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STEREOSCOPIC DEPTH PERCEPTION UNDER SUCCESSIVE EXPOSURE OF TEST STIMULI TO THE TWO EYES

By

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The two test stimuli provided for stereoscopic depth perception (S_1 and S_2) were exposed successively to their corresponding eyes, S_1 to one eye and then S_2 to the other. Even when there was no temporal overlapping between exposures of the two stimuli, usual stereoscopic depth was perceived if the duration of S_1 was less than approximately 375 msec. There existed, however, a limit to delay (critical delay time) past which stereoscopic depth can not be established. The critical delay time, which was measured from the termination of S_1 to the onset of S_2, increased as the exposure duration of S_1 decreased. When the duration of S_1 was extended over 375 msec., approximately 30 msec. overlapping of the tail of S_1 and the top of S_2 was needed for stereoscopic depth perception. These results were also confirmed through an experiment to measure critical exposure frequency.

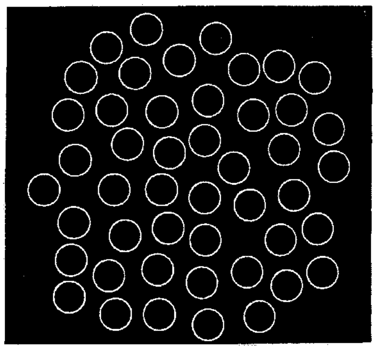
Based on these results, a model was constructed for the temporal courses of progress of the "process for stereoscopic depth perception" over the period of stimulus exposure and after it.

It is a problem whether or not stereoscopic depth can be perceived even though the two test stimuli for stereoscopic vision are exposed successively to their corresponding eyes in such a way as they are not temporally overlapped. If it can be, it may mean that a certain "process" which plays a role in establishing stereoscopic depth perception subsists its trace even after the termination of the stimulus exposure. The purpose of the present experiments is to examine into the above problem and to induce the temporal course of progress of the "process for stereoscopic depth perception" over the period of stimulus exposure and after it.

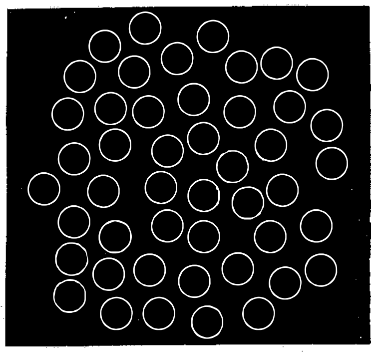
I. Critical Delay Time as Influenced by Decreasing Exposure Duration of Stereoscopic Stimuli

Problem

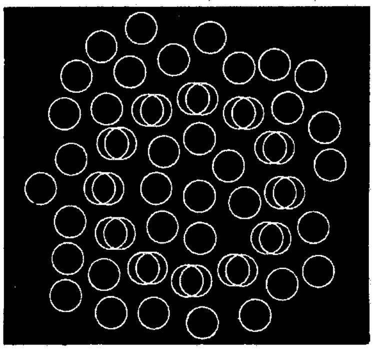
This experiment was designed to inquire into to what extent the exposure of S_2 could be allowed to delay after the termination of S_1 without extinguishing a stereoscopic depth cue. S_1 represents, here, one of a stereoscopic stimulus pair which was given to one eye and S_2 the other. Although S_1 and S_2 varied in exposure duration, their



Stimulus pattern in slide given to left eye (S_2)



Stimulus pattern in slide given to right eye (S_1)



Superposition of the above two patterns

Fig. 1. A stereo pair employed as the test detail. Twelve circlets around the center do not overlap each other. When they are given individually to their corresponding eyes through a stereoscope shown in Fig. 2, they are fusioned binocularly and appear in front in a ring against the others.

disparity, size, and brightness were held constant. And thus the critical delay times as the disappearance threshold of stereoscopic depth were measured.

METHOD

A stereo test detail employed here was a pair of stimulus patterns in slide as shown at the top of Fig. 1. The upper righthand pattern in Fig. 1 was exposed to the right eye of the observer (S_1), and the other to the left eye, through a stereoscope described in Fig. 2. The patterns consisted of 35 bright circlets each. At a usual glance, no depth gradient could be perceived about these circlets. When fusional vision was completed by the stereoscope, however, 12 of the 35 circlets appeared in front in a ring against the others around the center of the pattern as illustrated at the bottom of Fig. 1. The ring subtended a visual angle of 4° at the observer. The angular disparity between the rings of the two patterns was held at 11′ of arc. Ss were instructed to fix their glance at the center of the ring.

