DISCRIMINATION OF SHORT-DURATION (TWO-PULSE) FLASHES AS A FUNCTION OF SIGNAL LUMINANCE AND METHOD OF MEASUREMENT

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November 1971

Prepared for
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Aviation Medicine
Washington, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-AM-71-42		

4. Title and Subtitle	5. Report Date
DISCRIMINATION OF SHORT-DURATION (TWO-PULSE) FLASHES AS A FUNCTION OF SIGNAL LUMINANCE AND METHOD OF MEASUREMENT	November 1971
	6 Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Henry W. Mertens, M.A. Mark F. Lewis, Ph.D.	
9. Performing Organization Name and Address	10. Work Unit No.
FAA Civil Aeromedical Institute P. O. Box 25082 Oklahoma City, Oklahoma 73125	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S. W. Washington, D. C. 20590	OAM Report
	14. Sponsoring Agency Code

15. Supplementary Notes

This research was conducted under Task No. AM-A-70-PSY-15 and AM-A-71-PSY-15.

16. Abstract

The recent introduction of strobe lights for anticollision purposes raises the possibility of using temporal patterns of short duration flashes as information carrying signals. The current experiments are concerned with the detection of the minimum duration dark interval between signal light pulses as a function of signal luminance and the psychophysical method of measurement. Experiment I tested the theory of signal detectability (TSD) prediction that observer sensitivity is independent of the psychophysical method used in measurement. Discrimination of a constant duration comparison stimulus (three msec) and a variable duration test stimulus (seven to 32 msec) was measured with a two-alternative Forced-Choice (FC) procedure and a Yes-No procedure. Sensitivity was comparable under the two psychophysical procedures, thus supporting the application of TSD to the sensory processes involved in discrimination of two-pulse stimuli. Experiment II measured discrimination with the FC procedure at three luminance levels: 31.8, 318, and 3183 candelas per square meter. Discriminability increased with luminance. Thus, pulses separated by a dark interval short enough so that only a single flash is seen over the entire scotopic intensity range may, however, be seen at photopic intensities as two pulses, or appear to flicker, or otherwise appear to be of different character. To maintain a homogeneous flash appearance over the entire range of signal intensities, the dark interval duration for multi-pulse flashes should be determined for the highest intensity condition at which operational observation is anticipated.

17. Key Words	18. Distribution Statement
Vision Visual Signals Perception	Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	5	$3.00

Form DOT F 1700.7 (8-69)

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I. Introduction.

The recent introduction of strobe lights for anticollision raises the possibility of using temporal patterns of short duration flashes as information carrying signals. An individual flash can be produced by multiple brief light pulses, simulaneous or successive, as long as the component pulses are sufficiently close in time and space as to not be perceptually resolvable. The duration and intensity of a particular flash thus produced can be varied by manipulation of the temporal spacing and the number of component pulses. Variation of signal intensity will also normally occur with varying visual range, windshield transmissivity, atmospheric conditions and any other factors which affect the amount of light reaching the observer's eye.[1] In order to design multi-pulse signal flashes it is essential to know how the minimum detectable dark interval between brief pulses varies with signal intensity. The effect of luminance on the discrimination of duration differences between multi-pulse flashes is examined for the limiting case of two-pulse stimuli presented under night flight conditions.

Recent studies of temporal discrimination of two-pulse stimuli differing only in duration have produced varying luminance effects. Lewis[2] measured thresholds for temporal differences between two-pulse stimuli at luminances of 1.02 to 3183 candelas per square meter (cd/m²). Two-pulse thresholds were found to decrease in a negatively accelerated fashion as luminance increased, with only a small effect in the data of one observer for luminances above 31.8 cd/m². In a subsequent study, Lewis[3] measured two-pulse thresholds as a function of pulse luminance and area. Data for the 30-min stimulus, which was similar to the size used in other studies cited here, showed little, if any, effect of luminance in the range of 19.1 to 636 cd/m². A progressively greater effect of luminance was obtained as stimulus diameter was decreased.

