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VISUAL EFFECT OF HIGH INTENSITY FLASHES

Norma D. Miller
School of Optometry

15 May 1966 - 15 August 1966

USAF School of Aerospace Medicine
Brooks Air Force Base, Texas

Contract No. AF 41(609)-3078

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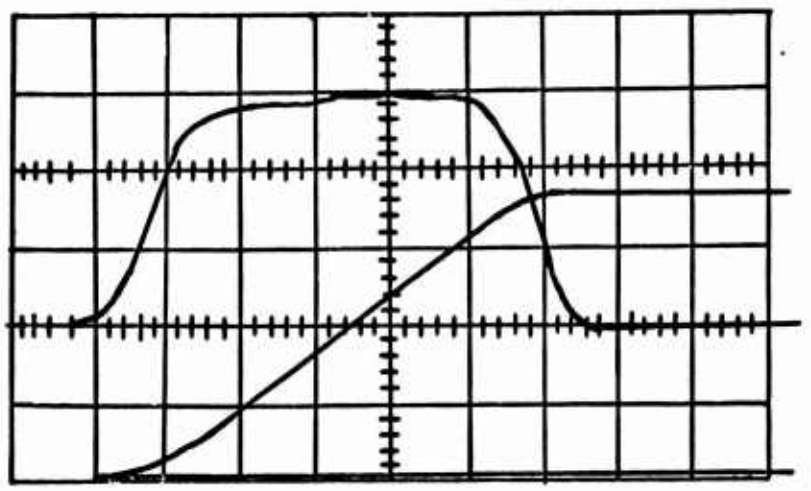
I. INTRODUCTION

Two main areas of investigation have been partially completed during the first quarter of the contract period. The first has been done at the School of Optometry at Ohio State University and is a continuation of the reciprocity failure study of high energy flashes of various durations. The previous work in this laboratory showed a failure in the reciprocity between intensity and duration for flashes shorter than one millisecond. The current study utilizes double flashes of 250 μsec duration with intervals between the flashes varying from zero to 1 msec. The second area of investigation is being carried out at Minneapolis Honeywell in cooperation with Dr. Harry Sperling. Two graduate student assistants, Vincent King and John Schoessler, have worked in Dr. Sperling's laboratory since the first of July determining the luminosity function for 45' monochromatic test flashes in the presence of 10^{o} white light adapting fields of various luminances.

II. DOUBLE FLASH EXPERIMENT

The experimental work on the double flash study of the reciprocity effect has been conducted by Vincent M. King as his Master's thesis research. The flash source was the 10,000 watt-second xenon discharge tube used in the previous work in this laboratory. The apparatus was the same as that described in the interim and the final report under Contract No. AF 41(609)-2426. The only modification was the substitution of sector disks containing two openings of various separations to provide the 250 μsec flashes with intervals between flashes of zero to one millisecond in 100 μsec steps. The sector disks were 10 inches in diameter and driven at 1725 rpm. The openings swept past an aperture 2.5 x 4.1 mm which was imaged in the plane of the subject's entrance pupil at a 1:1 magnification. A bright segment of the coil of the xenon tube was imaged on the aperture by a pair of telephoto lenses. The tube was triggered by means of a light activated SCR which was exposed through another opening in the sector disk. The triggering could be controlled precisely to permit the two flashes to be taken from the peak luminance of the tube discharge.

The flash durations and intervals were calibrated by means of a phototube signal displayed on a 555 Tektronix oscilloscope. Figure 1 shows typical CRT traces for the



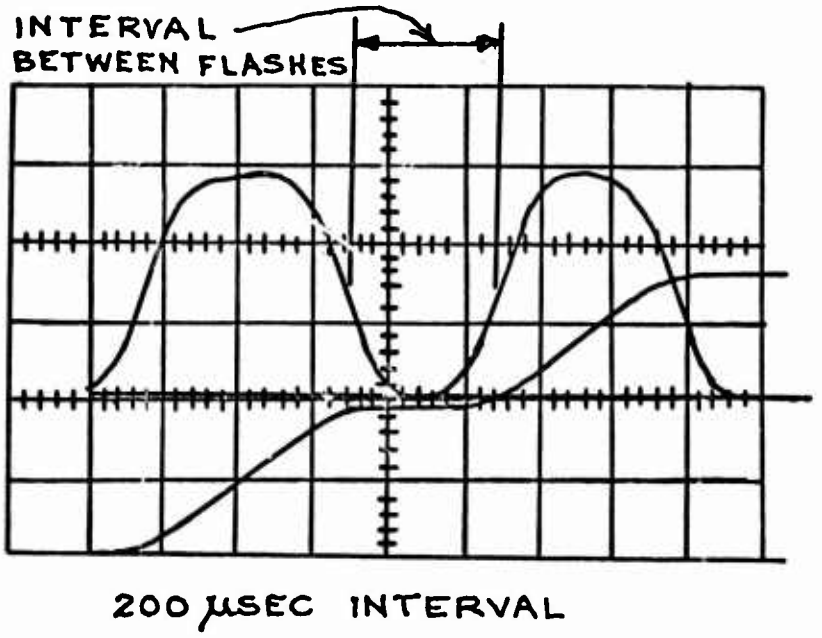


Figure 1. CRT traces of two double flash conditions and their integrated energies.

calibration and monitoring during experimental sessions. The lower trace in each picture shows the time course of radiance for the flashes and the interval between them and the upper trace is the integrated energy of the flashes. The interval between flashes was measured from the 50% points on the trailing edge of the first flash and the leading edge of the second flash. The calibration of the spectral composition of the xenon flash against a standard tungsten ribbon filament has been previously described. The absolute radiance at 555 mμ was determined each morning by comparing the phototube signals for the xenon flash and tungsten ribbon filament operated at standarized conditions through a 555 mμ interference filter. Each 250 μsec flash had an integrated energy of 5.5×10^6 td·sec, so each double flash exposure was 1.1×10^7 td·sec during the first series of the work. A second series was run with the energy reduced by a factor of 2 with a neutral density filter. During each experimental session, the integrated energies for all flashes were monitored with the phototube and held to within 5% of the nominal value.

Five subjects participated in the two series. The 10 flash intervals were independently randomized for each subject and were presented during a single experimental sessions for each. There was a five minute intertrial period between double flash exposures. The recovery times for recognition of 28.7' Sloan-Snellen letters presented at eight luminance levels were measured following each double flash exposure. Each subject replicated the recovery time measurements for the 10 flash intervals on five different days. The data for the individual subjects is recorded in Tables I-XI. The same procedure was followed in the second series with double flash energies of 5.5×10^6 td·sec.

In all cases the recovery time for the 500 μsec (or zero interval) flash was the shortest. In analyzing the data, the percentage increase in recovery time over that of the 500 μsec flash has been calculated for the mean data for each subject for each recovery target luminance. The variability of the data for the two lowest target luminances was so great as to obscure any effect of the flash interval so the data was discarded. The mean percentage increase in recovery time for all subjects for the first six target luminances for each flash interval is shown in the graph of Fig. 2. The peak at the 700 μsec interval is marked and an analysis of variance of the recovery for the 700 μsec interval versus the zero interval showed the difference in means to be significant at the 99.5% level. The results for one subject are shown in Fig. 3. The analysis for this subject was done

