Successive luminance difference thresholds and brightness as a function of the interstimulus interval and durations of successive flashes¹

SIDNEY STECHER,² MICHAEL SANDBERG, AND PAUL J. MINSKY³
BRANDEIS UNIVERSITY

Monocular, successive luminance difference thresholds (ΔI) and brightness matches (PSE) were obtained by the method of constant stimuli for two flashes successively presented to the same retinal area. Variations in interstimulus interval, first-flash duration, and second-flash duration were the independent variables investigated. ΔI decreased as a function of ISI, while PSE remained relatively uninfluenced. An intensity-duration reciprocity was observed with increases in either first- or second-flash duration. Equal increases in duration of both flashes led to a constant value of ΔI . A Broca-Sulzer effect was also noted. In another study, a 10-msec, variable-luminance standard was followed after 500 msec by either a 10-msec or a 320-msec test flash that was compared to the standard. The results indicated that the rate of change of brightness with changes in luminance of the standard was faster for the 10-msec flash than for the 320-msec flash. The rate-of-change hypothesis would predict that the 10-msec flash should have the smaller ΔI . The results for two Ss indicated the opposite: ΔI was smaller for 320-msec than for 10-msec flashes. A modification of the hypothesis was suggested such that it may be the energy increment ($\Delta I t$) required for detection that is related to the rate at which brightness changes with energy.

A number of investigators have suggested that different discriminatory processes may underlie different modes of stimulus presentation. Stecher (1968), for example, has shown that the luminance-difference threshold (ΔI) increases with increasing spatial separation between simultaneously presented fields and decreases with increasing temporal separation between fields presented successively to the same retinal area. The general shape of the Weber function was also found to change as a function of spatial separation. Blackwell (1963) has suggested that the stimulus-increment and stimulus-comparison methods yield luminance-discrimination data that are different, because different discriminatory processes underlie the different procedures. Cornsweet and Pinker (1965) have found

that a classic, rapidly decreasing Weber function or a horizontal Weber function (Weber's law) will be obtained dependent upon stimulating conditions. Even earlier, Bartlett (1942) distinguished between two ideal types of discrimination based upon two different stimulus-presentation modes.

Recently, Leshowitz, Taub, and Raab (1968) have obtained different slopes of the psychometric function, different forms of the Weber function, and different intensity-duration reciprocity relationships, dependent upon different modes of stimulus presentation. For example, as the duration of a brief increment was increased (simple detection), less intensity was required to yield a constant probability of detection (75% correct) for a range of durations up to 32 msec beyond which $\Delta I t$ was no longer equal to a constant. For pulsed discrimination, however, ΔI was found to be independent of duration, a horizontal function of duration being obtained. This was taken by the authors to be partial evidence that different discriminatory processes may be involved in each of the presentation modes, and that the simplifying assumptions concerning detection made by many theorists are unwarranted.

Nachmias and Steinman (1965) were also concerned with the underlying basis of discriminability and, using a successive monocular brightness-matching procedure, have shown that an intensity-duration reciprocity does occur under conditions similar to those used by Leshowitz, Taub, and Raab in the latter's pulse-discrimination experiment. The difference between the two results may reside in the fact that Nachmias and Steinman had their Ss make monocular matches of a variable-duration test flash to a fixed-duration, fixed-luminance first flash, when both flashes were of equal size and presented to the same retinal area, whereas Leshowitz, Taub, and Raab varied the duration of both of the successive flashes equally. In the case where Leshowitz, Taub, and Raab varied the duration of only the increment flash, the results are more comparable to those found by Nachmias and Steinman.

Another possibility for the difference in the results of the two studies may reside in

the fact that Leshowitz, Taub, and Raab used as their measure of detectability a 75%-correct level as obtained in a 2ATFC procedure; Nachmias and Steinman used the mean of successive brightness matches as obtained with a staircase procedure. Kietzman (1968) has recently pointed out that different detection probabilities yield different reciprocity results.