There were two major reasons why the pattern was chosen as the test detail : (1) It gave a well defined stereoscopic depth impression, (2) it scarcely had cues for an illusory monocular depth. It was unavoidable, however, as a result of repetitive demonstration that the 12 circlets came to be seen illusorily in front against the others, even though the pattern was presented monocularly, though it was very faint.

Both the stereoscope and the other instruments employed here are illustrated in Fig. 2. The patterns in slide were illuminated by a pair of Sylvania glow modulator tubes (R1131C). The tubes were illuminated continuously by feeble light fluxes from the actuators, so that they could fire in entire darkness. Lest the patterns should be illuminated by beams from the actuators and come in sight before the tubes fire, several neutral density filters were inserted between the slide cases and the tubes. Flush beams from the tubes which traveled through the filters were gathered by the condenser lenses and projected to the diffusing glasses. Through the convergence lenses, Ss observed binocularly the patterns in slide which were mounted in front of the diffusing glasses. Thus fusional binocular vision was completed. The pair of glow modulator tubes were fired by direct current from a pair of pulse generators. The time conditions for exposure of each stereo pattern (duration of exposure, delay between two exposures, and frequency of exposure repetition) were constructed by setting the time sequences of the DC pulse. The setting was monitored by a 2-channel synchroscope.

Following a dark adaptation for 10 min., Ss observed a train of intermittent exposures of a set of stimulation to the eyes. The time conditions for the set are shown in Fig. 3. The set consisted of a pair of individual exposures of the two patterns to both eyes, which were fixed at given durations. The onset of the pattern exposure to

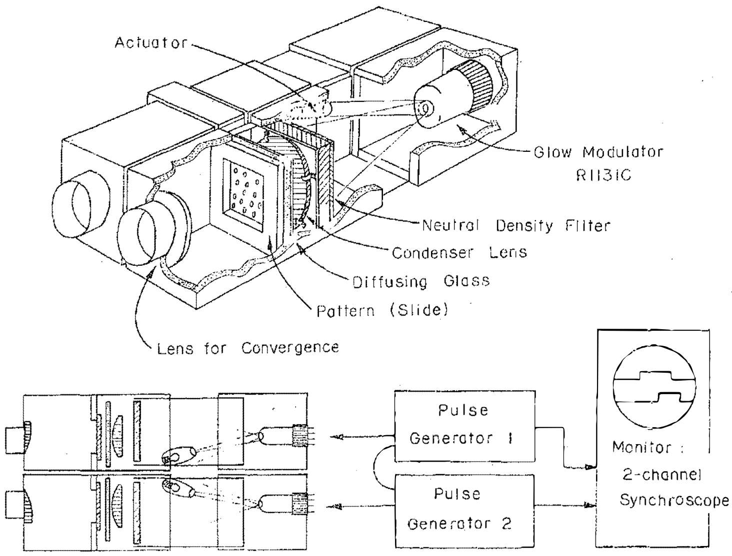


Fig. 2. Perspective view and block diagram of instrumentation.

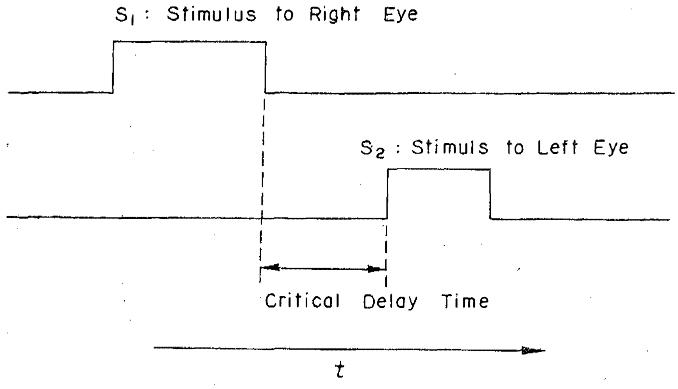


Fig. 3. Illustration of time condition in a set of stimulus exposure when a critical delay time was determined.

the right eye (S_1) preceded the exposure to the left (S_2). At the early stage of exposure, the time delay between the exposures of S_1 and S_2 was so adjusted that both were overlapped. The delay time was made longer little by little with each repetitive exposure. It was regulated by turning the dial of the pulse generator.