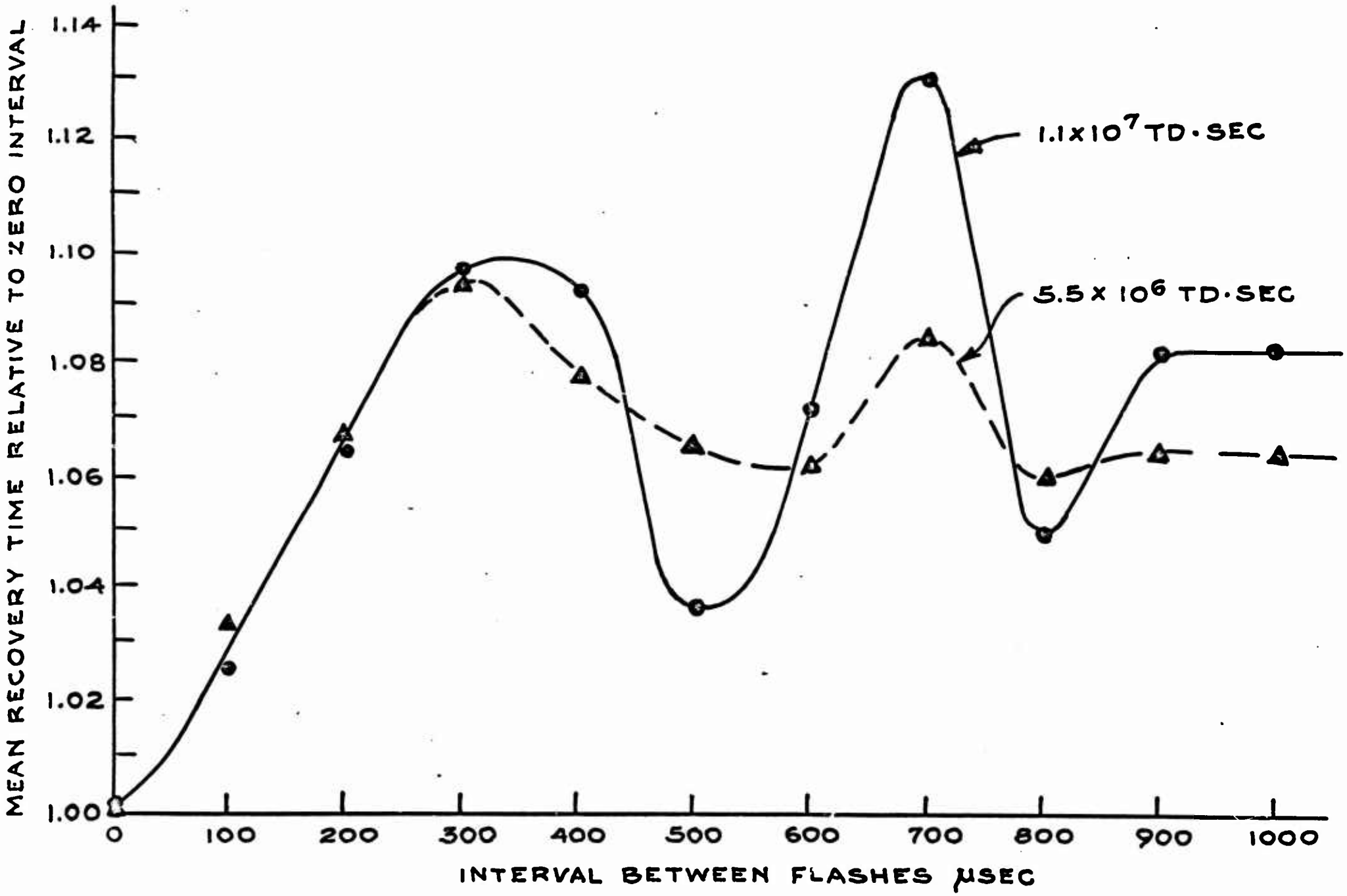


Figure 2. Mean data for five subjects for five recovery determinations each for six target luminances.

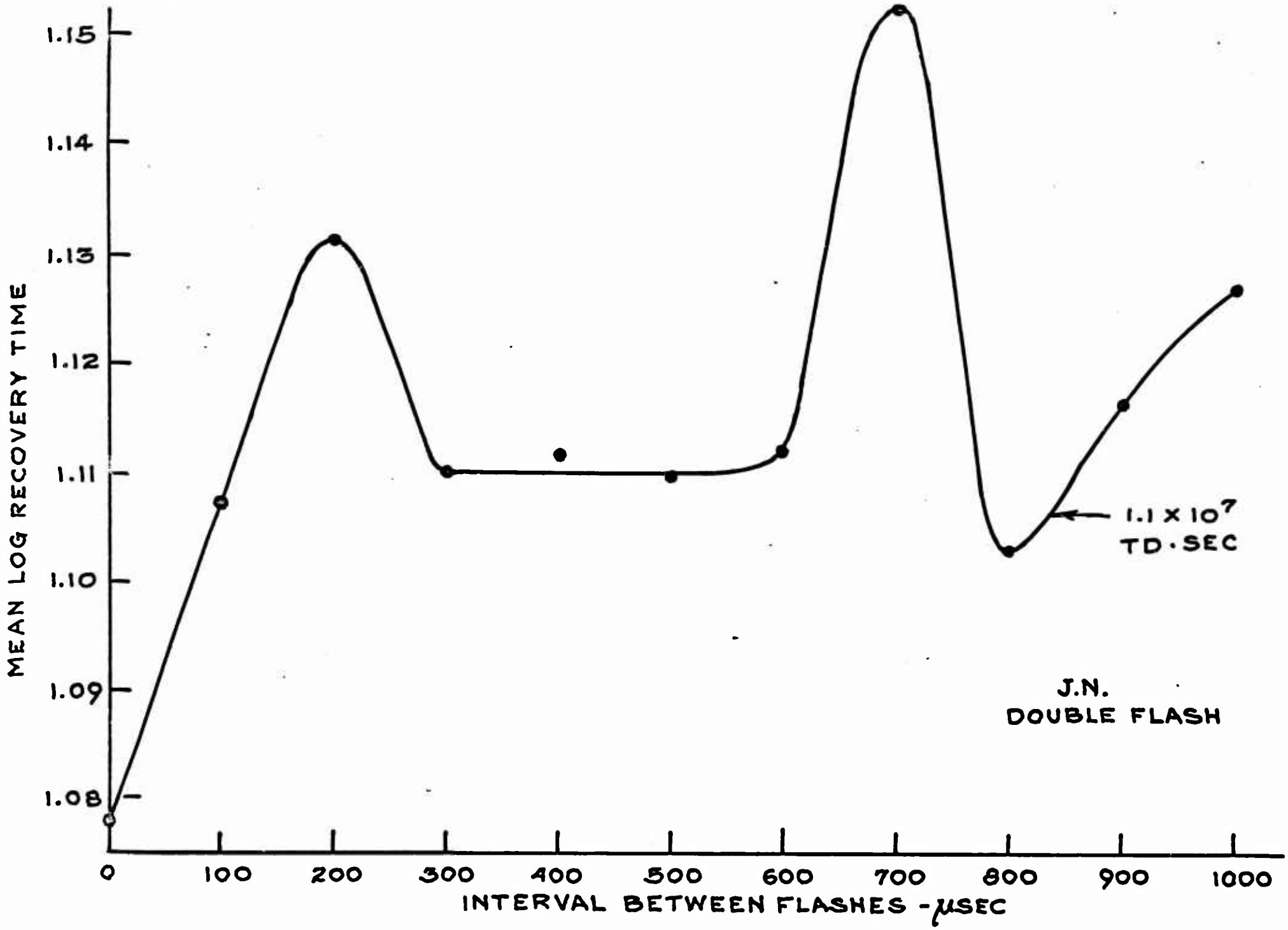


Figure 3. Mean data for one subject for five recovery determinations each for six target luminances.

in a slightly different manner. Each measured recovery time was transformed to the logarithm and the mean of the log recovery times for 6 target luminances for each flash interval is plotted as the ordinate.

It will take some time before the results can be interpreted as to the possible underlying mechanism, but the confidence in the validity of the measurements is strengthened by similarity of the results for the two series at different integrated energies. There has not been time to cross correlate the data with the measured energies for each double flash exposure. The relative energies in terms of the measured voltage of the integrated phototube signals are recorded in Tables XII and XIII.