As an alternative to the view that different stimulus presentation modes induce different bases of discrimination, Heinemann (1961) has introduced another hypothesis: The luminance difference threshold is related not to brightness but to the rate of change of brightness with change in luminance. It is a simple matter to extend this hypothesis to the situation of different stimulus presentation procedures: different functions of ΔI occur because the rate at which brightness changes in the different situations is different. Thus, if brightness changes more rapidly in one situation than it changes in another, then ΔI will be smaller in the more rapidly changing situation than in the less rapidly changing presentation mode. In order to investigate this hypothesis adequately, it is necessary to make both the brightness measurements and the measurements of the luminance-difference threshold under comparable conditions, since any change in the stimulating conditions may alter differentially the rates of growth of brightness and, hence, the relationship obtained between these two dependent variables.

Nachmias and Steinman (1965) tested this hypothesis; although their results fell short of providing quantitative support for the theory, the authors suggest that this may have been partially due to (1) a defective discriminability measure (d') and (2) a lack of comparability of the Ss' task in the successive brightness-matching and rating-scale discriminability procedures.

The successive brightness-matching procedure can be adapted to overcome these criticisms if it is used in conjunction with a constant stimulus design, where both a measure of the matching luminance (PSE) and ΔI (luminance difference between the mean and standard deviation values of the psychometric function) can be obtained from the same set of measurements. Raab

Fig. 1. Binocular Maxwellian field viewing system used in the experiments. The field system of optical projection was used for each of four channels. The first lens (L) in a given channel formed an image in the plane of the second lens. The latter was brought to a focus at the third lens, and Lens 3 reformed an image in the fourth lens plane. The sequence—image, focus, image, focus—was repeated to meet the configurational requirements of the system. Deviations from this pattern occurred once in each of the four channels, which allowed an image to be formed in the plane of a two-log-unit neutral-density wedge (W-1, W-2, W-3, W-4). S-1 flux was divided by a beam splitter, BS-1, the transmitted and reflected portions forming paths to the RE and LE, respectively. S-2 flux was divided by beam splitter, BS-8, the reflected and transmitted portions forming paths to the RE and LE, respectively. The two LE paths were subsequently recombined by Beam Splitter BS-6, which transmitted the path from S-1 and reflected the path from S-2. The RE paths were recombined by BS-3, the path from S-1 being transmitted and that from S-2 being reflected. The last lens in each channel, L5 and L12, formed an image in the plane of S's pupil after transmitting the flux through a beam splitter (BS-4 or BS-5) and reflecting the flux from a front surface mirror (M-3 or M-7) into an artificial pupil at E (not shown). FS are the field stops. AF refers to the adapting fields reflected into the artificial pupil by a beam splitter (BS-4 or BS-5). M-3 and M-7 could be adjusted for different interpupillary distances. F-1, F-2, F-3, F-4 are holders for neutral-density filters. M-1, M-2, M-4, M-5, M-6 are front-surface mirrors. BS-2 and BS-7 are thin cover slips used to transmit most of the flux and reflect a small portion into an RCA 929 phototube (PC) for output monitoring. Only the RE paths from each source were used in the present experiments.

(1962) has pointed out that the successive method, while having many advantages over such conventional procedures as binocular brightness matching and psychophysical scaling, has scarcely been used since its introduction by McDougall in 1904, because the optimal interval between flashes has not been determined. To date, no systematic investigation of the effects of variation in first-flash duration, second-flash duration, and interstimulus interval on measures of luminance detectability and brightness yielded by the successive method has been undertaken.

The investigation of these variables was the purpose of the present study. In the first study, stimulus area and luminance of the standard field were kept constant for foveally presented fields. Variations in the successive luminance-difference threshold and monocular successive-brightness matches were assessed by studying: (1) the influence of temporal separation of two equal-size (2 deg) visual fields presented to the same foveal area in succession, (2) the influence of duration of the first flash, and (3) the influence of duration of the second flash.

