THE INTENSITY - TIME RELATION OF A STIMULUS
IN SIMPLE VISUAL REACTION TIME

by

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ABSTRACT

In Experiment I, visual stimuli were presented at varying levels of stimulus duration and stimulus luminance. The durations ranged from 3 to 500 milliseconds, and the luminances from 2,670 to 0.42 millilamberts. The area of the visual stimulus was held constant at 20' throughout the experiments. In the second experiment, five durations from 30 to 120 milliseconds, and two luminances from 0.054 and 1.07 millilamberts were presented to subject T.S. Reaction time was measured as the dependent variable. The subject made his reactions by releasing a lever attached to a micro-switch.

In Experiment I, curves were plotted for all three subjects. One set of curves plotted median reaction times against log stimulus duration. These curves show that reaction time decreases as stimulus duration increases for the two lowest luminances, that reaction time approaches a constant at the highest luminance at all stimulus durations, and that reaction time appears to decrease most appreciably to increases of stimulus duration at threshold levels. Another set of curves plotted median reaction times for all three subjects against flash energy. These curves indicate that as the total flash energy increases, the reaction time decreases, insofar as the data for the two lower luminances are concerned.

The results of Experiment II where five stimulus durations were paired with three luminances were that reaction time was higher to energy values of less energy and increased duration and that an increase of total stimulus energy produces a decrease in reaction time.

It is mentioned in the discussion of this study that stimulus duration has a great effect upon reaction time particularly at threshold. It is pointed out that critical duration seems to depend upon flash luminance and that as higher luminance levels are reached, increases in duration (beyond some short critical period) do not affect the reducible margin of the reaction time.

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HISTORY

Simple reaction time as used in this paper is defined as the length of time between the onset of a stimulus and the completion of the response. Rarely, it has been used to mean the time between the termination of a stimulus and the onset of the response. However, in this second situation, the offset of the stimulus is a change of energy and can be regarded as a stimulus itself. The terms reaction time and response latency are used interchangeably. The term, reaction speed, refers to the reciprocal of the latent period and has been used as an index of the intensity of sensation (Piéron, 1920).

Piéron (1920) has stated that reaction speed is not the latency of sensation, but the latency of a total reaction. The total reaction time can be divided into two components; the irreducible minimum and the reducible margin. The irreducible minimum consists of the time of receptor processes and neural conduction, and is somewhat variable depending upon the level of efficiency of the various neural units involved. Therefore, in visual excitation, the components of the irreducible minimum are the afferent and efferent transmission delays and the time required for the completion of central processes. The irreducible minimum changes from experiment to experiment depending upon the variables which are held constant.

The reducible margin of reaction time is that portion which falls above the irreducible value; its duration is governed largely by the independent variables in the stimulus situation. This reducible

margin may be determined quite accurately by subtracting the maximum reaction time for threshold stimuli from the minimum reaction time to maximum stimulus intensities. The reducible margin may be related in systematic ways to a stimulus variable. An example of such a function was suggested by Piéron (1920)*. He stated that the hyperbolic function,

$$T = A/(I + C) + K,$$

describes the decline of reaction time with increasing flash luminance. In this equation T = reaction time, A = the reducible latency, I = flash intensity, and K = an irreducible limiting latency.

The variables of luminance and duration of a visual stimulus affect the reducible margin. Various studies will be cited to demonstrate the variety of relationships that have arisen out of reaction time data. The variable of stimulus intensity or luminance and its effects upon simple visual reaction time will be discussed first.

Froeberg (1907) studied the effects of the intensity of a visual stimulus upon human reaction time. His study was also concerned with the effects of duration upon reaction time, but these results will be discussed later in this paper. The method for both experiments was essentially the same, and it will be described thoroughly here. The source of illuminance was daylight reflected off Milton Bradley white baryta paper and Hering's grays. The illuminance from the Milton Bradley paper was designated as 100 and the other intensities were obtained from Hering's grays. They were compared with the white baryta paper by placing them on a color wheel. The degree of brightness was determined by the size of the white sector, expressed in terms of