During the time of overlapping, clear stereoscopic depth impression took place. It decayed with increment of the delay time, at last arriving at the stage where the depth was scarcely noticed. At this stage, the exposure was interrupted in response to Ss' sign and a critical delay time, which was from the termination of S_1 to the onset of S_2, was obtained. The descending series in the method of just noticeable difference was employed thus to determine the disappearance threshold of stereoscopic depth perception.

S_1 was exposed in 9 ways : for the duration of 10, 50, 100, 200, 300, 350, 400, 500, and 800 msec. (see Fig. 4). These were paired with three durations of 50, 100, and 200 msec. of S_2 and four or seven thresholds were measured per pair. A mean of these is the critical delay time per pair.

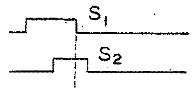
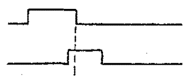
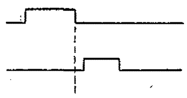
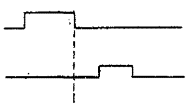
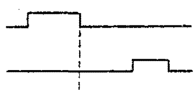
The circlets were kept at constant luminance of 0.035 mL when the duration was 800 msec., and the luminance was intensified when the duration was 50 and 10 msec., by reducing the neutral density filters, so that the brightness was equivalent to that of 800 msec. It, however, could not become guite equivalent when the duration was 10 msec., because it was too short to turn up its luminance.

The Ss who participated in this experiment were KM and TS.

Results

Table 1 indicates Ss' introspective remarks with respect to the mode of appearance of stereo pictures which served as a function of increment in the delay time between S_1 and S_2.

Table 1. Introspective remarks on decay process of depth impression.

Time Discrepancy between S_1 and S_2	Depth	Intermittency	Apparent Movement
	Clear	Lack	Lack
	Clear	Faint	Faint
	Faint	Faint	Faint
	Lack	Clear	Clear
	Lack	Clear	Lack

Fusional binocular vision took place over the stage where the delay time was kept short so that the two stimuli were overlapped. As the delay time was increased, stereoscopic depth impression became gradually weak, and it was replaced by another impression that the circlets on the ring skipped from right to left (stage of apparent movement). However, this stage of apparent movement went rapidly, and soon gave its place to the impression of intermittent succession of two circlets. The disappearance threshold of stereoscopic depth existed just before the stage of apparent movement.

The results of measurement are given in Fig. 4, where the critical delay times in three sets of S_2 are plotted as a function of duration of S_1. The experiments of TS were tried again, for his first data showed a marked fluctuation because of a few minutes interruption on the way as seen in Fig. 4c, and the new data are given in Fig. 4b.

The results of present experiment read from Fig. 4 are given in a summary as follows:

(1) Even when there was no temporal overlapping between exposures of the two stimuli, usual stereoscopic depth was perceived in the fusional image from S_1 and S_2, if the duration of S_1 was less than approximately 375 msec. as was read from both Fig. 4a and Fig. 4b.