The purpose of the second study was to investigate the relationship between brightness and luminance discrimination at different intensities for short- and long-duration flashes, when the measurements were made under comparable conditions. This latter experiment was a

replication of the important investigation of Nachmias and Steinman, with a few changes: the luminance discrimination and brightness measurements were obtained by a constant-stimulus procedure, and the durations investigated were different from those used by Nachmias and Steinman.

Apparatus

A schematic diagram of the apparatus used in the experiments is shown in Fig. 1.

The apparatus consisted of a specially constructed four-channel binocular Maxwellian field-viewing system.

The light flashes were produced by two glow-modulator tubes (Sylvania, R1131C), which were bathed in ultraviolet light (GE AR4) to avoid onset jitter. The outputs from the two tubes were optically superposed, and each eye received the combined flux. The two glow modulators were run at a constant current of 26 mA and could be controlled independently in duration, frequency, and interval between onsets of the flashes (ISI) by a Grass Physiological Stimulator (S-8), pulsed through a triode-connected gating circuit. The durations and ISIs between the left and right eye, however, could not be separately varied. Luminance was controlled independently by the use of neutral-density filters and neutral-density wedges placed in an image plane in each of the four channels.

Both channels presented to each eye were optically in focus on a field lens. In front of

the field lens was a field stop with a 1.3-cm square opening, through which the light from each channel passed. An image of the crater was formed by the field lens in the plane of the S's pupil after passing through a beam splitter, being then reflected by a final mirror and passed through a 2-mm artificial pupil. The field stop was at a distance of 37.2 cm from the artificial pupil, the opening thus subtending 2 deg.

To the side of the beam splitter (through which the light from the field lens was transmitted) was a 12-deg 15-min square adapting field illuminated at a level near the photopic threshold (.003 mL). The adapting field was at a distance of 17.9 cm from the S's eye. Light from this adapting field passed through a 4.0 log unit neutral-density filter and was then reflected through the beam splitter into S's pupil. The adapting field consisted of flashed opal glass evenly illuminated from behind by a 6-W bulb (Sylvania).

Just beyond each of the light sources, a cover slip was placed in each of the channels before the outputs were divided and sent to each eye. This cover slip reflected a constant proportion of the output from each of the glow modulators on to the cathode of one of two phototubes (RCA 929). The rise and fall times for 10-msec flashes were about 10 μ sec, and a close approximation to a rectangular pulse was obtained from each output. The outputs were continuously monitored by a dual beam CRO throughout

the course of the experiments. Adjustments were made in the durations and intervals between the flashes by adjustment of the S-8. Control of the current passing through each of the glow-modulator tubes was accomplished by adjusting either a biasing control or the amplitude dial of the S-8. The arrangement was such that the E could, by putting the S-8 into a dc mode of operation and by referring to an ammeter placed in series with either source, set a desired current for each tube. Changing the operational mode of the S-8 to the pulse position then produced flashes that were continuously monitored by the photocells and CRO. With each eye, S thus had a Maxwellian view of the opening in the field stop that was superimposed on a fixed adapting luminance. S sat in the dark and his head was held in place by a dental-impression biting board.

Centered above and below the square 2-deg field in each eye, two dim red points served as fixation stimuli for the S. S was asked to fixate on an imaginary vertical line between them. The fixation points were in the plane of focus of the stimulus array and were set just above the S's threshold by adjusting a variac (powerstat) that controlled the current passing through them. The stimulus arrangement consisted of the square 2-deg field that was presented in succession to S's right eye, left eye, or both eyes. Either the first flash or the second could be set to various luminances and durations. Either of the flashes could be occluded from view to either eye. With both fields presented simultaneously, they appeared adjacent to one another and of equal heights and widths, the fields to the two eyes being separated by a small dark space. In the present series of experiments, only the right eye was used, the left eye channels being occluded from view.