The above studies obtained thresholds with a variation of the method of limits ,the Block Up and Down Two Interval Forced Choice (BUDTIF) method developed by Campbell.[4] Similar findings were obtained by Kietzman[5] and Nilsson[6] using a variation of the method of constant stimuli involving a three-alternative forced choice response. Little effect of luminance on two-pulse threshold was observed when it was varied over a range of 7.96 to 1948 cd/m² by Kietzman, and 159 to 6366 cd/m² by Nilsson. All studies cited here have used a one-msec duration for component pulses of the two-pulse stimuli except for Kietzman's which used a five-msec duration.

Lewis and Mertens[7] measured two-pulse thresholds as a function of comparison stimulus duration at luminances between 31.8 and 3183 cd/m². Again, the BUDTIF technique was used. Two-pulse thresholds were found to be an increasing function of comparison stimulus duration with the rate of increase rising with luminance. This large effect of luminance in a range above 31.8 cd/m² is in disagreement with the findings discussed above and warrants further investigation.

The measures of sensitivity derived from the models of the theory of signal detectability (*TSD*) have not yet been applied to the case of temporal discrimination of brief two-pulse stimuli. It has been demonstrated in several auditory and visual experiments,[8] however, that *TSD* measures of sensitivity have the advantages of being independent of the observer's decision criterion and the particular psychophysical method used in taking the measurements, as predicted by *TSD*. Experiment I of the current study obtained psychometric functions for temporal discrimination of brief two-pulse stimuli derived from a Yes-No (*YN*) procedure and a Forced-Choice (*FC*) procedure. This experiment compares performance under two methods of controlling the observer's decision criterion and provides a test of internal consistency for *TSD*.

Experiment II measured the effect of luminance on temporal discrimination of brief two-pulse stimuli.

II. Experiment I.

Method for Experiment I

Observers. Three men served as observers. They had normal acuity, with correction, and were screened for color vision deficiency on a battery of tests that included the A.O.-H.R.R. and Dvorine plates, the Farnsworth-Munsell 100-Hue test, the Farnsworth Dichotomous (Panel D-15) test, and an anomaloscope examination. No evidence of color defect was found with BR or DM; HM was a deuteranope. Of the three observers, only DM had no experience in vision experiments. BR and HM were highly experienced observers, but only HM (the senior author) was familiar with the purpose and design of the experiment. BR and DM were paid an hourly wage.

Apparatus. The apparatus, which has been described previously,[2] included a Maxwellian view optical system with a Sylvania Glow Modulator tube used as a light source, and associated Iconix logic for control of stimulus duration. Luminance was calibrated with an SEI exposure photometer using a method described eariler.[9] The stimulus image was a white disc subtending 30′ which was presented in the center of four red fixation lines forming an open cross. Viewing was monocular with the right eye. A 2 mm viewing aperature was used. Stimulus luminance was constant at 3183 cd/m^2.

FC Procedure. At the beginning of each experimental session, the observer dark adapted for at least five min and then adjusted the intensity of the fixation lines until they were just visible. On an auditory ready signal, the observer pressed a button to start a trial. Three successive observation intervals were then presented during each trial. Each observation interval was defined by an auditory signal consisting of a low intensity one-half-sec duration burst of white noise. One-sec intervals of silence separated the observation intervals. A pair of one-msec stimulus pulses was presented at the end of each observation interval. In two of these intervals, a comparison pair was presented with [illegible] inter-pulse interval that was always one-msec in duration, producing a comparison stimulus duration of three msec. In the other interval, a test pair with a longer interpulse interval was presented. Test stimulus interpulse intervals of 5, 10, 15, 20, 25, and 30 msec in duration were used, thus producing test stimulus durations of 7, 12, 17, 22, 27, and 32 msec, respectively. A comparison stimulus was always presented in the first observation interval, while test and second comparison stimuli alternated randomly from trial-to-trial in the second and third observation intervals. The observer was instructed to report in which interval, the second or third, the different stimulus most likely occurred. He was told to use any characteristic (apparent duration, brightness, color, etc.) of the flashes which he found useful to make the discrimination. The observer used two push buttons to indicate his choice and was informed of the accuracy of his responses by a noise that came on momentarily following correct responses. Two hundred-fifty trials were presented in a single session. Intertrial intervals were at least 12 sec. A rest period was permitted whenever the observer felt he needed it. Each session lasted approximately 120 min. Each condition of test stimulus duration was presented in two sessions. The proportion of correct responses P(C) was computed for each condition and, therefore, was based on 500 responses. The random order in which test stimulus durations were presented was different for each observer.