III. LUMINOSITY FUNCTION AT HIGH ADAPTATION LEVELS

The work at Minneapolis Honeywell has produced some interesting results. The 10^{o} white light adapting field is provided by tungsten ribbon filament presented by Maxwellian view through a 2 mm diameter artificial pupil to the right eye. A 45' test flash of monochromatic light from a double monochromator is superimposed on the field for 400 msec each second. Threshold determinations for the whole visible spectrum at 10 mμ steps are made during each session for one adapting field luminance. The thresholds are determined by starting above threshold and decreasing the light until the test field cannot be seen and then starting below threshold and increasing the light until detection is acheived. The mean data for each of the subjects for 10 trails on 10 separate days is shown in Fig. 4 and 5 for a 10,000 td adapting field and in Figs. 6 and 7 for a 1,000 td adapting field. The standard luminosity curve for the 1931 standard observer is plotted on the same scale in Fig. 8 for comparison. The data from Dillon and Fegers for absolute threshold determinations for a 1^{o} test flash for six subjects is also plotted on Fig. 8.

Both subjects have normal color vision as tested on the anomaloscope and with the Farnsworth Hundred Hue test. The shape of the luminosity function is a result of the adapting field and is similar to the data that Dr. Sperling has acquired from his work with monkeys and on other human subjects. King and Schoessler will continue the work until the end of September and expect to extend the range of adapting field luminances down to one td and possibly up to 50,000 or 100,000 td.

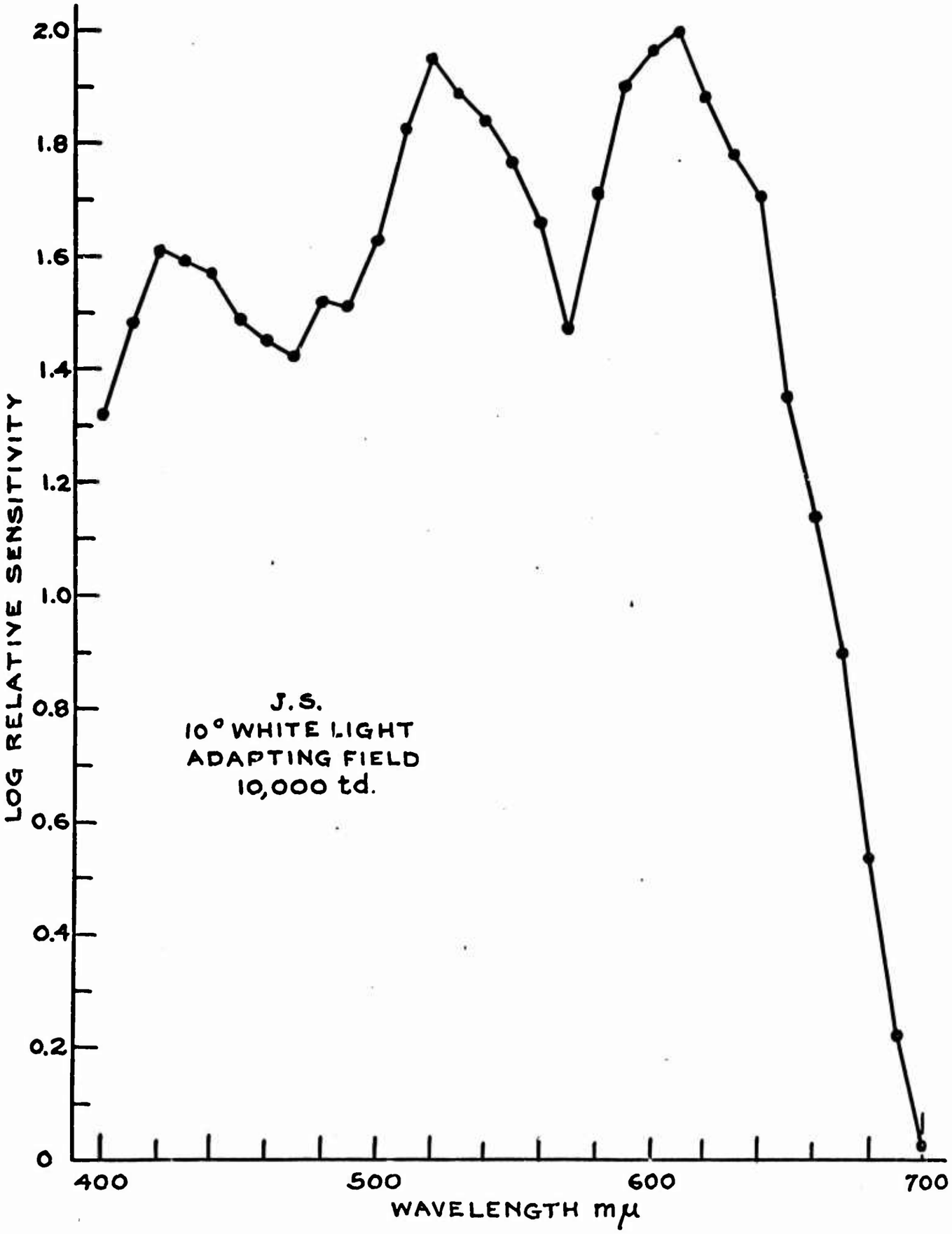


Figure 4. Luminosity function for subject J.S. for 45' monochromatic test flashes superimposed on a 10,000 td adapting field.