percentage of the whole circle that produced the same shade of gray as the paper to be tested. The lowest intensity used was daylight reflected off velvet black, and the other intensities were designated as 56, 25, 16, 10, $6 \frac{2}{3}$, $3 \frac{1}{2}$, $2 \frac{1}{4}$ and $\frac{3}{4}$. The stimulus durations were obtained by moving paper of a desired absorption value across an aperture varying in size from 3 to 48 millimeters. The paper was rotated at a rate of one millimeter per millisecond, therefore, each additional millimeter would add one millisecond to the duration of the stimulus. The duration for this experiment were 3, 6, 12, 24, and 48 milliseconds. Two subjects were used and 400 reactions were taken for each condition. Mean reaction times and mean variations were computed for each of the sets of data. It was stated that the lowest intensity used was well above threshold due to the limitation of the apparatus. The results showed that reaction time increases as the intensity of the stimulus decreases. More explicitly, the time of reaction tends to increase arithmetically as the intensity of the stimulus decreases geometrically. Reaction time was plotted against the logarithm of the stimulus intensity and a linear curve was obtained.

Hecht's (1918) work on Mya arenaria has shown a similar relation of luminance and reaction time. Mya, when exposed to light, retracts its siphon. Hecht used the time from the beginning of the exposure to the beginning of the retraction to calculate the velocity of light adaptation. He showed that reaction time is a reliable method of finding values of the increment of intensity which give the same degree of discrimination at different adaptation levels. In a similar study (1928), he found that reaction time appears to increase

linearly to the logarithm of the stimulus intensity.

Hovland (1936) investigating reaction times to field luminances and stimulus luminances in humans found a decrease in reaction time as the difference between the stimulus and adaptation field increased. Here reaction time is to a stimulus presented upon a variable field luminance rather than a fixed background.

In a similar study, although using more comprehensive stimulus ranges, Bartlett and Macleod (1954) studied the effects of flash and field luminance upon human reaction time. They found that reaction time shows little increase where the stimulus luminance is clearly distinguishable from the field luminance. There was, however, a large increase in reaction time as the field and flash luminances approached equal levels, using higher field luminances. The reaction time was faster for the foveal position than it was for the peripheral position, but with dim luminances the reverse was true. The functional relation of luminance to reaction time was demonstrated by fitting the following equation to the data:

$$T = \frac{1}{B \log I/I_0} + K,$$

where B is a slope constant, I is flash luminances, I_0 is a limiting flash intensity dependent on the field luminances, at which reaction time approaches infinity, and K is a limiting latency which reaction time approaches as I becomes very large. The essential difference between this formulation and that of Piéron's, mentioned earlier in this paper, is that Bartlett and Macleod employed logarithmic units instead of arithmetic units. This logarithmic unit substitution has more adequately described the extensive Bartlett and Macleod's data than

the formulation of Pieron. This study has shown that the reducible margin of reaction time can be directly related to stimulus changes, in this case luminance levels.

Temporal conditions of a visual stimulus also determine the magnitude of reaction time although not all investigators agree on the amount or directions of the effect. The first systematic investigation into the effects of duration of a visual stimulus upon reaction time was made by Froberg (1907). The method has been described earlier in this paper. From these results, Froberg stated that reaction time increases arithmetically as duration decreases geometrically, or that reaction time increases as duration decreases. Weighing the effects of the duration of stimulus against the effects of illuminance, he found that reaction time decreased with an increase in either variable, but that the increment produced by an increase in illuminance was twice that of the same increase in duration.

Wells (1913) studying the effects of the duration of a visual stimulus on reaction time did not find any evidence that reaction time increases as duration decreases. Wells obtained reactions from the onset of a stimulus light 12, 25, 64, 144, and 1,000 milliseconds in duration. A plastic disc forming a retinal image of 0.014 millimeters was illuminated by a Nernst filament. The illumination at the disc was $3\frac{1}{4}$ candle power at a distance of 142.5 centimeters. From these results, it was stated that if there was any relation between reaction time and the duration of stimulus, it was that the longer the duration of the stimulus the longer was the reaction. The probable relationship between the reaction time and duration of stimulus would be a direct one, that is, for every unit increase in stimulus duration there would

be an increase in reaction time although not in the same proportion.

Thus, the inverse relation that Froeberg found was not substantiated in Wells' data. Wells minimized the effects of duration in both his experiment and Froeberg's experiment because of the small differences in reaction time produced by successive increases in duration.

