ASSESSMENT OF THE BROCA-SULZER PHENOMENON VIA INTER- AND INTRA-MODALITY MATCHING PROCEDURES: STUDIES OF SIGNAL-LIGHT BRIGHTNESS

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I. Introduction.

The current study is directed toward evaluating the effective brightness of signal lights for observers in aviation. Since signal lights are usually presented to the observer as flashes with finite duration, the effect of flash duration on apparent brightness assumes importance. The apparent brightness of a light flash of constant supra-threshold luminance does not increase monotonically with duration, but rather passes through a maximum between 30 and 300 msec. and then decreases about 2 dB to a steady value.[1,2] This well known phenomenon, referred to as the Broca-Sulzer effect, is typically measured using brightness matching procedures in which subjects either adjust the luminance of a constant duration comparison stimulus to match the brightness of test flashes which vary in duration, or adjust the luminance of test flashes of varying duration to match the brightness of a comparison flash of fixed duration and luminance. Both procedures involve a visual comparison stimulus.

Some experiments using techniques other than brightness matching to measure perceived brightness have not found the Broca-Sulzer effect. Raab, Fehrer, and Hershenson[3] had three subjects make category judgments of brightness to flashes of constant luminance (3000 ft. L.) and varying duration (10 to 500 msec.). No Broca-Sulzer effect was observed. The authors hypothesized that Broca-Sulzer maxima may occur only when a visual comparison stimulus is presented along with the test flash and may not be solely a function of flash duration. Lewis[4] had two subjects make category judgments of brightness to flashes of varying luminance and duration. Luminance of flashes ranged from 10 to 3000 mL. and durations from 0.2 to 260 msec. No Broca-Sulzer effect was found.

Raab[5] did find the Broca-Sulzer effect when eighteen subjects made magnitude estimates of the apparent brightness of flashes whose luminance was between 0.035 and 100 mL. No effect was noted, however, when luminance fell above or below this range. Flash duration varied between 0.5 and 2000 msec. Stevens and Hall[6] also interpreted their magnitude estimation data as indicating a Broca-Sulzer effect. Durations used were 0.5 to 1000 msec. The effect appeared in their study at luminances between 0.3 and 300 mL; however, no effect appeared with the 3000 mL. luminance. The negative finding of Raab, Fehrer, and Hershenson, who employed a similar high luminance is, thus, in agreement with the results of the two studies just cited. The results of these magnitude estimation studies, as mentioned elsewhere,[7] are not unequivocal, however.

In a previous study,[8] each of two subjects adjusted the intensity of a 1000 Hz tone presented monaurally until he was satisfied that the tone was as loud as the flash was bright. Stimuli ranged in duration from 2 to 1024 msec., and in luminance from 7.9 to 15,850 mL. The results were interpreted as supporting the hypothesis that the Broca-Sulzer effect may be obtained only when a visual comparison stimulus is presented.

The current study compares brightness functions obtained using cross-modality matching with those obtained with conventional procedures in which a visual comparison stimulus is employed. These functions were obtained under both dark-adapted and light-adapted conditions.

II. Method.

A. *Subjects.* The three subjects (2 women and a man) were undergraduates of the University of Oklahoma. All were emmetropes with no color vision defects. All were paid an hourly wage. Data for one of the subjects (BB) are available only for the dark-adapted conditions.

B. *Apparatus.* A three field optical system was set up to deliver two adjacent 0.5° circular stimuli to the fovea by Maxwellian view. The stimuli were separated horizontally by approximately 0.2° in the field-of-view. In two of the channels light from a Sylvania Glow Modulator tube (R1131C) was collimated by one lens; an image of the 2.36 mm. crater was focused in the subject's pupil by a second lens after the light had passed through neutral density filters (Oriel Optics) and neutral density wedges (Optical Coating Laboratory) that were used to control stimulus intensity, then through a field stop, and a beam splitter. In the dark-adapted condition the subject fixated, through the 3 mm. artificial pupil, four red fixation lines provided through the third field. In the light-adapted condition, the tungsten source used in the fixation field was replaced by a third Sylvania Glow Modulator tube and the fixation lines were replaced with a clear reticle with four fixation lines inscribed upon it. Head position was controlled by a chin and forehead rest. The glow modulator tubes were driven by an Iconix light driver; the flash durations were controlled by an Iconix 6257 time base with preset controllers (Iconix 6010) and associated logic. Flashes were monitored with an RCA 1P21 photomultiplier tube operating behind a Kodak Wratten 106 filter. Temporal characteristics of the wave form of the light flashes showed that, at the current level used (40 mA.), rise time was less than 15μsec. and decay time less than 25 μsec. Luminance calibrations were made with a S. E. I. exposure photometer by a method described earlier (Lewis, 1965).