YN Procedure. The *YN* procedure was similar to the *FC* procedure except that a test stimulus was not presented on every trial. When a test stimulus was not scheduled, a third comparison stimulus was presented in its place. The same six test stimulus durations were used with the *YN* procedure and the duration used was constant in a particular session. Comparison stimulus duration was always three msec. The observer's criterion was manipulated by varying the probability of occurrence of a test stimulus. The probabilities used were 0.1, 0.3, 0.5, 0.7, and 0.9 and the probability was constant during a particular session.

Each combination of test stimulus duration and probability of test stimulus occurrence was presented in two sessions; one in which the test stimulus appeared only in the second observation interval of each trial and one session in which it only appeared in the third observation interval. The observer was instructed prior to each session regarding which observation interval the test stimulus would be presented in and what the probability of test stimulus occurrence would be for that session. His task was to indicate at the end of each trial whether or not he thought a test stimulus had been presented. All experimental conditions were presented with the test stimulus in the second position before replicating the experiment with the test stimulus in the third position. The experimental conditions of test stimulus duration were presented in a different random order in each replication. The relative area under the ROC curve P(A) was the dependent variable. As there were 250 trials in each session, each point in the ROC curve was based on 500 responses.

Two weeks of practice preceded data collection under each procedure. Data collection for the *FC* procedure took one month and preceded data collection with the *YN* procedure which took five months.

Results and Discussion of Experiment I

The distribution-free and theoretically similar[8] measures of sensitivity provided by P(C) for the *FC* method and P(A) for the *YN* method are plotted as a function of test stimulus duration for each observer in Figure 1. The measure $D(\Delta m, s)$, suggested by Green and Swets[8] is given in Table 1 and provides descriptive information about the ROC curves of the present experiment obtained from the *YN* procedure. The term Δm refers to the intercept of the ROC curve with $P(S/s) = 0.50$ and s is the slope; both are obtained from plots on double probability paper.

TABLE 1

$D(\Delta m, s)$ Obtained from the Yes-No Procedure as a Function of Test Stimulus Duration.

	Subject					
	DM		BR		HM	
Test Stimulus Duration	Δm	s	Δm	s	Δm	s
7	-0.10	1.03	-0.13	0.99	0.17	0.90
12	0.43	1.07	0.30	1.00	0.27	0.83
17	0.99	0.93	0.77	0.79	0.70	0.89
22	1.45	0.92	0.97	0.90	1.37	0.62
27	2.18	0.79	1.78	0.92	2.11	0.64
32	2.89	0.61	2.63	0.73	2.47	0.97