Froeberg and Wells used a wide range of durations which at the threshold level would lie within the critical duration, but their illuminances were too high to allow duration to determine much of the response. In order to demonstrate the effects of duration upon reaction time, near threshold luminances should be employed.

According to Graham and Ratoosh (1962) a luminance of high intensity may take somewhat less duration to be seen than another flash of lower luminance and the same duration, and any light coming in after the initial part of the flash has been seen will be wasted for this response.

The reciprocal relationship of stimulus intensity and stimulus duration, mentioned above, has been established for threshold stimuli. Bloch's Law (1855) states this reciprocity as $I \cdot t = C$, where I = luminances, t = time, and C = a constant with the proper dimensions. Bloch has applied this law to visual sensations stating that the reciprocal relationship of time and intensity exists within certain limits, namely for short flashes, to the visual process.

Graham and Margaria (1935) investigating area, intensity, and time relations in visual threshold in the peripheral retina found that with short durations, the energy of a flash, It , is constant for a given area, but with long durations all areas require an increase in

the It product necessary to reach threshold. In this same study, it was found that reciprocity existed for short exposures and small areas but if the exposure time was increased beyond 0.05 seconds, evidently the critical duration for peripheral threshold, the condition $I = C$ prevailed. Above critical duration, intensity alone seems to be effective in determining the response.

Graham and Kemp (1938) studied brightness discrimination and found that the intensity required to produce a just noticeable increase in apparent brightness decreases with an increase in duration up to a critical duration. Beyond critical duration the required intensity to produce an increase in apparent brightness of a stimulus field of a given intensity is constant.

In a study to follow up that by Graham and Kemp, Keller (1941) supported their findings. She found that $\Delta It = C$ holds for exposures of ΔI up to the limit of a critical duration at all levels of the basic intensity. Beyond the critical duration, ΔI equals a constant, and intensity discrimination is independent of duration. Keller intensively explored a smaller range of durations than did Graham and Kemp in order to explore the effect of small durations, thereby insuring a more accurate determination of the critical duration values. From both Graham and Kemp's and Keller's studies, it is clear that the critical duration is a function of the basic adaptation intensity.

The above mentioned threshold studies along with Hartline's (1934) study of threshold effects in the single fiber in the eye of Limulus polyphemus indicate that there is a fairly sharp break from the $It = C$ relation to $I = C$, indicating a critical duration after which intensity alone determines the response.

Although threshold studies have clearly pointed out this reciprocal relationship, reaction time studies have not. Most studies, such as those of Froeberg and Wells, have employed intensities of visual stimulus well above threshold. The threshold region, however, affords a longer duration, one in which stimulus energy may contribute to a sensory effect. It is reasonable, therefore, to look in the threshold region of luminances for the reaction time to show the effects of stimulus duration.

If previous studies have not found much effect of duration upon reaction time, it may be because of the high stimulus intensities that were used. It is the purpose of this study to measure the relation of stimulus intensity and stimulus duration upon simple human visual reaction time over a wide stimulus range. It is reasoned that if low luminances, approximating threshold, are used reaction time will exhibit the intensity-time relationship that has been shown in threshold studies. Duration, then, would be expected to determine part of the reaction up to a certain value, the critical duration, after which luminance alone would determine the magnitude of the response. As in threshold studies, reaction times measures should show that critical duration is a function of the level of luminance employed.

METHOD

Apparatus

The Visual Discriminator consisted of a covered tunnel $2\frac{1}{2}$ " x $3\frac{1}{2}$ " x $2\frac{1}{2}$ ", as shown in figure 1, which provided the stimulus and fixation sources. The light source was a Sylvania Glow Modulator (type RL131C) tube (A) with a rise and decay time less than 0.0001 seconds. The light from this source passed through a collimating lens (B) 22mm in diameter with a focal length of 162mm. Slots in the tunnel walls (C) held Wratten neutral density filters which could be inserted to obtain appropriate luminances. The field stop holder (D) enabled the selection of stimulus area by the insertion of area slides. After passing through the area slide, the light traversed a beam splitter (E), a converging lens 35mm in diameter with a focal length of 90mm (F), and then converged at an artificial pupil 3mm in diameter (H). The fixation point was reflected off a 45° inclined slide glass cover inserted between the converging lens and the artificial pupil (G). An opening above the glass received the light from a neon bulb (type NE51) mounted in a closed metal cylinder. The cylinder was covered with aluminum foil through which three pin-size holes were drilled 3.5mm apart, thus allowing a triangular fixation display which subtended $3^\circ 51'$ at the eye to be projected to the inclined glass. The fixation source was positioned