Acoustic stimuli were generated by a Krohn-Hite oscillator (model 440) and delivered monaurally through a Western Electric headset (#1002F) after passing through a Hewlett-Packard model 350D attenuator set used to control intensity.

C. *Procedure.* Each session was preceded by ten minutes of dark adaptation. Under the dark-adapted condition the subject was then required to adjust the intensity of the fixation lines until the fixation lines were just visible. For brightness matching conditions the comparison stimulus was a 500-msec. flash of either 10, 100, or 1000 mL. Termination of the comparison flash was coincident with termination of the test flash. There were ten test flash durations ranging from one to 1000 msec. The subjects adjusted the brightness of the test flash to match the brightness of the comparison flash by manipulating with synchros a neutral density wedge in the test field. The comparison stimulus always appeared on the right and the test stimulus on the left. For cross-modality matching, the comparison stimuli were 500-msec. presentations of a 1000–Hz tone whose intensity was either 97, 86, or 75 dB SPL, these intensities calculated from the data of Stevens, Mack, and Stevens[9] to match the luminance levels employed in the brightness matching procedure. Subjects were instructed to adjust the intensity of the test flash until it was as bright as the tone was loud. On a single trial, stimulus presentation occurred every 20 seconds in the dark-adapted condition and every 6 seconds in the light-adapted condition until the subject was satisfied with his match. In the light-adapted condition an adapting flash of 1.5 seconds duration was presented 2.5 seconds before onset of the comparison flash on each trial; the luminance of the adapting flash was identical with the luminance of the comparison flash.

III. Results and Discussion.

The mean test flash luminance required to match the comparison stimulus is plotted in Figures 1–14 as a function of test flash duration with luminance or loudness of the comparison stimulus as the parameter. Standard deviations of these matches are presented in Tables 1–4. The data from cross-modality matches to the 75 dB and 86 dB comparison stimuli in the light-adapted conditions were lost due to a technical error in controlling the luminance of the light-adapting field.

TABLE 1. Standard deviations in log mL. of inter-modality matches in the dark-adapted condition.

S	Comparison stimulus loudness (dB)	Test flash duration (msec.)									
		1	2	5	10	20	50	100	200	500	1000
BB	75	.39	.34	.38	.45	.37	.32	.25	.27	.30	.28
	86	.64	.51	.71	.58	.53	.38	.52	.53	.50	.44
	97	.57	.57	.50	.65	.72	.77	.71	.78	.65	.68
KT	75	.60	.58	.60	.64	.61	.59	.68	.73	.59	.53
	86	.52	.58	.51	.61	.57	.72	.75	.78	.70	.73
	97	.53	.52	.47	.56	.58	.61	.64	.70	.54	.62
BJ	75	.58	.48	.46	.48	.31	.55	.36	.48	.37	.38
	86	.55	.57	.60	.61	.50	.62	.55	.51	.54	.49
	97	.66	.67	.69	.76	.78	.64	.77	.71	.78	.77
Combined	75	.52	.47	.48	.52	.43	.49	.43	.49	.42	.40
	86	.57	.55	.59	.60	.53	.57	.61	.61	.58	.55
	97	.59	.59	.55	.66	.69	.67	.71	.73	.66	.69

TABLE 2. Standard deviations in log mL. of inter-modality matches in the light-adapted condition.

S	Comparison stimulus loudness (dB)	Test flash duration (msec.)									
		1	2	5	10	20	50	100	200	500	1000
KT	97	.34	.43	.37	.57	.58	.48	.72	.63	.62	.53
BJ	97	.57	.59	.60	.20	.73	.65	.83	.76	.75	.67
Combined	97	.46	.51	.48	.38	.66	.56	.78	.70	.68	.60

TABLE 3. Standard deviations in log mL. of intra-modality matches in the dark-adapted condition.