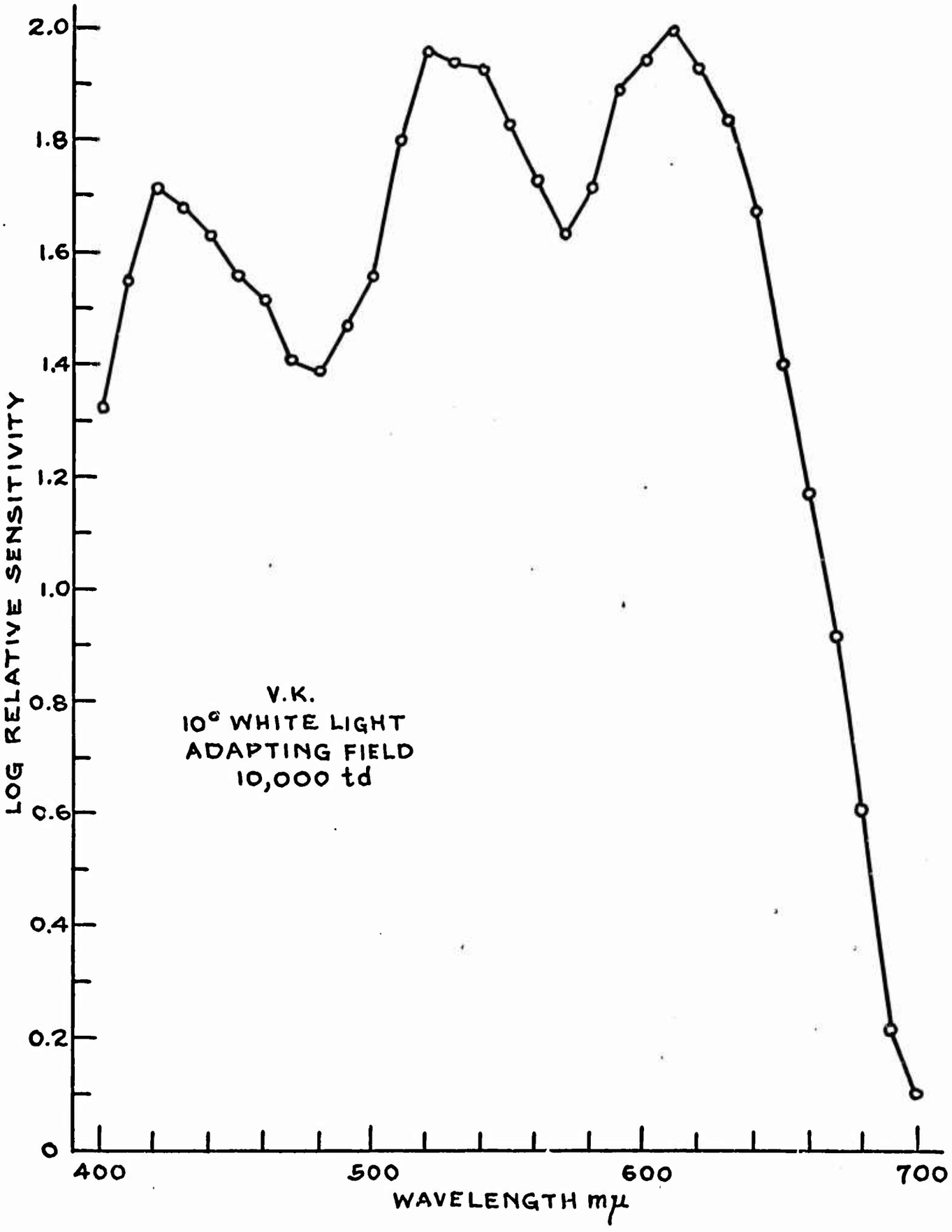


Figure 5. Luminosity function for subject V.K. for 45' monochromatic test flashes superimposed on a 10,000 td adapting field.

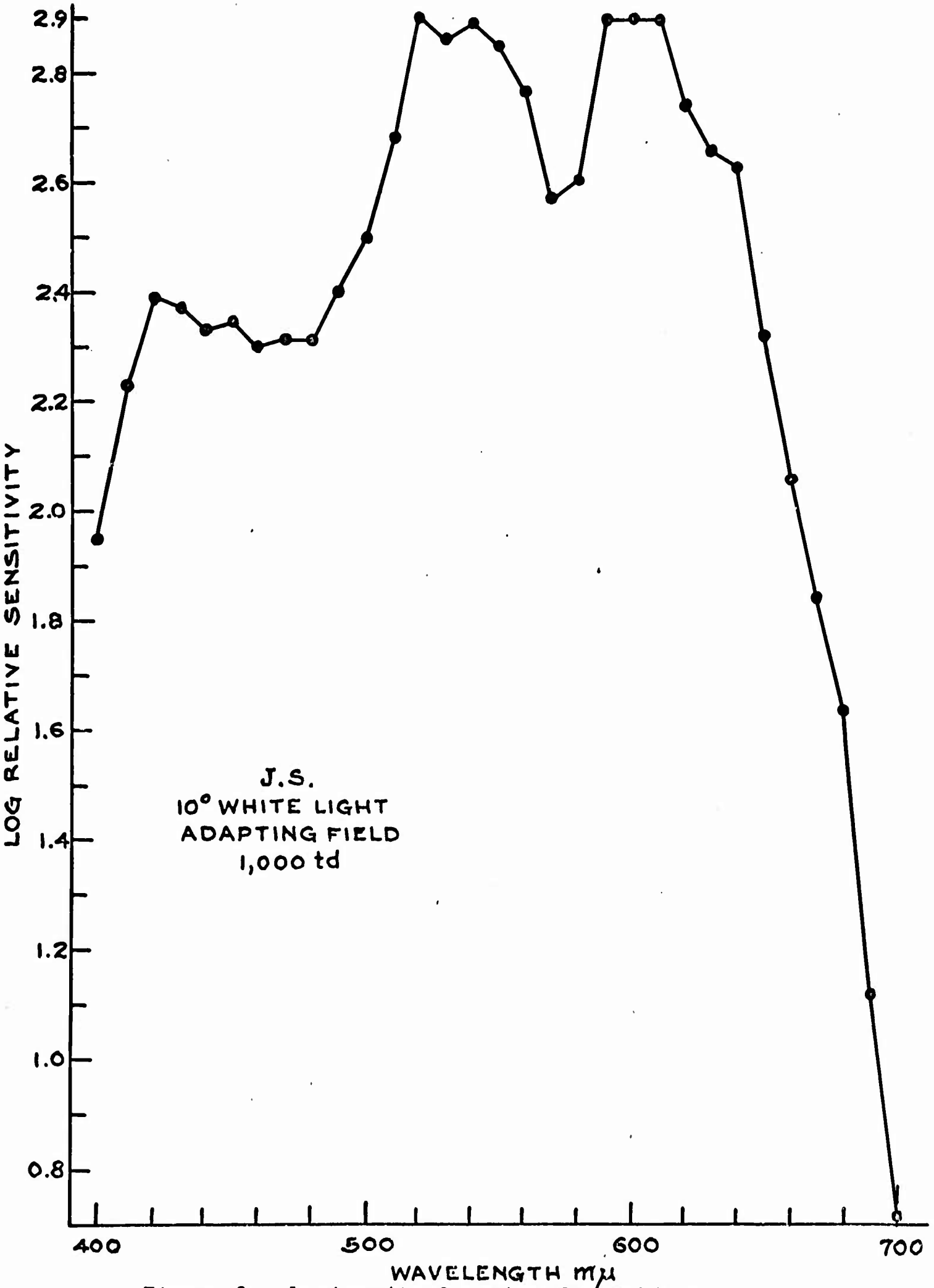


Figure 6. Luminosity function for subject J.S. for 45' monochromatic test flashes superimposed on a 1,000 td adapting field.