FIGURE 1. Apparatus as described in text.

so that S would receive the stimulus 15° from the fovea on the temporal region of the retina. S maintained a steady position by holding a bite plate (I) in his teeth. The bite plate was made from "Fastray", a self-curing dental plastic and was clamped between two pieces of plywood affixed to the booth wall. An individual bite plate was made for each S. S sat in a light-secure, ventilated booth 65" x 36". The end of the visual discriminator containing the fixation cover glass and the artificial pupil extended three inches into the booth through the back panel. As S sat in the fixation position, he rested his right arm on a six-inch shelf attached to the side of the booth. A micro-switch (BZ-2RW80) was mounted in a slot in the shelf. A lever was attached to this switch and bent so that the lever was parallel with the base of the switch and was stopped by a metal plate which limited the distance to which it would be depressed to 2mm. To execute a reaction, S held the lever against the stop until the onset of the stimulus, and lifted his forefinger as rapidly as possible.

The Electronic Response-Indicator System (model R-2) manufactured by the Psychological Instrument and Research Laboratory of Rome, New York, contained both the stimulus source power supply and a Berkeley Electronic Counter which measured reactions to 0.0001 seconds. Hunter Decade Interval Timers (model 1000) controlled both the stimulus duration and the duration of the foreperiod. S initiated the foreperiod by depressing a foot switch which closed the timer circuit. At the end of the foreperiod, the timer device triggered the counter and stimulus light simultaneously, and the counter was stopped when S released the reaction lever, opening the counter circuit.

Twelve durations, covering a wide span of time, were used in this study. They were 3, 6, 12, 30, 40, 48, 60, 80, 96, 120, and 500 milliseconds. Area was held constant by the use of a .083 inch field stop which subtended a visual angle of 20'. The field stop was constructed by drilling opaque film sprayed with flat black paint to eliminate any light leaks. The film was mounted in an aluminum frame which was inserted into the visual discriminator.

Five luminances were used, ranging from near threshold to very bright. They were determined by inserting Wratten neutral density filters in front of either a 26,700 millilambert (mL) source (source A) or a 34,200 mL source (source B). These luminances were calibrated with a MacBeth Illuminometer. All three subjects received the luminances from source A which were (a) 0.42 mL (density value 4.8); (b) 0.84 mL (density value 4.5); and (c) 2,670 mL (density value 1.0). Subject T.S. received, in addition to the source A values, the two source B values which were (a) 0.54 mL (density value 5.8) and (b) 1.07 mL (density value 5.5).

SUBJECTS

Subjects were three male graduate students in the Department of Psychology. Each subject practiced this reaction time task fifteen hours prior to the test trials.

PROCEDURE

This study encompassed two similar experiments which will be referred to in the text as Experiment I and Experiment II.

Prior to each session, each S dark adapted 30 minutes in the reaction booth. After this period of time, S was ready to react to the stimuli, each of which was preceded by a variable foreperiod. The length of the foreperiod ranged in steps of tenths of a second from two to four seconds. The foreperiod length was predetermined by use of a table of random numbers. Pairs of numbers were selected from this table, the first digit corresponding to seconds and the second digit to tenths of seconds. E set the foreperiod on the Hunter Timer, and then said, "Ready". This was the signal for S to depress the response key and the foot switch to signal he was prepared to react. The foot switch initiated the foreperiod and was held down until the reaction had been executed. By lifting his forefinger from the lever, S stopped the counter. E would then read the reaction time aloud to S and record it on the data sheet. This process was repeated until all the data were recorded for each block. A rest period of 10 minutes separated one block from another. When a low energy flash followed a high one in the trials, a rest period was inserted to allow S to readapt to previous levels. Each session lasted from 1 to 2 hours.

In Experiment I, trials were administered in blocks of 35. Each block was identified by one of the three luminance values which was paired with each of the seven durations giving a total of 7 conditions for each one of the three blocks. The order of each duration as it was paired with each intensity is given in Table I. Five reaction times were collected for each duration in any one block every session. Fifty reactions were collected for each duration-luminance condition over ten sessions. The S sat for one session per day.