S	Comparison flash luminance (log mL.)	Test flash duration (msec.)									
		1	2	5	10	20	50	100	200	500	1000
BB	1.0	.35	.31	.33	.26	.28	.28	.31	.34	.32	.39
	2.0	.45	.49	.45	.37	.39	.35	.34	.41	.26	.33
	3.0	.41	.35	.37	.37	.44	.34	.30	.38	.27	.35
KT	1.0	.50	.46	.37	.41	.51	.33	.47	.40	.24	.27
	2.0	.43	.40	.50	.59	.50	.45	.38	.43	.30	.29
	3.0	.25	.43	.46	.53	.47	.54	.42	.55	.36	.44
BJ	1.0	.29	.29	.32	.36	.41	.25	.27	.31	.18	.16
	2.0	.46	.41	.38	.40	.28	.41	.35	.37	.46	.34
	3.0	.37	.45	.51	.60	.44	.50	.43	.42	.36	.34
Combined	1.0	.38	.35	.34	.34	.40	.29	.35	.35	.25	.27
	2.0	.45	.43	.44	.45	.39	.40	.36	.40	.34	.32
	3.0	.34	.41	.45	.50	.45	.46	.38	.45	.33	.38

TABLE 4. Standard deviations in log mL. of intra-modality matches in the light-adapted condition.

S	Comparison flash luminance (log mL.)	Test flash duration (msec.)									
		1	2	5	10	20	50	100	200	500	1000
	1.0	.45	.33	.33	.43	.38	.28	.33	.32	.21	.22
KT	2.0	.32	.39	.41	.39	.40	.30	.26	.33	.47	.28
	3.0	.19	.26	.37	.48	.42	.42	.45	.31	.27	.30
	1.0	.46	.38	.43	.37	.27	.39	.29	.33	.17	.33
BJ	2.0	.48	.47	.33	.39	.26	.36	.40	.35	.29	.25
	3.0	.30	.60	.58	.54	.55	.49	.53	.35	.38	.27
	1.0	.46	.36	.38	.40	.32	.34	.31	.32	.19	.28
Combined	2.0	.40	.43	.37	.39	.33	.33	.33	.34	.38	.26
	3.0	.24	.43	.48	.51	.48	.46	.49	.33	.32	.28

The results of cross-modality matching with dark-adaptation (Figures 1–4) reveal the possibility of a Broca-Sulzer effect in the data of BJ for the 97 dB comparison stimulus and in the data of KT for the 86 dB comparison stimulus. The high variability of the inter-modality data could easily have masked small effects in this condition or could have caused the deviations of the single points just mentioned. The cross-modality matching data for the light-adapted condition (Figures 5–7) show a Broca-Sulzer effect for BJ with the 97 dB comparison stimulus. The minimum in the curve for KT at 500 msec., which involves displacement of only one point, is probably due to response variability, as it is beyond the range of durations in which the maximum Broca-Sulzer effect occurs. The clear hump in the curve for BJ is most likely an appearance of the Broca-Sulzer effect.

The results of the brightness-matching conditions show a clear Broca-Sulzer effect for the 1000 mL. comparison stimulus in both the light-adapted condition (Figures 8–11) and in the dark-adapted condition (Figures 12–14).

The Broca-Sulzer effect is unequivocally present only at the highest comparison stimulus level in all instances. The minima of curves, indicating a Broca-Sulzer effect, appear in every case at the 50 and 100 msec. durations. Subject KT consistently shows less effect than the other subjects, but this does not seem to be due to her data being more variable than that of the other subjects.

The data of the cross-modality matching conditions of this experiment indicate a Broca-Sulzer effect for one subject with the effect clearly attenuated in the dark-adapted condition. This finding is in disagreement with a previous study using cross-modality matching[8] in which no Broca-Sulzer effect was obtained. The conditions of the previous experiment were similar to the dark-adapted inter-modality matching condition of the current study and included the same luminances. It appears that the earlier failure to obtain the Broca-Sulzer effect may be due to the inherently greater variability of cross-modality matching data and possible attenuation of the Broca-Sulzer effect in the dark-adapted eye, this attenuation having previously been noted by Baumgardt.[10]

The current experiment does confirm the appearance of the Broca-Sulzer effect with brightness measurements not involving a visual comparison stimulus, in agreement with the studies of Raab[5] and of Stevens and Hall.[6] Unlike the inter-modality matching condition of the current study, the Broca-Sulzer effect appeared in the latter two studies with dark-adapted observers. An interaction between adaptive state and method of measuring perceived brightness in the determination of the Broca-Sulzer effect may be indicated.