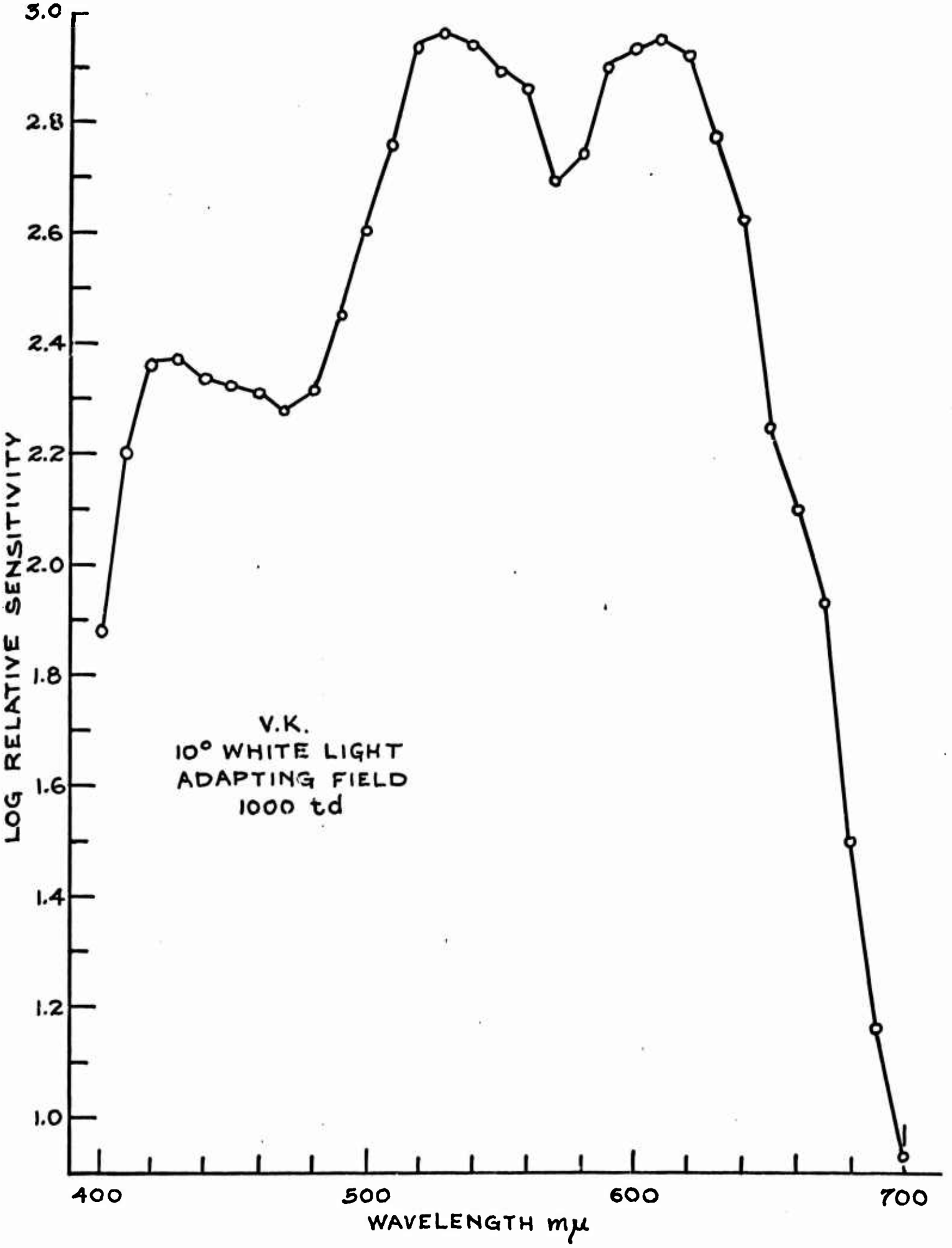


Figure 7. Luminosity function for subject V.K. for 45' monochromatic test flashes superimposed on a 1,000 td adapting field.

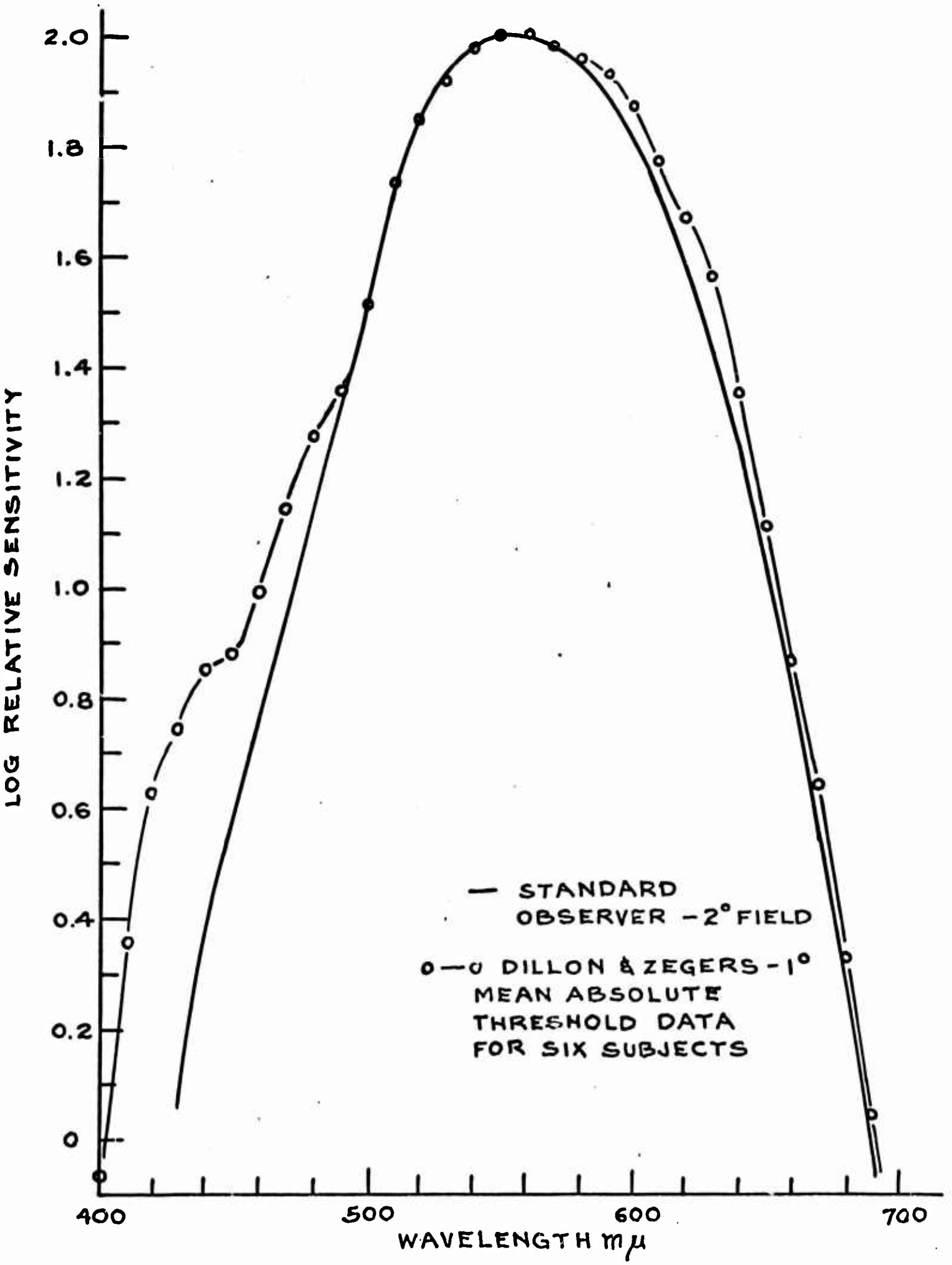


Figure 8. Luminosity function for 1931 Standard Observer for 2° field and for the mean of six subjects for absolute threshold determinations of a 1° field.

TABLE I. Recovery times for various target luminances following the zero interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminance mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	4.2	6.5	19.4	23.1	26.4	28.8
	3.5	8.1	10.2	18.2	20.6	29.1
W.P.	3.5	5.8	8.0	10.3	21.1	27.0
	6.8	9.1	11.5	14.0	25.9	32.4
	2.9	6.1	11.9	14.3	16.5	19.2
Mean	4.18	7.12	12.20	15.98	22.10	27.30
	4.3	6.2	13.3	15.5	17.9	34.3
	---	7.5	11.1	13.4	19.3	29.9
J.N.	3.8	7.0	9.5	12.9	21.3	29.5
	6.7	8.9	12.5	16.2	18.7	30.4
	3.8	6.3	10.3	12.8	16.3	30.3
Mean	4.65	7.18	11.34	14.16	18.70	30.88
	---	6.4	9.3	15.4	18.9	24.1
	5.8	8.3	10.5	15.3	22.1	45.8
J.M.	5.6	11.2	13.5	19.4	23.2	46.4
	5.1	7.4	9.7	20.2	22.7	39.2
	5.3	8.7	11.0	14.4	25.0	31.2
Mean	5.45	8.40	10.80	16.94	22.38	37.34
	4.9	7.2	9.6	20.0	26.0	31.9
	5.8	10.6	14.1	18.8	30.5	49.5
R.E.	4.4	7.3	10.9	20.3	23.9	39.2
	4.4	7.6	13.4	20.7	30.0	42.2
	4.9	7.3	13.1	18.9	26.1	49.5
Mean	4.88	8.00	12.22	19.74	27.3	42.46
	5.1	7.9	14.2	17.2	25.2	49.7
	5.8	8.1	10.4	16.3	22.2	49.0
D.G.	5.7	9.1	11.4	17.3	27.8	39.8
	5.0	8.0	10.3	15.3	18.7	45.7
	7.1	9.5	11.9	15.3	17.6	43.7
Mean	5.74	8.52	11.64	16.28	22.3	45.58