TABLE I

The Experimental Design of Experiment I

Luminances are represented by capital letters, and durations are represented by their value in milliseconds. Each duration-luminance condition was repeated 5 times, as explained in the text.

Day	Conditions
1	<div>A_{3,96,6,24,12,48,500} B_{6,24,12,48,500,96,3}</div> <div>C_{12,48,500,96,3,24,6}</div>
2	<div>B_{3,96,6,24,12,48,500} C_{6,24,12,48,500,96,3}</div> <div>A_{12,48,500,96,3,24,6}</div>
3	<div>C_{3,96,6,24,12,48,500} A_{6,24,12,48,500,96,3}</div> <div>B_{12,48,500,96,3,24,6}</div>
4	<div>A_{3,96,6,24,12,48,500} C_{12,48,500,96,3,24,6}</div> <div>B_{6,24,12,48,500,96,3}</div>
5	<div>B_{3,96,6,24,12,48,500} A_{12,48,500,96,3,24,6}</div> <div>C_{6,24,12,48,500,96,3}</div>
6	<div>C_{3,96,6,24,12,48,500} B_{12,48,500,96,3,24,6}</div> <div>A_{6,24,12,48,500,96,3}</div>
7	<div>A_{96,24,500,6,3,12,48} B_{500,6,3,12,48,24,96}</div> <div>C_{3,12,48,24,96,6,500}</div>
8	<div>B_{96,24,500,6,3,12,48} C_{500,6,3,12,48,24,96}</div> <div>A_{3,12,48,24,96,6,500}</div>
9	<div>C_{96,24,500,6,3,12,48} A_{500,6,3,12,48,24,96}</div> <div>B_{3,12,48,24,96,6,500}</div>
10	<div>A_{6,500,12,48,24,96,3} C_{24,96,3,500,6,48,12}</div> <div>B_{12,48,24,96,3,500,6}</div>

In Experiment II, trials were administered in four blocks. Five durations were used, and each duration was paired with each luminance represented in every block. Every luminance, then, was represented in two blocks. Table II shows the design for Experiment II. Five reaction times were collected for each duration-luminance condition in every block yielding a total of 10 reactions per day per condition. Five days were required to collect a total of 50 reactions for every condition. The remaining procedure for Experiment II was the same as that for Experiment I.

TABLE II

The Experimental Design of Experiment II

Luminances are represented by capital letters, and durations are represented by their value in milleseconds. Each luminance appears twice in each session paired with each of 5 durations.

<u>Day</u>	<u>Conditions</u>	
1	A _{30,40,60,80,120}	B _{40,60,80,120,30}
	A _{60,80,120,30,40}	B _{80,120,30,40,60}
2	B _{40,60,80,120,30}	A _{60,80,120,30,40}
	B _{80,120,30,40,60}	A _{120,30,40,60,80}
3	A _{60,80,120,30,40}	B _{80,120,30,40,60}
	B _{120,30,40,60,80}	A _{30,40,60,80,120}
4	B _{80,120,30,40,60}	A _{120,30,40,60,80}
	A _{30,40,60,80,120}	B _{40,60,80,120,30}
5	A _{120,30,40,60,80}	A _{30,40,60,80,120}
	B _{40,60,80,120,30}	B _{60,80,120,30,40}

RESULTS

Experiment I

The design of this experiment was constructed so that a luminance-by-duration-by-subjects analysis of variance might be performed on the data. The analysis was performed on median reaction time scores and not mean reaction time scores. This was done because in some conditions, some flashes were not seen by the subject. Thus a flash at threshold levels might not be seen and thus would be counted as an infinite reaction time, hence the median is the only meaningful measure of central tendency. The F ratio for the analysis of variance was tested at the 0.1 percent level of confidence. The effects of duration, luminance, and duration by luminance were tested.

In this experiment, seven durations were administered to the subject at three luminances. The luminances ranged from near threshold to intense values. Figures 2, 3, and 4 present the median reaction times of all three subjects plotted against the duration of the stimulus at each of the three luminance levels.