The wedges were arranged so that different wedge positions could be attained by manual operation by the E or S, or by remote-control operation by the S alone. This was accomplished by the use of a tape reader (Ohr-tronics, 119) whose output controlled the position of a motor (Bodine, KYC-22RC). The motor, in turn, governed the wedge position in each of the four channels. The output from the tape reader randomly activated a preset potentiometer.

Fig. 2. PSE in log mL as a function of log duration of the test flash (milliseconds) for two Ss. The equal-energy line is a line of slope = -1.0. The functions shown are for a long (320-msec) flash duration (standard) and for a long (500-msec) and short (95-msec) interstimulus interval. PSE reflects the luminance of the test flash judged equal to the standard luminance, the latter being set to 100 mL in all conditions. PSE is the mean of the least square ogive fit to the data.

This caused the motor to stop at a position corresponding to a particular resistance setting, the latter having been set by the E to correspond to a particular stimulus value. The apparatus was capable of presenting one of seven randomized stimuli to the S upon command of S. Responses of the S were recorded by a Gerbrands event recorder for the discrete trials used in the luminance-discrimination study. Responses of the S could also be recorded by two chart recorders that were precalibrated for wedge position for continuous brightness matching tasks used in other experiments (Heath Servo-Recorder, EUW-20A) (Stecher & Sandberg, 1970).

Procedure

The S was dark adapted for 15 min. He then looked at the adapting field for 5 more minutes with the right eye. The method of constant stimuli was used (without correction), where the S had to indicate whether the second variable-luminance test flash was brighter or dimmer than the first standard flash, the latter always being at a fixed luminance. After a least-square ogive was fitted to the per cent "brighter-than" judgments, a mean and standard deviation were computed. The mean indicated the value of the variable-luminance test field that matched the standard (PSE). The luminance difference between the mean and standard deviation of the ogive was taken to correspond to ΔI (Guilford, 1954).

The principal independent variables studied in the first experiment were the temporal separation between the two successively presented 2-deg fields and various combinations of first- (standard) and second- (test field) flash durations. These durations ranged from 10 to 320 msec, while the six ISIs used were 95, 120, 150, 180, 250, and 500 msec. The luminance of

the standard flash was fixed at 100 mL. In each of the substudies, the appropriate stimulus parameter was randomized. Values of ΔI and PSE were based on 35-50 judgments for each of five to seven luminances, for a total of between 175 and 350 judgments per point for S DSB, and slightly less for PJM. All interstimulus intervals were measured from the cessation of the first flash to the onset of the second flash.

The principal independent variable studied in the second experiment was the luminance of the 10-msec standard that was followed, after a 500-msec ISI, by a test field of 10-msec or 320-msec duration, the test field being adjusted in luminance by a constant-stimulus procedure to yield a measure of PSE and ΔI . The luminance range of the standard was from 1 to 1000 mL in one log-unit step. Two Ss (DSB and RMS) were used in the experiments and gave virtually identical results.

Absolute luminance calibrations were made by photometrically matching the Maxwellian fields presented to the right eye to the adapting field presented to the left eye, the adapting field being at a known luminance. The luminance of the adapting field was measured with a Macbeth illuminometer without the artificial pupil in place; the Maxwellian field to adapting field matches were made with the artificial pupil in place.

Results and Conclusions

Figure 2 is a plot of the luminance of the test flash (ordinate) required to match a constant-luminance/constant-duration standard flash that preceded the test flash by various interstimulus intervals as a function of the duration of the test flash (abscissa). The functions shown are for a long (320-msec) and a short (10-msec) first-flash

Fig. 3. ΔI in log mL as a function of the log duration of the test flash for a long (320-msec) and short (10-msec) standard flash and a long (500-msec) and short (95-msec) interstimulus interval. Functions are shown for two Ss. The equal-energy line is a line of slope = -1.0 and indicates a theoretical intensity-duration reciprocity. The first number to the right of each function indicates the duration of the standard; the second number indicates the interstimulus interval after which the test field was presented for the durations indicated on the abscissa.

duration, and for a long (500-msec) and a short (95-msec) ISI. The equal-energy line shown for comparison purposes is a line of slope = -1.0 and demonstrates the theoretically expected results of an intensity-duration reciprocity. The results for S DSB appear less variable than those for PJM, a greater number of judgments being made per point by DSB.