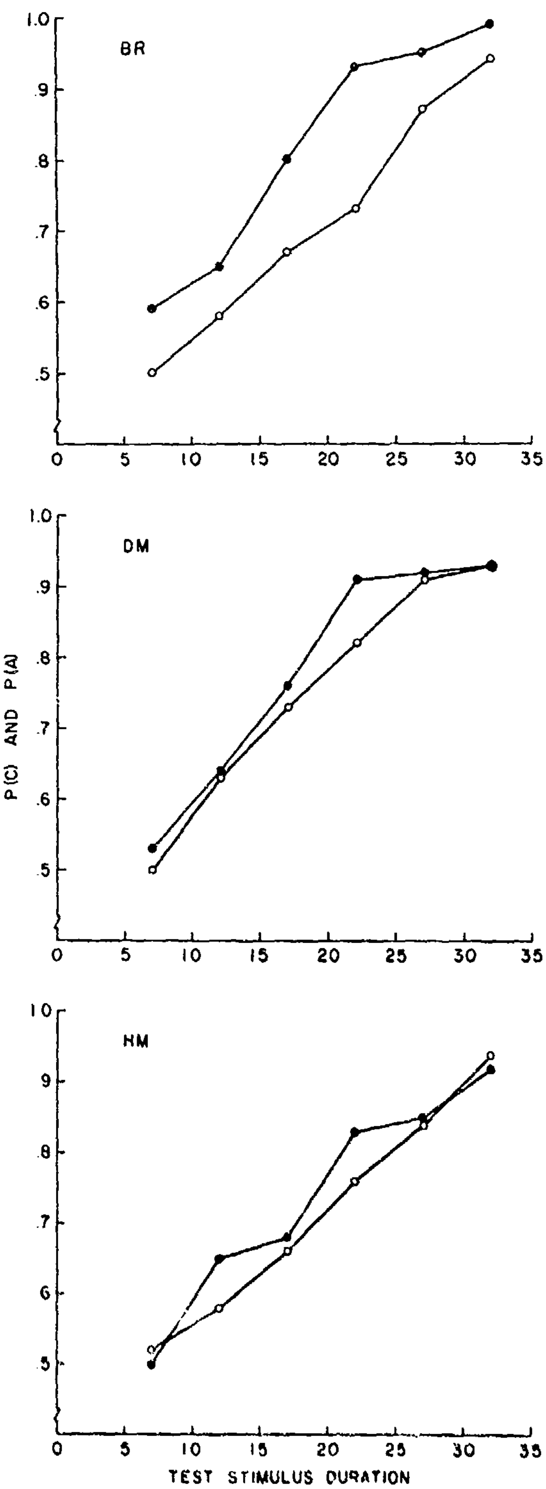

FIGURE 1. Discrimination of two-pulse stimuli as a function of test stimulus duration under FC and YN procedures measured with three observers. Values of P(C) from the FC procedure are indicated by closed circles and values of P(A) from the YN procedure are indicated by open circles.

For all observers, sensitivity measures rise with test stimulus duration. The data from the two procedures are in close agreement for two of the three observers. The decrease in performanc of BR under the *YN* procedure is discussed below. Although there is a tendency for discriminability to be higher under the *FC* procedure, there appears to be no significant difference between indices of sensitivity obtained from the two procedures. The similarity of P(C) and P(A) measures in the data of two observers should encourage additional efforts to apply *TSD* in similar studies of temporal discrimination.

III. Experiment II.

Method for Experiment II

Temporal discrimination of brief two-pulse stimuli was measured at three luminance levels, 31.8, 318, and 3183 cd/m². The procedure used in this experiment was identical to the *FC* procedure of Experiment I. Comparison and test stimuli were also identical to those used in Experiment I, with the addition of a 42 msec duration (40-msec interflash interval) test stimulus. Only BR and HM participated in Experiment II. Schedule changes prevented DM from serving as an observer. One week of practice was given before the data collection was begun. Data collection took one month.

Results and Discussion of Experiment II

The data are presented in Figure 2. The proportion of correct responses P(C) is given as a function of test stimulus duration with luminance as the parameter. The data of both observers show an increase in P(C) with increasing test stimulus duration; the rate of increase rises with luminance.