(2) There existed, however, a limit to delay (critical delay time) past which

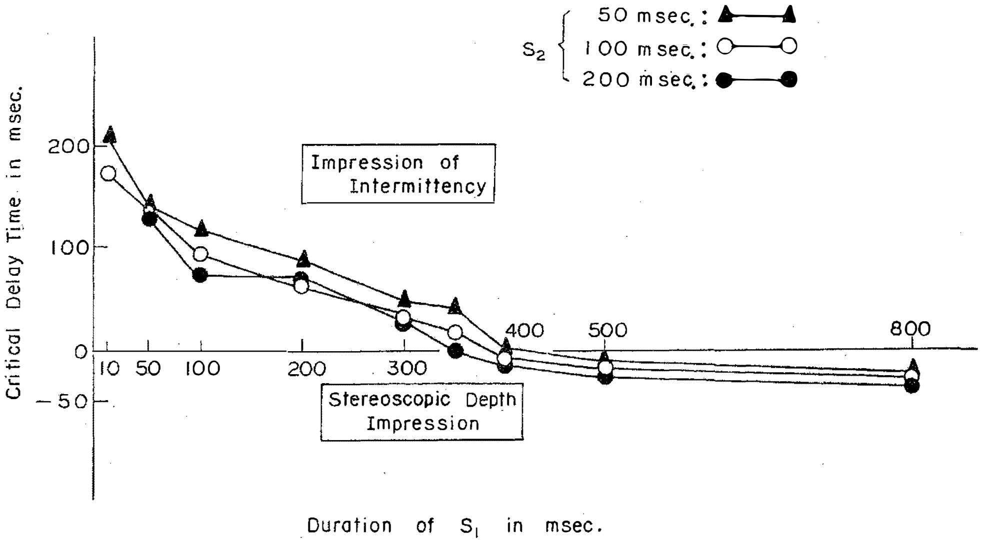


Fig. 4a. Results of KM. Critical delay times in three sets of S_2 are plotted as a function of duration of S_1.

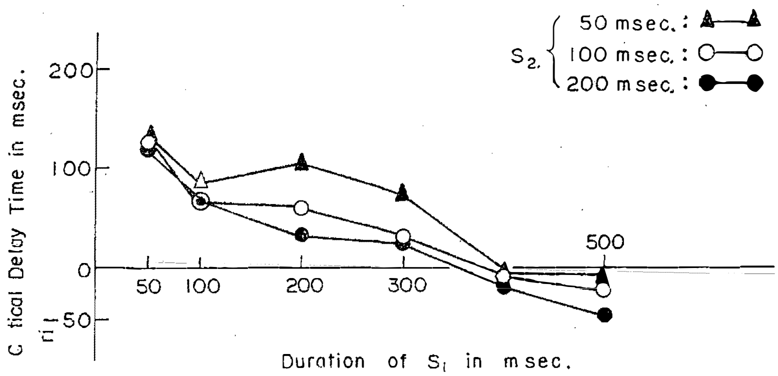


Fig. 4b. Results of TS, obtained by 2nd measurement.

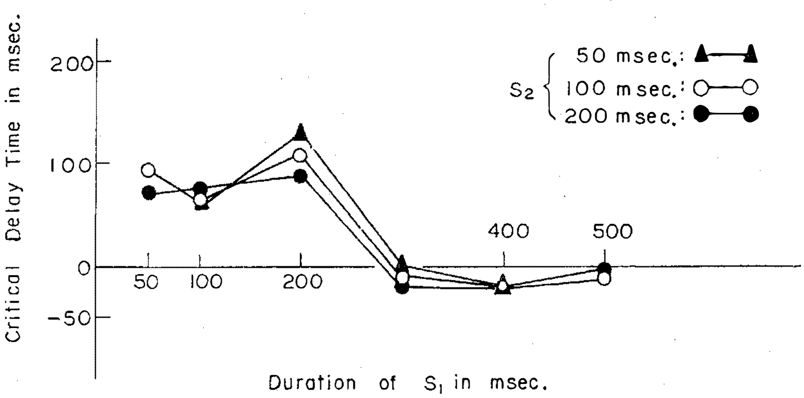


Fig. 4c. Results of TS, obtained by 1st measurement.

stereoscopic depth perception could not be established. The critical delay time increased as the exposure duration of S_1 decreased.

(3) When the duration of S_1 was extended over 375 msec., it was necessary to lap the tail of S_1 over the top of S_2 for approximately 30 msec. at least. This limiting overlap time of 30 msec. seems to be constant without regard to the duration of S_1.

(4) Three variations in the duration of S_2 did not give any different critical delay time.

Discussion

Based on the above results, the following postulates may be deduced :

(1) From the result that, when the duration of S_1 was less than 375 msec., stereoscopic depth was perceived even though there was no temporal overlapping between the two stimuli, it may be postulated that a certain process contributing to the establishment of stereoscopic depth perception ("process for stereoscopic depth perception") among which both of cortical and peripheral processes are included, persists for a time even though S_1 has been removed.