As the duration of the variable-luminance test flash is increased, the luminance required for a match to a constant-brightness standard first flash decreases. The decrease is approximately inversely proportional to the duration of the test flash up to a duration of about 60-80 msec. Further increases in duration lead to a greater luminance required for a match. This latter effect is known as the Broca-Sulzer phenomenon, and has been noted by many previous investigators (Katz, 1964; Raab, 1962; Aiba & Stevens, 1964; Nachmias & Steinman, 1965; Stevens, 1966). The present results show a remarkable similarity to the results obtained by Katz (1964), who used monocular and binocular presentation, and Aiba and Stevens (1964), who used a binocular brightness matching procedure, and Nachmias and Steinman (1965), who used a monocular successive brightness matching procedure.

The effects of variations in ISI, however, have not previously been reported. Nachmias and Steinman, for example, used a successive presentation procedure in which the ISI was 10 sec. For the range of ISI investigated in the present study, a minimal effect is noted on the log PSE. The effect of first-flash duration, however, is quite important in that an increase in the duration of the standard leads to an increase in the luminance required for a match at all test-flash durations.

Figure 3 is a plot of ΔI in log mL (ordinate) as a function of log duration of the test flash (abscissa) for a long (320-msec) and a short (10-msec) first-flash duration standard, and for a long (500-msec) and a short (95-msec) interstimulus interval. The equal-energy line is a line of slope = -1.0 , and indicates a theoretical intensity-duration reciprocity (not shown).

The initial segments of the functions all appear to follow a reciprocity relationship

up to a test-flash duration of approximately 80-100 msec. Further increases in duration of the test flash lead to further increases in log ΔI . Thus, sensitivity decreases with further increases in duration beyond this critical duration. These results share many similarities with the results obtained by other investigators using the increment method of luminance-difference detection (Graham & Kemp, 1938; Keller, 1941; Baumgardt & Hillman, 1961).

Unlike the effect of ISI on log PSE, the log ΔI functions appear ordered as a function of ISI, such that an increase in the interstimulus interval decreases ΔI . This is in accordance with results reported previously for equal-duration flashes (Stecker, 1967).

Increasing the duration of the first standard flash tends to decrease detectability. It also appears that either increasing the duration of the first flash or decreasing the ISI is roughly comparable in their effect on luminance discrimination for the present values investigated. Thus, a short first-flash duration (10 msec) followed by a short ISI (95 msec) is roughly comparable in the ΔI obtained to a long first-flash duration (320 msec) followed by a long ISI (500 msec).

The influence of ISI on both ΔI and matching luminance is more clearly illustrated in Fig. 4, where both ΔI and PSE were determined as a function of the ISI.

The ordinate indicates the value of log ΔI and log PSE obtained as a function of log ISI for a long (320-msec) and a short (10-msec) first-flash duration, and for a constant test-flash duration (10 msec). While log ΔI is seen to decrease as a function of increases in ISI, matching luminance tends to remain relatively constant. The extent of the decrease in ΔI is about .6-.7 log unit for both long and short first-flash durations. For all ISIs, an increase in the first-flash duration leads to a greater value of log PSE and a greater value of log ΔI .

Figure 5 represents the results of an experiment done to determine the effects of variation in first-flash duration on matching

luminance and luminance-difference detectability for long (320-msec) and short (10-msec) test-flash durations.

The results indicate that the matching luminance increases up to a certain duration (about 80 msec) with increases in first-flash duration, further increases in duration leading to a decrease in matching luminance. This is an alternative procedure for measuring the Broca-Sulzer effect, the present result being quite similar to that found by other investigators using a variety of other methods (Katz, 1964; Aiba & Stevens, 1964; Stevens, 1966; J. C. Stevens & Hall, 1966).