Inspection of these curves reveal that, generally, reaction time is inversely related to an increase in duration for the two lowest luminances (0.42 mL and 0.84 mL), and that for the highest luminance (2,670 mL) there seems to be little effect of duration upon reaction time. Further inspection reveals that for all three subjects for the two lowest luminances, reaction time decreases with additional increases in duration to a point after which reaction

FIGURE 2. Median reaction times plotted as a function of log stimulus duration for subject J.B.

FIGURE 3. Median reaction times plotted as a function of log stimulus duration for subject L.H.

FIGURE 4. Median reaction times plotted as a function of log stimulus duration for subject T.S.

time no longer decreases. This point seems to lie near 48 milliseconds for all subjects.

The greatest difference between any two consecutive points on the curve is between the threshold flash (3 milliseconds at 0.42 millilamberts) and the next highest flash (6 milliseconds at 0.42 millilamberts). Reaction times for the first flash of the low threshold curve are 100 or more milliseconds higher than the reaction times for the second flash on that curve. Reaction time appears, then, to decrease most appreciably to increases of stimulus duration at threshold levels. The doubling of stimulus duration from 3 milliseconds to 6 milliseconds enabled the subjects to see this second flash 100 percent of the time, whereas the first flash was seen around 50 percent of the time. In the next curve for a luminance of 0.84 millilamberts, the difference between the 3 millisecond flash and the 6 millisecond flash is not as great as in the threshold flash.

Table III shows the results of the analysis of variance performed upon these data. The effects of duration are highly significant as are the effects of luminance. The effects of the interaction of duration and luminance, however, for this statistical test are not significant. This would indicate that the effects of duration and the effects of luminance may be acting independently of each other.

Figures 5, 6, and 7 present the curves for median reaction times plotted against $\log$ (stimulus luminance time stimulus duration), or the total flash energy. These curves show that as the total flash energy increases, the reaction time decreases, insofar as the data for the two lower luminances are concerned. Theoretically

TABLE III

Analysis of variance for the data of Experiment I

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO	SIGNIFICANCE AT 0.1 PERCENT
Duration	51,941.20	6	8,656.86	$F_L = 279.79$	61.25
Luminance	133,385.94	2	66,692.97		
Subjects	3,304.42	2	1,652.21		
DXS	1,103.30	12	91.94	$F_D = 94.15$	8.38
LXS	953.47	4	238.36		
LXD	35,635.15	12	2,969.59	$F_{LD} = 1.75$	4.39
SXLXD	40,695.95	24	1,695.66

FIGURE 5. Median reaction times plotted as a function of log (stimulus luminance times stimulus duration) for subject J.B.

FIGURE 6. Median reaction times plotted as a function of $\log (\text{stimulus luminance times stimulus duration})$ for subject L.H.

FIGURE 7. Median reaction times plotted as a function of log (stimulus luminance times stimulus duration) for subject T.S.

the reaction time to a flash of 6 milliseconds at 0.42 millilamberts should be equal to the reaction time to a flash of 3 milliseconds at 0.84 millilamberts, but as the curves show, this does not seem to be true indicating that luminance has more effect upon determining the time of reaction than does duration. The highest luminance curve (2,670 ml.) does not for any of the three subjects show any appreciable decline of reaction time with further increase in energy due to increasing flash duration. For this high luminance, over the range of durations tested, reaction time is probably dependent upon luminance alone, and not duration.

Figure 8 presents cumulative percentage frequency curves plotted for four durations at 0.84 ml. for subject T.S. The stimulus durations shown are a sample of the eight tested. This figure shows that the brief flash (3 milliseconds at 0.84 millilamberts) produces an increased variability of response as well as longer reaction times. Increases in flash duration decrease variability and decrease the baseline position of each curve in this graph. Evidently changing the duration changes the population of responses being sampled.

Table IV presents the reaction time data for Experiment I in the forms of Median, means and standard deviations. Means and standard deviations were computed only where 50 reactions were collected for each condition. It will be noticed that where means were computed they do not differ in any great degree from the medians that have been computed. Standard deviations were fairly low due to the use of well practiced subjects.

FIGURE 8. Cumulative percentage curves of four stimulus durations at 0.84 millilamberts for subject T.S.