(2) From the result that some overlapping was needed between the two stimuli for stereoscopic depth perception when the duration of S_1 was extended over 375 msec., it may be postulated that the "process" itself does not stay when the duration of S_1 is extended more than 375 msec. Thus it may be regarded that no marked off-phenomenon appears there.

(3) From the result that the critical delay time was constant irrespective of the duration of S_1, it may be postulated that essential progress of the "process" develops at the initial period of exposure.

(4) From the result that the critical delay time increased as the duration of S_1 decreased, it may be postulated that the period of time for which the "process" persists after the termination of S_1 increases as the duration of S_1 decreases. It suggests that rapid and powerful rise in excitation of the "process" (on-phenomenon) takes place with the onset of stimulus exposure.

According to these postulates, the temporal courses of progress of the "process for stereoscopic depth perception" may be constructed as shown in Fig. 5.

(1) The "process" rises rapidly with the onset of stimulus exposure (on-phenomenon). (2) After that, it turns the course to decay soon, (3) and settles down at a certain level (standard level of the "process") approximately 375 msec. after the onset of stimulus, even though the exposure is continued. This level is the minimal magnitude necessary for stereoscopic depth perception. (4) When the exposure is interrupted at some points within 375 msec., it takes some time to decay completely. The earlier the interruption is, the longer decay time is needed, because the magnitude of excitation of the "process" increases near the onset of exposure. Accordingly, the critical delay time increases as the duration of S_1 decreases.