Figure 5 also indicates, however, that, while the Broca-Sulzer effect may appear when magnitude-estimation procedures (Raab, 1962; Stevens & Hall, 1966) and brightness matches using long-duration matching stimuli (Katz, 1964; Aiba & Stevens, 1964) are used, the results using short-duration stimuli presented successively and matched to variable-duration constant-luminance standard stimuli are not the same. Thus, Aiba and Stevens, using a 1-sec matching flash, Broca and Sulzer (1903), using a 2-sec flash, Katz (1964), using 200-msec flashes, and the present study, using 320-msec matching flashes, all found the Broca-Sulzer enhancement. When short (10-msec) matching flashes were used, however, the brightness matches appeared independent of first-flash duration.

The luminance-difference threshold functions were found to follow the same trends as that found for matching luminance when the first-flash duration was varied. Thus, ΔI was found to increase with an increase in the duration of the standard for a long test flash, but remained relatively horizontal as a function of first-flash duration when a short-duration test flash was used.

Data for both the pulse- and simple-detection situations were extrapolated from the published functions of Leshowitz, Taub, and Raab (1968) for

Fig. 4. Monocular matching luminance (PSE) and ΔI in log ML for a constant-duration standard and test flash as a function of the log of the ISI. The first number represents the duration of the standard flash; the second number is the duration of the second flash (milliseconds).

the range of durations appropriate for the present comparison, and are shown in Fig. 6.

These results were contrasted with the results obtained from S DSB and shown as the functions marked 320-500 varied and equal duration. For the former function, a 320-msec first flash set to 100 mLe was followed 500 msec after its cessation by a test flash of variable duration. The durations of the variable flash are indicated on the abscissa. The initial segment of the function has a slope = -1.0, indicating temporal summation up to a critical duration of about 90 msec. This segment of the function is parallel to the initial segment of the function obtained by Leshowitz, Taub, and Raab in their simple-detection experiment, which also indicated a reciprocity between intensity and duration up to a critical duration of 32 msec.

The data for the function marked equal duration were obtained by changing the duration of both the first and second flashes simultaneously. Thus, not just the test-field duration, but also the duration of the standard was changed for each duration for which an observation was made. This is precisely the procedure used by Leshowitz, Taub, and Raab (Raab, personal communication) in the pulse-detection condition. The results indicate that ΔI is a horizontal function of duration for both the pulsed condition of Leshowitz, Taub, and Raab and for the equal-duration condition of the present study.

The conclusion reached by Leshowitz, Taub, and Raab, "whereas perfect temporal summation is found within the critical duration for the case of simple detection, there is a surprising absence of reciprocity between duration and signal intensity in the pulsed-detection condition [p. 209]," does not substantiate their argument of different bases of discrimination, as both procedures yield the same results if duration is manipulated in the same way in both experiments. Leshowitz, Taub, and Raab, however, manipulated the duration of both the standard and variable flashes in the pulsed-detection experiment, while they varied the duration of only the increment flash in the simple-detection experiment. The two situations, not being comparable in stimulation, gave noncomparable results. Thus, while the hypothesis that different stimulus presentation procedures yield different luminance-discrimination functions may be correct, the results of their experiments are not convincing evidence that this is so. We have shown (Fig. 5) that increases in first-flash duration lead to increases in log ΔI for constant-duration test flashes, while increases in test-flash duration lead to a decrease in log ΔI (Fig. 3) for constant-duration standard flashes. Thus, simultaneous increases in standard and test flashes would tend to yield values of ΔI that do not change with duration, since the

increases in ΔI due to increases in first-flash duration would be cancelled by the decreases in ΔI due to subsequent test-flash duration increases.

In the second investigation, a 10-msec standard flash was followed 500 msec after its cessation by a 320- or 10-msec test flash, with the standard set to various luminances. The second flash was compared to the first. Both brightness matches and luminance-difference thresholds were obtained from the same set of data in the present study, while this was not the case in the study of Nachmias and Steinman.