Differences between psychometric functions of the two observers are apparent. Discrimination increases with test stimulus duration much more rapidly for HM than for BR at the 318 and 3183 cd/m² levels. At the 31.8 and 318 levels, discrimination does not differ for BR until test stimulus duration exceeds 17 msec, whereas for HM a clear difference is present at these luminances for all durations of test stimulus. Significant individual differences are also apparent in the two-pulse threshold data of previous experiments.[2, 6, 7]

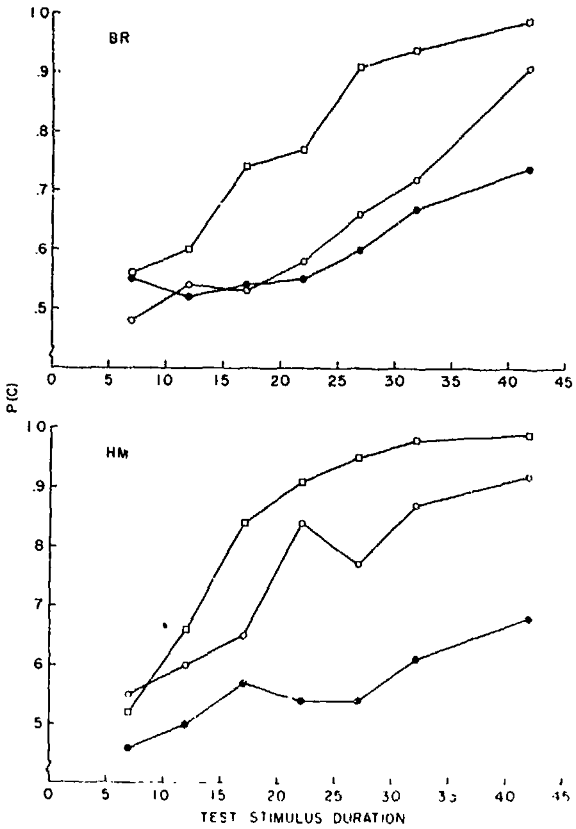

FIGURE 2. Discrimination of two-pulse stimuli as a function of test stimulus duration at three luminance levels as measured with two observers with the FC procedure. The luminances were 31.8, 318, and 3183 cd/m² and are represented by closed circles, open circles, and open squares, respectively.

The 3183 cd/m² luminance was used in both Experiments I and II with the *FC* procedure. Comparison of performance in these conditions provides information about the reliability of this particular temporal discrimination response. The *FC* curves for BR in Figures 1 and 2 for the 3183 cd/m² luminance reveal a downward shift in discriminability in Experiment II. The curve from Experiment II is actually closer to the *YN* curve of Experiment I than the *FC* curve of Experiment I. The corresponding curves for HM show a shift in the opposite direction. As these changes involve shifts of entire curves rather than the variability of individual data points, it is probable that they reflect shifts in the sensitivity of the observers. These shifts may be due to practice effects or change in general level of motivation and atter on over the five month period which separated the two sets of measurements. The shifts in the curves for both observers are, however, smaller than the luminance effects observed.

The current study supports the previous indication[7] of a luminance effect at higher levels. Nilsson's[6] suggestion that luminance effects on temporal discrimination of brief two-pulse stimuli exist only in the scotopic range is clearly contradicted. His criterion for scotopic stimuli was luminance less than 63.7 cd/m² for a total timulus "on" duration of 2 msec. The 318 and 3183 cd/m² luminances of the current study are above this range, yet discrimination clearly differs between the two conditions.

As the stimuli used in all previous studies[2 3 5 6 7] were similar, other methodological factors are likely to have produced the variability among findings. The methodological differences between these experiments cannot be related to the appearance or absence of luminance effects at present. Methodological differences which should receive future investigation involve procedures for varying luminance and test stimulus duration in experimental sessions, the number of observations per data point, the use of feedback, and the preliminary practice of observers.

This study indicates that the ability of the eye to detect the dark interpulse interval in two-pulse flashes increases with intensity in the photopic as well as the scotopic range. Thus, pulses separated by a dark interval short enough so that only a single flash is seen over the entire scotopic intensity range may, however, be seen at photopic intensities as two pulses, or appear to flicker, or otherwise appear to be of different character. To maintain a homogeneous flash apperance over the entire range of signal intensities, the dark interval duration for multi-pulse flashes should be determined for the highest intensity condition at which operational observation is anticipated.

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