TABLE LIV

Reaction time in milliseconds for all three subjects taken under the conditions of Experiment I

STIMULUS LUMINANCE (ml.)	M E D I A N S																							
	SUBJECT J.B.								SUBJECT L.H.								SUBJECT T.S.							
	STIMULUS DURATIONS IN MILLISECONDS																							
	<u>3</u>	<u>6</u>	<u>12</u>	<u>24</u>	<u>28</u>	<u>96</u>	<u>500</u>	<u>3</u>	<u>6</u>	<u>12</u>	<u>24</u>	<u>28</u>	<u>96</u>	<u>500</u>	<u>3</u>	<u>6</u>	<u>12</u>	<u>24</u>	<u>28</u>	<u>96</u>	<u>500</u>			
.42	438	309	295	279	278	275	276	409	286	276	272	262	264	260	472	311	295	287	280	280	282			
.84	371	283	280	280	269	268	266	310	281	268	263	253	255	254	354	298	286	271	271	270	269			
2670	203	199	200	191	193	192	193	199	199	192	193	190	195	195	210	203	203	194	200	198	202			
	M E A N S																							
.42	315	299	283	277	276	282		291	278	272	265	264	263		319	302	293	279	279	281				
.84	284	284	283	273	269	269		283	269	263	253	259	259		307	288	277	270	273	267				
2670	207	200	199	195	196	197	195	207	201	194	193	191	196	194	210	205	203	199	199	199	204			
	S T A N D A R D D E V I A T I O N S																							
.42	24	24	21	20	23	20		23	17	19	21	15	19		30	30	24	20	20	19				
.84	25	25	24	24	18	21		21	16	16	13	14	21		29	23	25	20	17	14				
2670	20	15	13	15	12	20	15	6	15	11	4	11	14	15	16	14	15	12	16	16	16			

Experiment II

This experiment was similar to Experiment I, but its purpose was to investigate, in detail for one trained subject, the effect of an increase in duration in a threshold flash. Subject T.S. was given five durations, 30, 40, 60, 80, and 120 milliseconds at two luminances of 0.054 ml. and 1.07 ml. Figure 7 shows the curves for this data, the plots being represented by the solid symbols. The total energy for the 30 millisecond and 0.054 millilamberts flash and for the 3 millisecond and 0.42 millilamberts flash of Experiment I is approximately the same. The reaction time to both of these flashes would be the same if the effects of duration were equal to those of luminance. These curves show that reaction time is higher to 30 millisecond - 0.42 millilambert combination than to the one of equal energy involving higher luminances and shorter durations. As in all of the other curves for near threshold conditions, increase of total stimulus energy produces a decrease in reaction time.

DISCUSSION

The principle purpose of this study was to determine the effects of duration of a visual stimulus upon simple human reaction time. Since previous studies have employed a limited range of stimulus durations at high luminances, this study has used a large range of durations from 3 to 500 milliseconds at luminances that ranged from threshold to very bright values.

The first experiment showed that reaction time is inversely related to an increase in duration for the two lowest luminances tested, and the reaction time is fairly constant to the remaining very high luminance. Furthermore for the two low luminance curves, reaction time decreases as stimulus duration increases up to a certain duration after which reaction time is a constant. These findings are in accord with the study by Graham and Margaria (1935) on the area, intensity, and time relations in visual threshold in the peripheral retina. The principle finding here was that approximately reciprocity exists for short exposures and small areas, but if the exposure time is increased beyond a certain critical duration then luminance alone determines the response. This is precisely the effect that is expected. Previous reaction time studies have not clearly shown this relationship, and indeed at least one study has indicated that duration of a visual stimulus has no effect upon reaction time.

To summarize some findings of early investigations into the duration of a visual stimulus and reaction time mentioned in a previous section of this paper, two contrary relationships have been

reported, Froeberg (1907) found that reaction time increases arithmetically as duration decreases geometrically, or that reaction time increases as duration decreases. This finding seems to fit in with the results of this present experiment, but as Wells has point out (1913) Froeberg's data were not very convincing since the differences produced by the addition of duration were light and probably not above the influences of chance or error. Wells (1913) in an attempt to clear up many of the difficulties that arose out of Froeberg's data investigated the effects of duration of a visual stimulus upon reaction time, but reported less positive results than Froeberg. Wells found that reaction time did not decrease as duration increased, and it was stated that if there was any relation between reaction time and the duration of stimulus, it was that the longer the duration of the stimulus the longer was the reaction. This indicates a direct relationship between duration and reaction time. According to this, then, if duration increases reaction time would increase.