The results obtained for the matching luminances are presented in Fig. 7 where, following Nachmias and Steinman, luminances at which 10- and 320-msec flashes matching a standard 10-msec flash set to various luminances are plotted against each other. The circles represent the results obtained from DSB; the triangles represent those from RMS. The straight line has been fitted by eye, the slope being equal to .76, and is very similar to the results obtained by Nachmias and Steinman, using 230- and 52-msec flashes. (The slope for S DSB was .66, exactly equal to Nachmias and Steinman, while the slope for RMS was = .86). The results indicate that, with changes in luminance, the brightness of short flashes changes more rapidly than the brightness of long flashes. This result has been substantiated by other investigators using other methods (Aiba & Stevens, 1964; Stevens, 1966; Anglin & Mansfield, 1968). If the rate of change of brightness were related to ΔI , one would predict that ΔI for the 10-msec flash would be smaller than that for the 320-msec flash, since the rate of growth of brightness is much more rapid for the short than for the long flash. This is so since a smaller luminance change would be required to yield a detectable brightness change in the more rapidly changing condition than in the less rapidly changing condition. Nachmias and Steinman found qualitative, but not quantitative, support for this position using d' as a discriminability measure. The results of the present study are

Fig. 5. (Left) ΔI in log mLe for a short (10-msec) and long (320-msec) constant-duration test flash as a function of log duration of a constant-luminance (100 mLe), variable-duration standard flash. Standard and test flashes were separated by 500 msec. Data shown for DSB. (Right) PSE (matching luminance) in log mLe for a short (10-msec) and long (320-msec) constant-duration test flash as a function of log duration of a constant-luminance (100 mLe), variable-duration standard field. Standard and test flashes were separated by 500 msec. Data shown for S DSB is representative of that also found on other Ss.

Fig. 6. Log ΔI (mL) as a function of log duration (milliseconds). The pulse detection (LTR) and simple detection functions were extrapolated from the results presented by Leshowitz, Taub, and Raab. For both the pulse-detection condition of LTR and the equal-duration function of the present study, the abscissa refers to the duration of both the standard and test flashes. The simple detection results are contrasted with the 320-500 varied function (standard = 320 msec, ISI = 500 msec) of the present study. In both of these conditions, only the test flash was varied in duration.

presented in Fig. 8, where log ΔI is plotted as a function of the luminance of the standard for the short- and long-duration test fields for two Ss.

The results indicate that short flashes are less discriminable than long flashes. This is contrary to the theoretical prediction, in spite of the fact that the discrimination data were obtained under identical conditions as the brightness-matching functions.

The reasons for the discrepancy between the discrimination data of the two studies

may arise from a number of factors. For example, energy (I_t) considerations have been shown to be important in the determination of luminance-difference thresholds in the present set of studies as well as in previous investigations (Graham & Kemp, 1938; Baumgardt & Hillman, 1961). It may not be that ΔI is related to the rate at which brightness changes with changes in luminance in the present situation, but the energy increment (ΔI_t) required for detection that is related to the rate at which

brightness changes with changes in test-field energy. As the long flash used in the present investigation was outside of the critical duration, this hypothesis is difficult to evaluate from the present data. Research currently in progress is directed to this question.

REFERENCES

- AIBA, T. S., & STEVENS, S. S. Relation of brightness to duration under light- and dark-adaptation. *Vision Research*, 1964, 4, 391-401.
- ANGLIN, J. M., & MANSFIELD, R. J. W. On the brightness of short and long flashes. *Perception & Psychophysics*, 1968, 4, 3, 161-162.

Fig. 7. Log luminance (mL) of a 10-msec and 320-msec test flash matching various luminances of a 10-msec standard flash plotted against each other. The ordinate represents the matching luminance of the 10-msec flash, while the abscissa shows the matching luminances of the 320-msec test flash. Straight line of slope = .76 is fit by eye.