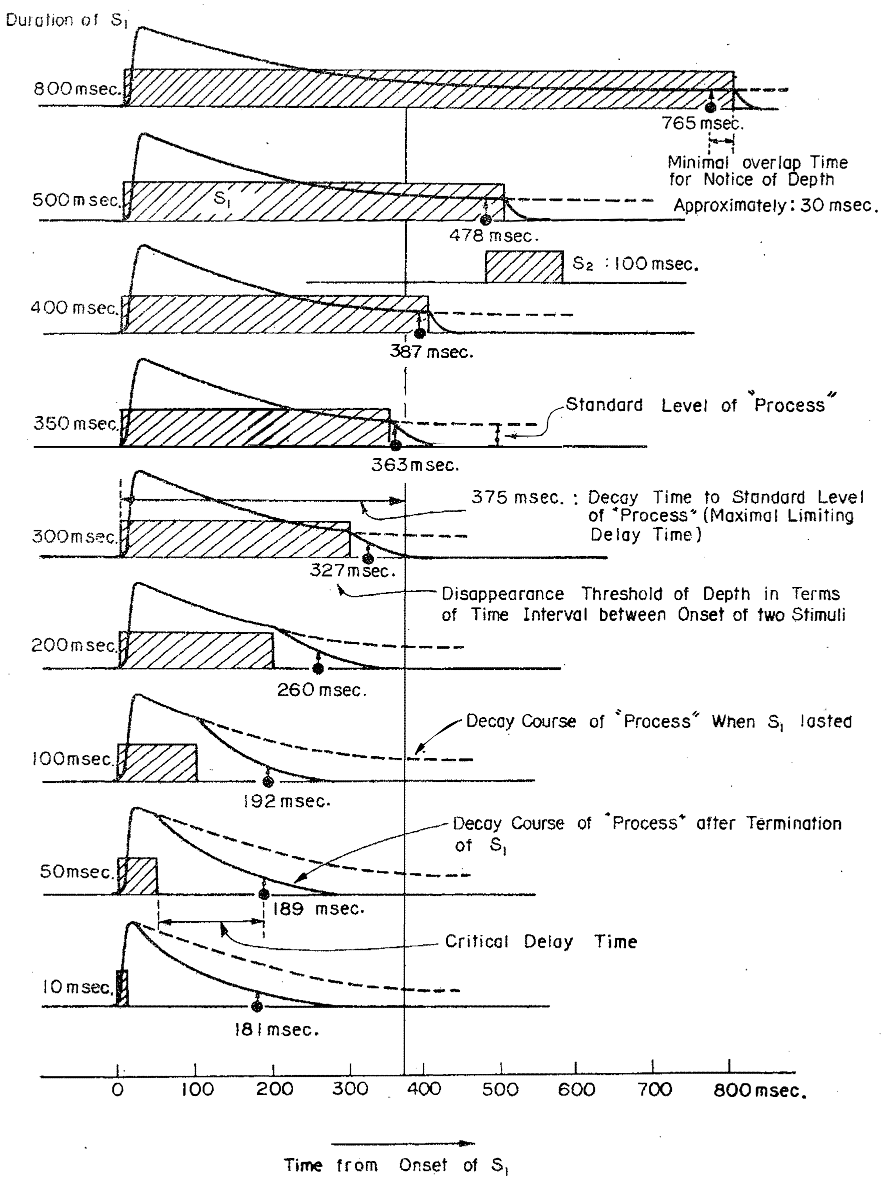


Fig. 5a. Postulated temporal courses of the "process for stereoscopic depth perception" over the period of exposure of S_1 and after it, constructed from the results of KM (S_2: 100 msec.) shown in Fig. 4a. Abscissa: time which elapsed after the onset of S_1. Ordinate: magnitude of excitation of the "process". Illustrations are given for all variations of S_1 used in the experiment as arranged from top to bottom in the order of length of exposure. Under the marks of ↑, the disappearance thresholds of stereoscopic depth are attached. Each is shown in terms of the delay time between the onset of S_1 and that of S_2 (sum of the duration time of S_1 and the critical delay time).

In the datum for 800 msec., the "process" caused by S_1 grows rapidly immediately after the onset of exposure and turns the course to decay even though the exposure continues. It

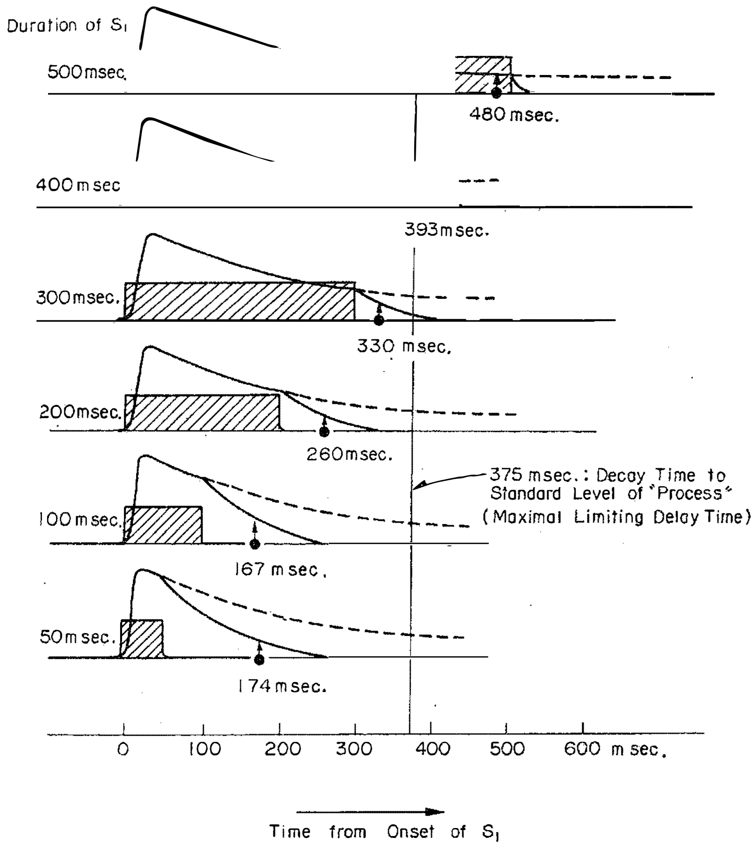


Fig. 5b. Postulated construction for the results of TS from Fig. 4b (S_2: 100 msec.).

stops to decay and settles down at a certain level (standard level) approximately 375 msec. after the onset of exposure and this level is maintained to the termination of stimulation. With the termination, however, it vanishes instantly. Stereoscopic depth perception is established if S_2 is exposed to the eye at some points within the period of exposure. However, when S_2 is exposed at the tail of S_1, it is not established unless the top of S_2 laps over the tail of S_1 for approximately 30 msec. at least.

In the datum for 100 msec., the "process' which has risen immediately after the onset of S_1 fails to follow the course of decay as it does in case of 800 msec., because S_1 vanishes after 100 msec. It takes another course shown in the figure decaying and vanishes earlier than in case of prolonged exposure. Since its level of excitation is high at the moment of interruption, there exists some lag of time for complete extinction as shown in the figure. Even though the exposure of S_1 has terminated, stereoscopic depth can be perceived if S_2 is exposed to the eye before the "process" caused by S_1 vanishes.