TABLE II. Recovery times for various target luminances following the 100 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminance mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	3.1	5.3	8.7	11.1	13.5	15.9
	4.0	7.3	10.8	13.2	22.7	28.8
W.P.	3.9	8.3	10.6	13.2	15.5	19.3
	5.4	9.7	12.0	14.5	18.2	34.7
	4.6	6.9	9.3	12.8	21.2	24.8
Mean	4.2	7.5	10.28	12.96	18.22	24.70
	5.2	7.3	11.8	17.9	21.3	23.8
	4.1	6.4	8.9	15.8	19.6	23.0
J.N.	4.5	8.8	16.0	18.3	20.8	34.5
	4.1	8.6	12.1	14.6	29.7	32.3
	4.1	8.3	10.8	15.4	23.9	37.2
Mean	4.40	7.88	11.92	16.40	23.06	30.16
	---	8.2	10.0	19.9	27.0	37.5
	5.8	8.0	10.4	17.7	24.6	34.3
J.M.	6.5	8.8	11.1	13.5	28.7	37.2
	5.2	8.3	10.7	19.3	26.2	40.2
	5.6	7.8	10.2	16.1	21.9	40.9
Mean	5.78	8.22	10.48	17.30	25.68	38.02
	---	7.2	13.6	15.6	17.4	33.6
	---	7.9	12.7	22.3	29.6	57.6
R.E.	4.5	6.4	14.5	19.4	25.0	40.3
	4.2	6.5	11.0	22.8	28.7	40.4
	5.1	8.6	13.3	26.2	29.7	47.8
Mean	4.60	7.32	13.02	21.26	26.08	43.94
	6.1	8.3	19.0	24.9	36.4	45.6
	6.3	8.6	11.1	15.7	25.4	46.4
D.G.	5.9	8.2	10.5	15.3	23.7	40.0
	7.0	9.5	14.1	15.3	22.4	42.3
	5.4	8.7	11.0	13.3	15.7	47.3
Mean	6.14	8.66	13.14	16.9	24.72	44.32

TABLE III. Recovery times for various target luminances following the 200 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

Subject	Target Luminance mL					
	134.0	27.3	6.08	1.56	0.70	0.26
	4.6	7.1	10.6	17.7	20.1	43.5
	4.4	6.4	8.8	11.2	19.5	31.2
W.P.	3.7	6.1	8.4	10.8	16.9	20.4
	4.9	7.8	10.5	18.6	25.5	27.9
	4.4	8.8	12.3	14.7	17.4	21.0
Mean	4.40	7.24	10.12	14.60	19.88	28.80
	4.3	6.4	9.7	15.8	22.8	28.9
	4.5	7.8	10.2	14.7	20.7	29.0
J.N.	7.6	10.0	12.5	18.4	20.8	36.1
	7.6	9.9	12.3	18.2	20.6	37.1
	5.0	9.4	12.7	15.2	20.9	31.5
Mean	5.80	8.70	11.48	16.46	21.16	32.52
	5.4	7.8	10.1	15.8	20.7	35.1
	5.4	7.7	10.1	17.3	24.2	42.1
J.M.	5.4	7.6	10.1	17.1	25.4	45.4
	5.2	7.5	9.9	11.6	26.3	32.3
	4.8	9.1	11.6	14.0	23.5	34.0
Mean	5.24	7.94	10.36	15.16	24.02	37.78
	4.3	8.9	12.4	19.4	22.0	45.4
	7.0	9.4	14.0	21.2	29.5	49.4
R.E.	7.5	9.9	12.3	19.5	30.0	44.0
	4.7	8.0	10.5	21.5	29.4	45.8
	4.8	9.5	14.1	21.9	22.6	35.7
Mean	5.66	9.14	12.66	20.7	26.7	44.06
	5.1	11.7	30.5	41.2	46.9	65.5
	5.9	9.4	11.7	16.6	23.5	38.7
D.G.	5.6	7.0	11.7	18.6	26.7	53.7
	6.9	9.1	11.7	14.0	21.1	40.0
	7.4	9.6	11.8	14.7	21.4	40.1
Mean	6.18	9.36	15.48	21.02	27.92	47.6

TABLE IV. Recovery times for various target luminances following the 300 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminances mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	---	9.2	11.5	18.8	26.9	30.5
	4.4	7.8	10.1	16.0	25.7	32.7
W.P.	5.1	7.4	9.8	12.2	16.8	24.0
	3.9	8.1	10.3	13.0	20.0	44.5
	6.2	9.9	12.3	14.7	18.1	29.9
Mean	4.90	8.48	10.80	14.94	21.50	32.32
	---	6.5	9.7	13.0	23.9	38.0
	---	6.1	9.6	15.4	20.1	35.4
J.N.	4.3	8.5	11.0	12.8	20.5	24.2
	5.7	10.2	12.5	17.1	19.8	29.2
	6.1	8.4	12.9	17.9	23.8	28.8
Mean	5.37	7.94	11.14	15.24	21.62	31.12
	6.3	18.1	23.8	42.5	53.1	59.2
	6.3	8.6	11.1	13.5	25.1	42.1
J.M.	6.1	9.3	14.2	17.1	18.9	55.4
	6.5	9.0	11.2	19.5	23.0	46.6
	5.3	6.8	8.7	16.8	25.3	35.7
Mean	6.1	10.36	13.84	21.88	29.08	47.8
	4.6	7.8	12.6	15.3	17.4	38.4
	6.4	9.9	13.4	20.5	33.4	58.1
R.E.	6.4	8.7	12.4	19.4	21.9	38.3
	6.7	10.2	12.5	23.1	28.0	45.5
	4.4	8.7	12.6	19.4	36.1	52.8
Mean	5.70	9.06	12.70	19.54	27.36	46.62
	5.7	8.0	10.5	16.2	24.4	39.7
	---	6.9	9.3	14.9	25.6	53.7
D.G.	5.8	7.9	10.3	15.0	17.3	45.5
	6.2	8.4	12.0	18.0	20.4	45.2
	9.9	12.0	14.6	17.4	26.4	47.2
Mean	6.9	8.64	11.34	16.3	22.82	46.26

TABLE V. Recovery times for various target luminances following the 400 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminances mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	7.0	9.2	13.7	16.1	23.8	31.8
	4.0	6.3	11.0	14.7	20.6	35.8
W.P.	3.7	5.9	8.2	11.9	14.2	18.0
	7.4	11.1	13.3	16.0	19.1	42.8
	5.1	7.1	9.3	12.4	19.0	21.9
Mean	5.44	7.92	11.10	14.22	19.34	30.06
	5.0	7.1	9.5	15.2	21.2	29.4
	---	7.1	10.4	16.3	21.2	29.6
J.N.	6.4	8.5	12.3	15.9	19.2	38.1
	5.6	7.7	12.6	16.2	20.9	23.6
	4.5	8.9	12.4	14.8	24.1	30.2
Mean	5.38	7.86	11.44	15.68	21.32	30.18
	---	8.6	10.9	12.8	13.7	33.4
	6.2	8.1	10.6	14.1	26.0	43.5
J.M.	8.0	10.3	13.9	19.7	27.9	44.5
	9.5	11.9	14.2	16.6	18.9	34.5
	5.9	8.2	11.6	14.2	20.4	32.0
Mean	7.4	9.42	12.24	15.48	21.38	37.58
	5.1	8.4	13.1	15.6	24.9	40.5
	5.5	9.1	14.8	23.3	33.8	37.5
R.E.	4.8	8.0	15.7	17.4	26.9	50.5
	5.1	8.3	12.8	20.2	24.7	48.2
	5.4	9.6	12.1	21.8	28.8	49.7
Mean	5.18	8.68	13.70	19.66	27.82	45.28
	5.9	17.4	23.4	33.9	---	63.3
	5.5	7.8	10.2	14.7	23.0	44.3
D.G.	5.4	9.9	12.4	20.7	33.4	40.8
	7.0	10.4	12.9	18.9	21.6	47.1
	8.4	10.6	13.0	15.6	19.0	43.8
Mean	6.44	11.22	14.38	20.76	24.25	47.86