The intra-modality matching data in the dark-adapted condition of the current experiment do not show significant attenuation of the Broca-Sulzer effect. The latter finding is in agreement with Aiba and Stevens[11] who presented stimuli under dark adaptation and at luminance levels above and below the range of the present study.

There is even a slight tendency for the effect to be greater with dark adaptation in their study. Baumgardt's method was different in that he used hapaloscopic presentation of stimuli in a brightness matching task. The possibility remains that dark adaptation may have an inhibiting effect as observed in the current study and by Baumgardt when comparison stimuli and test stimuli are not presented to the same eye in a brightness matching task, or if a method of measuring brightness is used which does not involve a visual comparison stimulus.

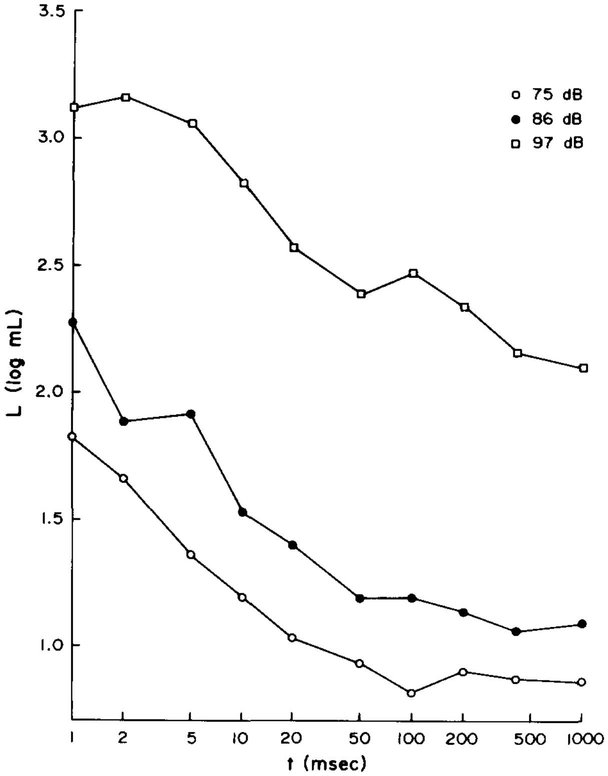

FIGURE 1. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration for Subject BB in the dark-adapted condition. Each mean represents 44 matches.

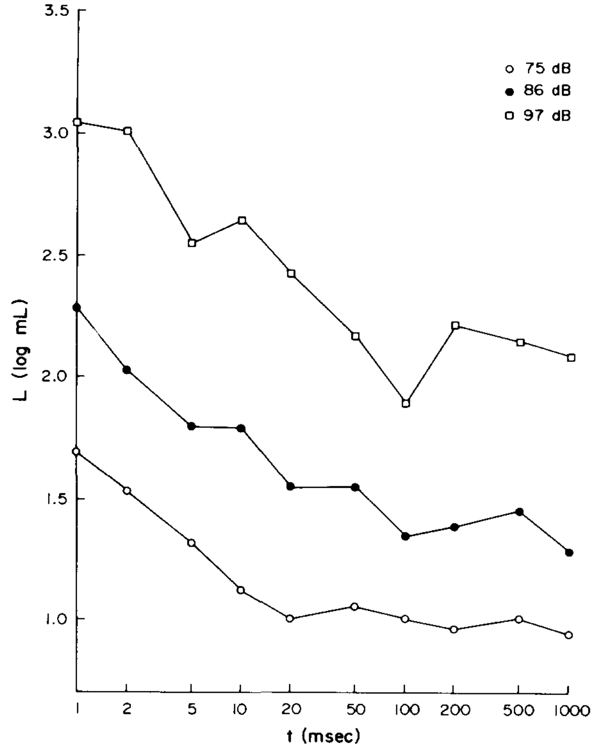

FIGURE 2. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration for Subject BJ in the dark-adapted condition. Each mean represents 48 matches.