Fig. 5 shows the postulated temporal courses of progress of the "process" constructed in relation to the critical delay times determined. Fig. 5a was constructed on the basis of the results of KM (S_2:100 msec.), which are shown in Fig. 4a. Fig. 5b was also constructed for TS (S_2: 100 msec.) from the results shown in Fig. 4b.

The present experiment was performed without knowledge of the data from Ogle (1963), and the Fig. 5 was also constructed independently. The data here, however, are in essential agreement with those of Ogle. Moreover, the postulated temporal courses of progress of the "process" shown in Fig. 5 have certain points of resemblance to Ogle's, for which he postulated a cortical excitation process. There exists, however, a disparity between both sets of data as to the maximal limiting delay time between the onset of S_1 and that of S_2 past which some temporal overlapping is always needed for stereoscopic depth perception. Ogle gave 250 msec. for it, while the present experiment showed 375 msec. The discrepancy of 125 msec. might have been caused by the following two major factors : (1) Difference of test details employed — Ogle's experiment concerned the two lines of white thread, while the present experiment employed a specific pattern. (2) Difference of the thresholds determined — the maximal limiting delay time obtained here may have been somewhat longer than Ogle's, because the former was shown in terms of the disappearance threshold, while Ogle's in terms of 50% limen of probable stereoscopic depth perception.

The two sets of data show good agreement as to the essential aspect of result that the critical delay time increased as the exposure time of S_1 decreased. This does not agree to Tsuji's data (1967) which were also obtained independently of the present data. Tsuji reported that the critical delay times showed a constant value when S_1 ranged from 5 over to 200 msec.

Although Ogle regarded the process as a cortical excitation which persists after S_1 has terminated and contributes to stereoscopic depth perception, the present authors postulated the "process for stereoscopic depth perception" which includes not only the cortical process, but also the peripheral processes such as "Abklingen" process of sensation or afterimage. However, afterimage may scarcely play an important role here, as indicated by Ogle.

II. Critical Exposure Frequency as Influenced by Durations of Two Stimuli

Problem

The same process for stereoscopic depth perception as is produced through the right eye by exposure of S_1 is also expected through the left eye by the exposure of S_2.

If an experiment is designed in such a way as (1) the delay time from the termination of S_1 to the onset of S_2 is equal to the critical delay time of S_1 (cd_1), and (2) a thus settled pair of S_1 and S_2 are exposed repeatedly not at a constant rate but with the rate increased, then finally the rate will be expected to arrive at a critical exposure

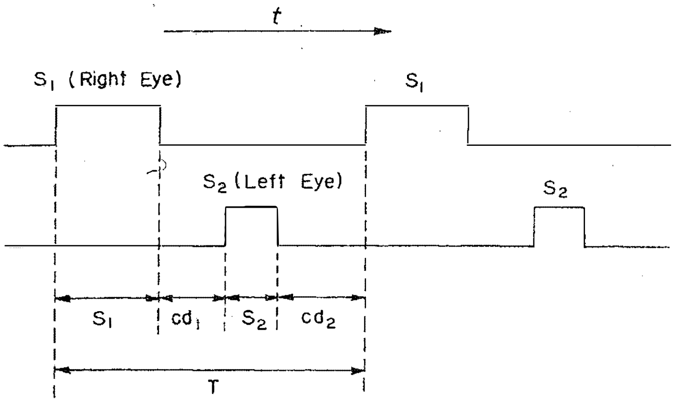


Fig. 6. Schematic representation of time relationship on stimulus exposures.

frequency where the minimal stereoscopic depth can be perceived in every transitional part from the termination of S_1 to the onset of S_2 and vice versa, for the interval from the termination of S_2 to the onset of S_1 becomes equivalent to the critical delay time of S_2 (cd_2).

The present experiment was designed to confirm the expectation mentioned above and to examine the validity of the preceding data.

Method

The test details as well as the apparatus used here were essentially the same as those for the preceding experiment. Both KM and TS were also employed for the experiment as Ss.