TABLE VI. Recovery times for various target luminances following the 500 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminances mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	3.1	7.4	9.6	12.0	14.4	22.8
	3.6	5.9	8.2	19.9	24.7	28.3
W.P.	---	6.3	8.6	11.0	16.9	20.4
	6.5	8.6	10.9	15.7	18.8	50.8
	4.5	6.7	9.2	16.2	18.7	30.3
Mean	4.43	6.98	9.30	14.96	18.70	30.52
	5.2	7.9	12.7	16.1	22.2	36.2
	---	8.9	11.3	13.5	19.4	32.4
J.N.	6.7	8.2	10.6	18.9	21.1	28.6
	4.1	7.3	9.6	17.9	20.3	36.8
	3.9	6.8	11.8	15.0	17.5	34.0
Mean	4.98	7.82	11.2	16.28	20.10	33.60
	---	8.4	10.8	14.3	21.6	32.1
	8.5	10.8	14.3	16.9	19.4	39.3
J.M.	5.9	9.2	11.4	20.8	23.3	39.7
	6.2	8.1	10.5	14.0	18.7	34.3
	5.5	7.6	11.0	15.8	25.5	35.7
Mean	6.53	8.82	11.6	16.36	21.7	36.22
	4.8	8.6	10.9	16.7	23.9	28.5
	5.4	9.8	12.3	23.2	28.7	47.5
R.B.	5.2	8.1	13.4	18.2	24.1	40.5
	4.8	10.1	12.7	20.8	31.5	39.9
	6.3	8.3	13.0	21.2	26.5	39.3
Mean	5.3	8.98	12.46	20.02	26.94	39.14
	5.5	7.9	10.4	26.7	40.9	43.6
	5.7	7.9	12.7	14.9	21.4	35.2
D.G.	6.0	8.2	11.7	14.1	28.2	48.2
	6.3	8.6	12.3	18.1	26.4	42.9
	6.5	10.1	12.5	14.9	28.8	50.2
Mean	6.0	8.54	11.92	17.74	29.14	44.02

TABLE VII. Recovery times for various target luminances following the 600 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

Subject	Target Luminances mL					
	134.0	27.3	6.08	1.56	0.70	0.26
	3.4	5.6	8.0	10.5	14.3	26.1
	5.0	6.9	9.7	15.1	24.5	29.6
W.P.	4.3	6.6	8.8	11.2	14.8	20.5
	10.9	16.9	21.5	23.6	26.4	33.6
	4.3	5.6	8.8	12.3	16.0	27.4
Mean	5.58	8.32	11.36	14.54	19.20	27.44
	5.5	9.9	13.3	15.7	22.9	32.2
	---	8.5	14.4	17.9	23.7	41.4
J.N.	4.4	7.5	11.0	14.0	19.3	38.2
	5.5	7.7	10.1	16.5	18.5	25.7
	3.6	7.7	11.7	14.0	17.9	32.5
Mean	4.75	8.26	12.10	15.62	20.46	34.00
	---	9.2	11.5	17.4	21.0	39.9
	6.3	8.5	12.1	18.0	25.1	42.7
J.M.	5.7	8.0	13.9	17.3	19.7	37.3
	6.7	8.7	11.1	13.5	24.1	47.7
	5.5	7.6	10.0	16.5	23.4	29.1
Mean	6.05	8.4	11.72	16.54	22.66	39.34
	5.0	7.1	13.0	20.1	24.7	42.4
	4.9	8.5	16.5	24.6	32.0	59.8
R.E.	4.5	9.2	13.9	19.8	25.7	39.9
	5.2	8.2	15.8	24.1	26.7	55.9
	5.2	10.8	15.6	20.4	31.1	47.7
Mean	4.96	8.76	14.96	21.80	28.04	49.14
	5.3	8.9	14.7	33.5	44.3	48.0
	6.2	8.3	10.7	14.8	---	44.9
D.G.	6.9	9.3	11.5	14.0	25.8	28.3
	5.8	7.6	13.5	17.1	23.3	52.5
	5.7	8.0	11.6	16.2	26.2	52.8
Mean	5.98	8.42	12.4	19.12	29.9	45.3

TABLE VIII. Recovery times for various target luminances following the 700 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminance mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	5.3	11.1	14.8	17.1	22.8	28.3
	4.8	8.4	10.8	13.1	15.3	37.9
W.P.	---	7.7	9.9	18.4	23.2	39.8
	4.5	10.1	12.9	14.8	25.4	38.5
	3.7	7.2	10.5	14.0	21.9	31.8
Mean	4.58	8.90	11.78	15.48	21.72	35.26
	---	8.6	11.2	17.2	19.5	25.8
	---	10.0	13.6	16.1	23.1	32.4
J.N.	6.8	8.5	10.5	14.6	18.8	37.5
	7.6	12.2	14.7	17.2	24.1	30.4
	4.3	6.5	14.8	18.4	24.2	38.5
Mean	6.23	9.16	12.96	16.70	21.94	32.92
	---	9.6	14.1	16.6	20.0	35.4
	7.0	9.3	11.7	18.0	22.4	47.0
J.M.	7.3	10.8	13.2	15.7	28.6	31.1
	6.9	9.4	11.6	18.6	23.5	38.6
	6.0	7.8	9.6	15.4	17.8	36.5
Mean	6.8	9.3	12.04	16.86	22.46	37.72
	4.6	9.1	11.4	19.8	30.2	48.9
	6.8	10.1	16.0	24.4	40.7	52.4
R.E.	7.0	11.9	14.2	22.5	24.9	43.8
	5.5	8.9	11.4	17.5	23.7	38.8
	5.2	11.5	15.1	22.2	29.6	73.0
Mean	5.82	10.30	13.62	21.28	29.82	51.38
	5.5	11.3	22.0	27.9	46.6	59.8
	5.8	9.2	11.5	14.2	26.8	30.9
D.G.	7.4	10.6	14.5	18.0	25.0	39.3
	6.0	8.5	11.8	14.3	21.3	40.3
	5.1	7.4	9.6	13.2	20.1	34.7
Mean	5.96	9.4	13.88	17.52	27.96	41.0

TABLE IX. Recovery times for various target luminances following the 800 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

Subject	Target Luminances mL					
	134.0	27.3	6.08	1.56	0.70	0.26
	5.0	9.6	11.9	20.2	23.1	46.0
	4.4	6.7	9.1	13.9	26.8	38.4
W.P.	---	5.8	8.0	10.3	13.9	17.5
	6.3	8.6	11.0	15.0	27.5	39.4
	4.4	6.2	9.0	10.7	20.9	26.7
Mean	5.03	7.38	9.80	14.02	22.44	33.60
	5.1	7.1	10.6	15.7	18.3	34.1
	5.0	7.3	9.6	14.0	24.6	---
J.N.	4.0	6.5	10.6	17.5	20.1	29.4
	7.2	9.5	11.8	16.6	20.1	30.9
	4.5	6.4	12.2	15.7	20.5	32.5
Mean	5.16	7.36	10.96	15.90	20.72	31.73
	4.9	7.1	10.6	13.0	17.6	31.8
	7.5	9.5	12.0	15.7	19.6	45.1
J.M.	5.8	8.1	10.4	16.2	21.0	41.1
	5.2	7.2	9.8	13.2	16.6	29.8
	6.2	10.7	13.1	15.4	17.9	30.0
Mean	5.92	8.52	11.14	14.7	18.54	35.56
	5.0	8.6	12.2	16.7	21.5	33.2
	7.7	9.9	14.6	19.6	32.2	56.8
R.E.	5.4	8.9	14.8	18.3	30.1	39.5
	4.9	9.2	12.7	22.2	32.8	48.0
	4.7	8.3	15.3	25.8	36.6	65.8
Mean	5.54	8.98	13.92	20.52	30.64	48.66
	6.2	8.5	16.9	27.4	37.9	56.8
	5.9	7.9	13.8	16.4	23.8	41.0
D.G.	---	6.5	9.9	15.8	27.6	46.7
	7.9	10.2	14.9	17.2	32.5	51.4
	6.5	8.7	10.9	15.7	16.5	46.3
Mean	6.62	8.36	13.28	18.5	27.66	48.44