In the light of the threshold studies mentioned previously in this paper, these findings do not make good sense. In threshold studies $I_t = C$ holds up to a critical duration after which $I = C$. It was the purpose of this study to employ intensities of visual stimuli in the threshold region where a longer duration is afforded and stimulus energy might contribute to the sensory effect.

The discrepancy of the data of Wells and Froeberg is probably due to the high stimulus intensities that were used, and if critical duration depends upon flash luminance then their intensities determined the response and duration had little influence. The results of this

present study indicate that critical duration seems to depend upon flash luminance, and that as higher luminance levels are reached increases in duration (beyond some short critical period) do not affect the reducible margin of the reaction time. It is therefore incorrect to state, as did Wells, that stimulus duration has no effect on reaction time. The analysis of variance performed on the data of this study reveals that the effects of duration are highly significant as are the effects of luminance.

SUMMARY

Reaction times have been recorded for various combinations of stimulus durations and stimulus luminances for the peripheral retina of the human.

The results of Experiment I where seven durations were paired with three luminances are summarized as follows:

1. Reaction time decreases as stimulus duration increases for the two lowest luminances.
2. Reaction time approaches a constant at the highest luminance at all stimulus durations.
3. In the low luminance curves, reaction decreases with additional increases in duration to a point after which reaction time no longer decreases.
4. Reaction time appears to decrease most appreciably to increases of stimulus duration at threshold levels.
5. As the total flash energy increases, the reaction time decreases, insofar as the data for the two lower luminances are concerned.
6. The highest luminance curve (2,670 ml.) does not for any of the three subjects show any appreciable decline of reaction time with further increase in energy due to increasing flash duration over the range of durations tested.

These results are interpreted as indicating that up until a critical duration, the temporal length of a visual stimulus affects reaction time, further critical duration itself is dependent on flash luminance.

The results of Experiment II where five stimulus durations were paired with three luminances are summarized as follows:

1. For the durations tested a flash of given energy content, the reaction time is longer for a flash involving long duration and low luminance than one with short duration and higher luminance.

2. An increase of total stimulus energy produces a decrease in reaction time; this effect is seen with increases in duration, up to a critical duration dependent on the flash luminance, and with increases in luminance.

The data are regarded as confirming the conclusions of the first experiment.

BIBLIOGRAPHY

- Bartlett, N.R., and Macleod, S. 1954. Effect of flash and field luminance upon human reaction time. J. Opt. Soc. Amer., 44, 4, 306-311.
- Bloch, A.M. 1885. Experiences sur la vision. Paris: Soc. Biol. Mem., 27, 493-495.
- Froemberg, S. 1907. The relation between magnitude of the stimulus and the time of the reaction. Arch. Psychol., 16, 8, 1-38.
- Graham, C.H., and E.H. Kemp. 1938. Brightness discrimination as a function of the duration of the increment in intensity. J. Gen. Physiol., 21, 635-650.
- Graham, C.H., and R. Margaria. 1955. Area and the intensity-time relation in the peripheral retina. Amer. J. Physiol., 113, 299-305.
- Graham, C.H., and P. Ratoosh. 1962. Psychology: A Study of a Science (S. Koch, Ed.) Vol. IV. New York: McGraw-Hill. 731 pp. Notes on some inter relations of sensory psychology, perception and behavior. 483-513.
- Hartline, H.K. 1934. Intensity and duration in the excitation of single photoreceptor units, J. cell. comp. Physiol., 5, 299-247.
- Hecht, S. 1918. Sensory equilibrium and dark adaptation in Mya arenaria. J. Gen. Physiol., 1, 545-558.
- Hovland, C.I. 1936. The influence of adaptation illumination upon visual reaction time. J. Gen. Psychol., 14, 346-359.
- Keller, M. 1941. The relation between the critical duration and intensity in brightness discrimination. J. Exp. Psychol., 28, 3, 407-418.
- Piéron, H. De la variation de l'énergie liminaire en fonction de la durée d'excitation pour la vision périphérique. C.R. Acad. Sci., Paris, 170, 1, 203-306.
- Wells, G.R. 1913. The influence of stimulus duration on reaction time. Psychol. Monogr., 15, 5, 1-69.