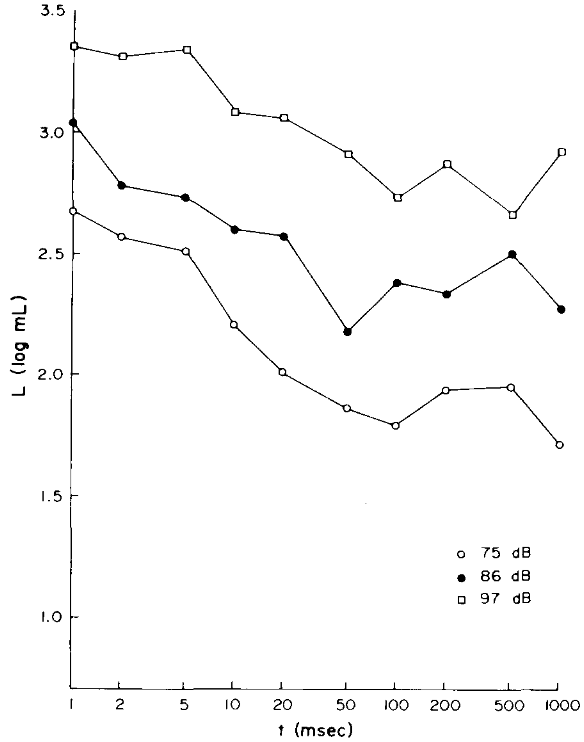

FIGURE 3. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration for Subject KT in the dark-adapted condition. Each mean represents 58 matches.

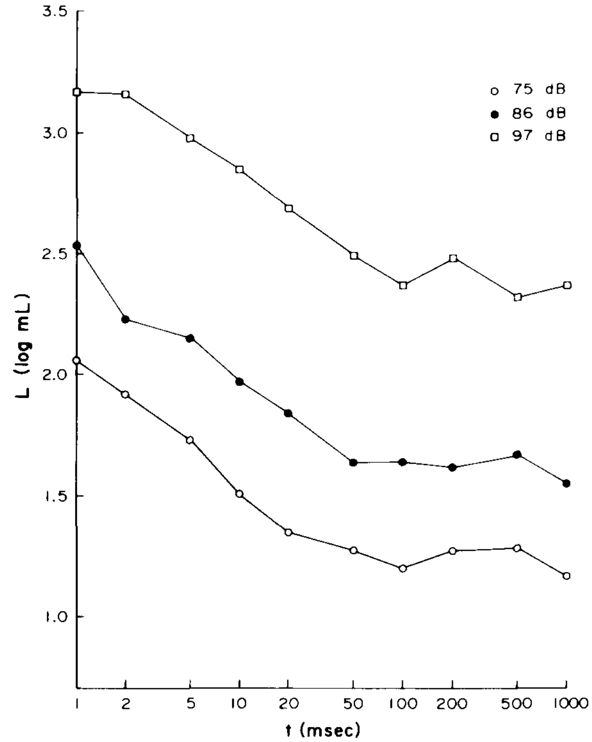

FIGURE 4. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration. Data of the three subjects are combined.

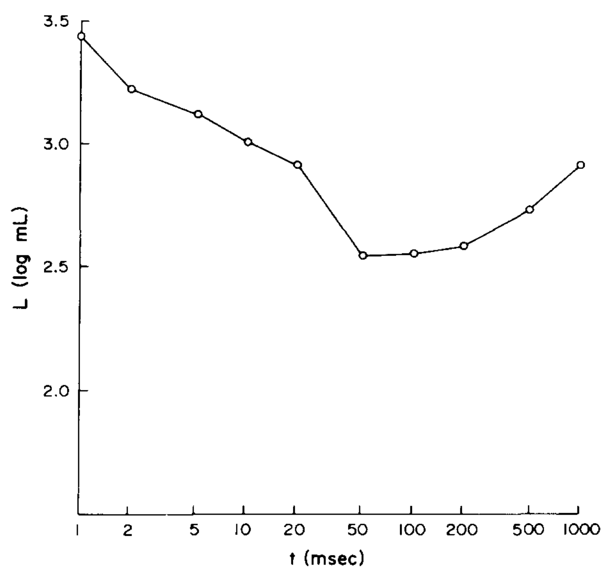

FIGURE 5. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration for Subject BJ in the light-adapted condition. Each mean represents 28 matches.