Fig. 8. ΔI (log mL) as a function of luminance of the standard stimulus. The results are shown for two Ss. The first number refers to the duration of the standard (10 msec in all conditions) followed by an ISI = 500 msec and either a 10-msec or a 320-msec test-flash duration.

- BARTLETT, N. R. The discrimination of two simultaneously presented brightnesses. *Journal of Experimental Psychology*, 1942, 31, 380.
- BAUMGARDT, E., & HILLMAN, B. Duration and size as determinants of peripheral retinal response. *Journal of the Optical Society of America*, 1961, 51, 340.
- BLACKWELL, H. R. Neural theories of simple visual discrimination. *Journal of the Optical Society of America*, 1963, 53, 129-160.
- BROCA, A., & SULZER, D. La sensation lumineuse en fonction de temps. *Canadian Royal Academy of Science*, 1903, 137, 944-946, 977-979, 1046-1049.
- CORNSWEET, J., & PINSKER, H. M. Luminance discrimination of brief flashes under various conditions of adaptation. *Journal of Physiology*, 1965, 176, 294-310.
- GRAHAM, C. H., & KEMP, E. H. Brightness discrimination as a function of the duration of the increment in intensity. *Journal of General Physiology*, 1938, 21, 635-650.
- GUILFORD, J. P. *Psychometric methods*. New York: McGraw-Hill, 1954.
- HEINEMANN, E. G. The relation of apparent brightness to the threshold for differences in luminance. *Journal of Experimental Psychology*, 1961, 61, 389-399.
- KATZ, M. S. Brief flash brightness. *Vision Research*, 1964, 4, 361-375.
- KIETZMAN, M. L. Response variables in suprathreshold studies of stimulus reciprocity. Paper read at APA Symposium: Temporal integration in vision and audition. San Francisco, 1968.
- KELLER, M. The relation between the critical duration and intensity in brightness discrimination. *Journal of Experimental Psychology*, 1941, 28, 407-418.
- LESHOWITZ, B., TAUB, H. B., & RAAB, D. H. Visual detection of signals in the presence of continuous and pulsed backgrounds. *Perception & Psychophysics*, 1968, 4, 207-213.
- McDOUGALL, W. The variation of the intensity of visual sensation with the duration of the stimulus. *British Journal of Psychology*, 1904, 1, 151-189.
- NACHMIAS, J., & STEINMAN, R. M. Brightness and discriminability of light flashes. *Vision Research*, 1965, 5, 545-557.
- RAAB, D. Magnitude estimation of the brightness of brief foveal stimuli. *Science*, 1962, 135, 42-43.
- STECHEER, S. Discrimination of luminance differences between temporally separated paired flashes. *Journal of the Optical Society of America*, 1967, 57, 1271-1272.
- STECHEER, S. Temporal and spatial effects in luminance discrimination. *Perception & Psychophysics*, 1968, 4, 155-158.
- STECHEER, S., & SANDBERG, M. The relationship between binocular brightness matches and luminance difference discriminability of successively presented light flashes. *Perception & Psychophysics*, 1970, 7, 86-90.
- STEVENS, S. S. Duration, luminance and the brightness exponent. *Perception & Psychophysics*, 1966, 1, 96-100.
- STEVENS, J. C., & HALL, J. Brightness and loudness as functions of stimulus duration. *Perception & Psychophysics*, 1966, 1, 319-327.

NOTES

1. This research was supported by Grant R01-NB-07340-01 from the National Institute of Neurological Diseases and Blindness, United States Public Health Service, to the senior author. The authors wish to thank Drs. Eric Heinemann, David Raab, and Mitchell Grossberg for much time spent in discussion.

2. Address: Department of Psychology, Brandeis University, Waltham, Massachusetts 02154.

3. Present address: Psychology Department, Brown University, Providence, Rhode Island.

(Accepted for publication May 13, 1969.)