TABLE X. Recovery times for various target luminances following the 900 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminance mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	---	10.5	12.8	17.6	19.9	35.2
	3.9	6.1	9.7	15.6	34.4	36.6
W.P.	---	6.7	8.7	12.3	14.5	20.4
	6.6	8.9	13.5	15.9	24.2	32.7
	4.2	7.7	10.0	13.9	24.3	27.6
Mean	4.90	7.98	10.94	15.06	23.46	30.50
	5.9	8.0	12.6	16.3	25.6	38.9
	4.3	6.7	11.2	17.0	24.1	31.4
J.N.	4.9	7.0	9.9	15.1	21.1	33.0
	4.9	7.1	9.8	14.2	20.3	26.5
	6.1	8.7	11.9	14.5	21.7	43.1
Mean	5.22	7.50	11.08	15.42	22.56	34.58
	5.6	7.9	11.3	14.9	19.7	33.9
	10.7	13.6	16.2	18.8	29.4	32.9
J.M.	5.8	8.0	11.5	16.2	23.3	47.2
	7.2	9.5	12.0	14.4	21.5	28.7
	5.8	9.1	11.4	18.6	20.8	34.0
Mean	7.02	9.62	12.48	16.58	22.94	35.34
	4.5	8.0	10.3	18.6	21.0	41.1
	5.8	9.3	13.9	21.1	29.5	50.3
R.E.	5.8	8.1	11.8	21.2	26.2	61.1
	5.1	7.2	12.0	18.0	28.7	45.5
	6.5	8.8	13.7	20.6	33.6	55.0
Mean	5.54	8.28	12.34	19.90	27.80	50.60
	---	6.4	8.9	16.8	20.4	40.4
	6.2	8.6	11.0	18.0	27.4	46.2
D.G.	8.1	11.6	14.3	16.7	30.7	50.6
	5.7	8.8	11.2	17.1	19.6	38.4
	7.6	10.0	13.4	15.7	28.9	45.3
Mean	6.9	9.08	11.76	16.86	25.4	44.18

TABLE XI. Recovery times for various target luminances following the 1000 μsec interval double flash of 1.1×10^7 td·sec integrated energy.

	Target Luminances mL					
Subject	134.0	27.3	6.08	1.56	0.70	0.26
	6.0	9.2	13.9	17.6	22.3	45.9
	4.5	6.7	8.9	14.3	19.6	44.3
W.P.	4.4	6.3	10.0	15.6	20.4	34.9
	5.1	7.2	9.5	14.5	22.7	42.6
	3.8	10.2	13.1	15.2	19.9	26.0
Mean	4.76	7.92	11.08	15.44	20.98	38.74
	3.7	6.7	10.4	13.1	19.9	31.4
	---	7.0	10.4	14.2	21.1	30.5
J.N.	4.3	7.4	11.9	14.9	20.2	38.0
	6.1	8.5	10.8	15.6	19.2	29.9
	6.7	9.2	11.5	16.5	21.9	32.9
Mean	5.20	7.76	11.0	14.86	20.46	32.54
	6.0	7.8	10.6	14.3	25.0	37.9
	6.0	9.4	11.9	16.6	22.6	42.4
J.M.	8.9	11.2	13.7	21.8	25.3	40.5
	6.3	8.5	10.9	13.4	23.3	32.2
	5.6	7.7	10.3	19.5	23.2	44.2
Mean	6.56	8.92	11.48	17.12	23.88	39.44
	4.9	7.8	11.4	16.0	19.7	32.7
	5.7	9.2	16.2	23.4	38.5	62.5
R.E.	5.1	9.8	13.2	22.8	29.9	44.4
	7.4	10.7	14.2	19.2	30.0	54.4
	6.3	8.8	12.3	22.9	29.9	60.6
Mean	5.88	9.26	13.46	20.86	29.60	50.92
	---	7.1	12.7	15.2	28.1	50.7
	6.2	8.6	11.1	13.5	22.8	38.2
D.G.	6.1	8.5	10.8	18.1	35.5	43.8
	5.4	8.7	11.2	17.2	21.0	44.1
	8.8	11.2	14.0	18.6	23.1	39.7
Mean	6.62	8.82	11.96	16.52	26.1	43.3

TABLE XII. Relative integrated energies for the double flash exposures for the various trials and flash intervals.

Subject	Zero	100	200	300	400	500
	2.88	2.93	2.93	2.93	2.88	2.82
	2.88	2.77	2.71	2.82	2.65	2.60
W.P.	2.71	2.77	2.77	2.71	2.65	2.65
	2.93	2.93	2.93	2.99	2.93	2.82
	2.65	2.77	2.77	2.88	2.77	2.77
Mean	2.81	2.83	2.82	2.87	2.78	2.73
	2.54	2.60	2.71	2.71	2.77	2.65
	2.88	2.88	2.77	2.82	2.88	2.82
J.N.	2.82	2.88	2.77	2.77	2.82	2.77
	2.88	2.88	2.99	2.99	2.88	2.82
	2.88	2.88	2.71	2.77	2.82	2.60
Mean	2.80	2.82	2.79	2.81	2.83	2.73
	2.93	2.93	2.99	2.93	2.99	2.93
	2.71	2.71	2.77	2.77	2.60	2.71
J.M.	2.99	3.04	2.93	2.99	2.93	2.88
	2.71	2.60	2.77	2.60	2.65	2.60
	2.65	2.77	2.77	2.77	2.77	2.71
Mean	2.80	2.81	2.85	2.81	2.79	2.77
	2.77	2.82	2.71	2.71	2.71	2.65
	2.77	2.82	2.77	2.82	2.77	2.77
R.E.	2.54	2.71	2.82	2.65	2.65	2.60
	2.65	2.71	2.87	2.65	2.82	2.77
	2.87	2.71	2.71	2.82	2.82	2.65
Mean	2.72	2.75	2.78	2.73	2.75	2.69
	2.82	2.82	2.93	3.04	2.77	----
	2.71	2.71	2.77	2.60	2.65	2.65
D.G.	2.65	2.71	2.54	2.71	2.65	2.65
	2.93	2.88	2.82	2.99	2.77	2.88
	2.65	2.71	2.54	2.65	2.65	2.65
Mean	2.75	2.77	2.72	2.80	2.70	2.71

TABLE XIII. Relative integrated energies for the double flash exposures for the various trials and flash intervals.

Subject	600	700	800	900	1000
	2.82	2.99	2.77	2.77	2.77
	2.77	2.77	2.65	2.54	2.60
W.P.	2.71	2.77	2.88	2.60	2.65
	2.88	2.93	2.82	2.88	2.71
	2.77	2.77	2.88	2.77	2.65
Mean	2.79	2.85	2.80	2.71	2.68
	2.71	2.65	2.54	2.43	2.60
	2.71	2.82	2.71	2.65	2.77
J.N.	2.65	2.82	2.71	2.77	2.65
	2.99	2.93	2.82	2.77	2.82
	2.77	2.71	2.71	2.56	2.71
Mean	2.77	2.79	2.70	2.64	2.71
	2.99	2.82	2.77	2.71	2.71
	2.71	2.71	2.82	2.54	2.54
J.M.	2.87	2.88	2.77	2.82	2.82
	2.77	2.71	2.60	2.77	2.54
	2.77	2.77	2.71	2.60	2.60
Mean	2.82	2.78	2.73	2.69	2.64
	2.65	2.77	2.65	2.49	2.65
	2.71	2.65	2.71	2.65	2.65
R.E.	2.77	2.71	2.65	2.54	2.54
	2.71	2.65	2.65	2.60	2.54
	2.82	2.71	2.82	2.65	2.65
Mean	2.73	2.70	2.70	2.59	2.61
	2.88	2.88	2.77	2.71	2.71
	2.65	2.54	2.65	2.49	2.60
D.G.	2.71	2.54	2.43	2.54	2.43
	2.82	3.04	2.88	2.93	2.82
	2.65	2.65	2.65	2.60	2.60
Mean	2.74	2.73	2.68	2.65	2.63