results. In the present experiments, the positive TOE was found even in no interval between standard duration and the reproduction, and increased as ISI increased, and it was found that the second duration was overestimated relatively to the same duration without the first stimulus. Therefore, for more comprehensive understanding of TOE in comparison of durations, further studies on the mutual interaction between the first duration and the second one, especially the effect of the first on the second, should be required.

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