The temporal relationship between the two stimuli is presented in Fig. 6. Four kinds of duration of S_1 and S_2 were paired as shown in Table 2. Each critical delay time for S_1 in these pairs was read from Fig. 4a with regard to KM and from Fig. 4b with regard to TS. As to the pair of 50: 500 msec., it was measured here separately from the others. All these are shown in Table 2 as S_1+S_2.

In the experiment, three durations of S_1, cd_1, and S_2, were fixed at given length by the pulse generators. At first a set of these was exposed repeatedly with low frequency. The frequency increased gradually with the passage of time. It was terminated at the moment Ss could perceive faint stereoscopic depth in every transitional part from the termination of S_1 to the onset of S_2 and vice versa, and the exposure frequency was read from the pulse generators in terms of a cycle per second. Five or seven measurements were made per pair and a mean of them was obtained as the critical exposure frequency (cf_m).

Results

The critical exposure frequencies (cf_m) with KM as well as with TS measured in

Table 2. Time relationship between S_1 and S_2. Expected and measured values of critical exposure frequency.

Duration (msec.) S_1 : S_2	S_1+cd_1 (msec.)	S_2+cd_2 (msec.)	T (msec.)	cf_e (cps)	cf_m (cps)	Ss
50:500	189	488	677	1.5	1.5	KM
	177	490	667	1.5	1.1	TS
50:100	189	215	404	2.4	2.6	KM
	174	182	356	2.8	2.7	TS
50:50	190	190	380	2.6	3.1	KM
	171	171	342	2.9	2.5	TS
100:200	172	260	432	2.3	2.4	KM
	168	260	428	2.3	1.9	TS

this way are presented in Table 2.

That stereoscopic depth began to be perceived in the transitional part from the termination of S_2 to the onset of S_1, is to mean that the time interval of this transitional part became equivalent to the critical delay time of S_1. If there is no marked difference in critical delay time between both eyes, that of S_2 (cd_2, left eye) can be obtained from that of the right eye : Fig. 4a describing the data of KM and Fig. 4b describing those of TS. The values of S_2+cd_2 thus calculated are presented in Table 2. Total of S_1, cd_1, S_2, and cd_2 is denoted by T as illustrated in Fig. 6. From this T, the critical exposure frequencies expected previously (cf_e) are obtained as 1/T, which are presented in Table 2.

When each cf_e and its corresponding cf_m are compared, the values are in good agreement with each other as seen in Table 2. This evidence comes up to the expectation of the present experiment and also supports the validity of the preceding experiment.

References

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Tsuji, M. 1967 An analysis of stereoscopic depth perception. *Acta Soc. Ophthalm. Jap.*, **71**, 779-784.

Zusammenfassung

Die zwei für die stereoskopische Tiefenwahrnehmung bereitgestellten Reize (S_1 und S_2) werden sukzessive gegen die ihnen entsprechenden Augen ausgesetzt, S_1 gegen das eine Auge und dann S_2 gegen das andere. Wenn auch es kein zeitliches Übereinanderliegen zwischen Aussetzungen der zwei Reize gibt, wird die gewöhnliche stereoskopische Tiefe wahrgenommen, wenn die Dauer des S_1 minder als etwa 375 msec. ist. Jedoch gibt es eine Grenze der Aufschiebung (kritische Aufschiebsdauer), jenseits dessen die stereoskopsiche Tiefe nicht festgesetzt werden kann. Die kritische Aufschiebsdauer, die von der Beendigung des S_1 bis zum Angriff des S_2 gemessen wird, nimmt zu, indem die Aussetzungsdauer des S_1 abnimmt. Wenn die Aussetzungsdauer mehr als 375 msec. wird, so bedarf das Übereinanderliegen des Schwanzes des S_1 auf die Spitze des S_2 etwa 30 msec. für die Wahrnehmung der stereoskopischen Tiefe. Diese

Ergebnisse sind auch durch das Experiment, um die kritische Periode der wiederholten Aussetzung zu messen, bestätigt worden.

Auf Grund der Ergebnisse, haben wir ein Modell für die zeitlichen Gänge gebaut, nach denen der „Prozess der stereoskopischen Tiefenwahrnehmung“ bie und nach der Reizesaussetzung veläuft.

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