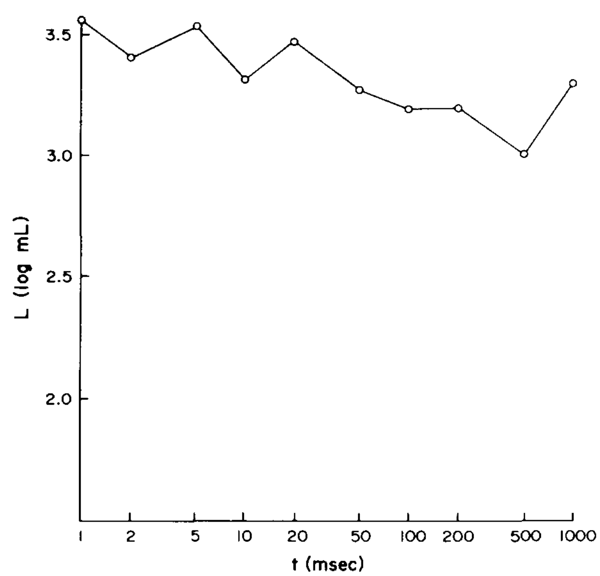

FIGURE 6. Mean test flash luminance required for intermodality matches to three comparison stimulus loudnesses as a function of test stimulus duration for Subject KT in the light-adapted condition. Each mean represents 24 matches.

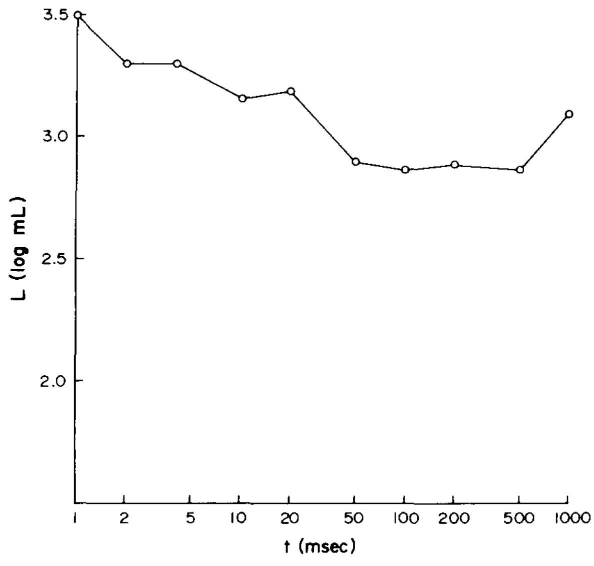

FIGURE 7. Mean test flash luminance required for inter-modality matches to three comparison stimulus loudnesses as a function of test stimulus duration. Data of both subjects in the light-adapted condition are combined.

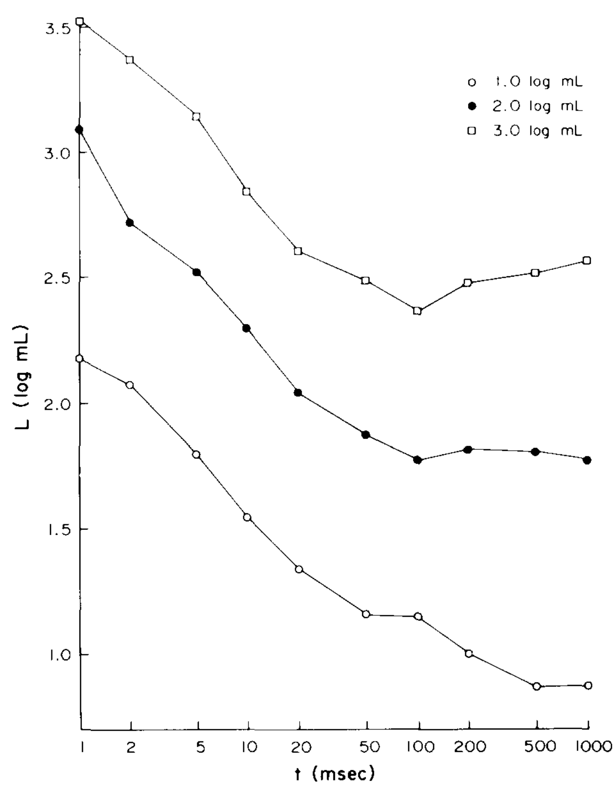

FIGURE 8. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration for Subject BB in the dark-adapted condition. Each mean represents 44 matches.

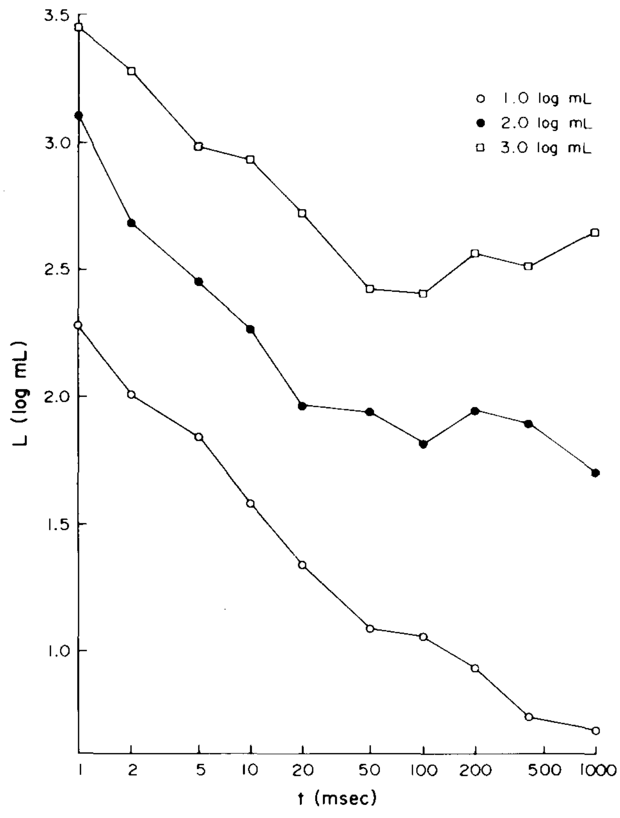

FIGURE 9. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration for Subject BJ in the dark-adapted condition. Each mean represents 48 matches.

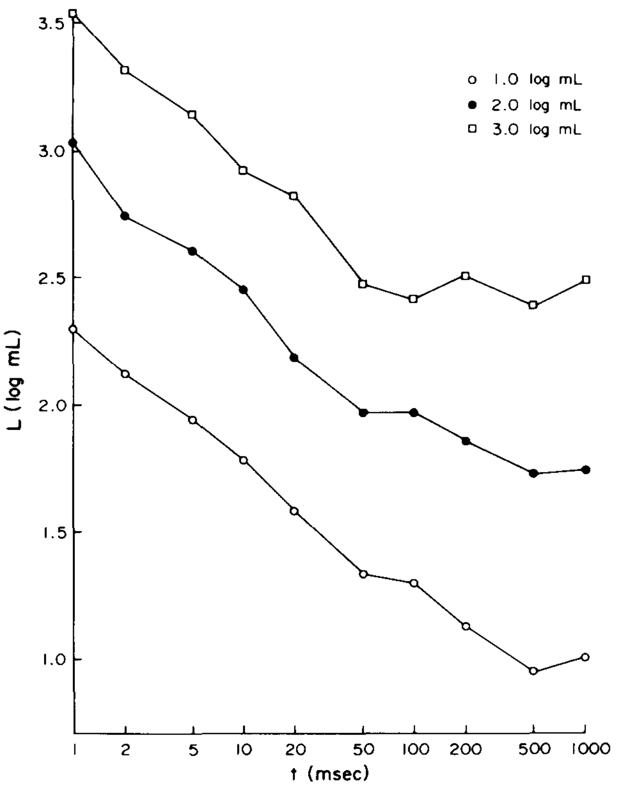

FIGURE 10. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration for Subject KT in the dark-adapted condition. Each mean represents 58 matches.

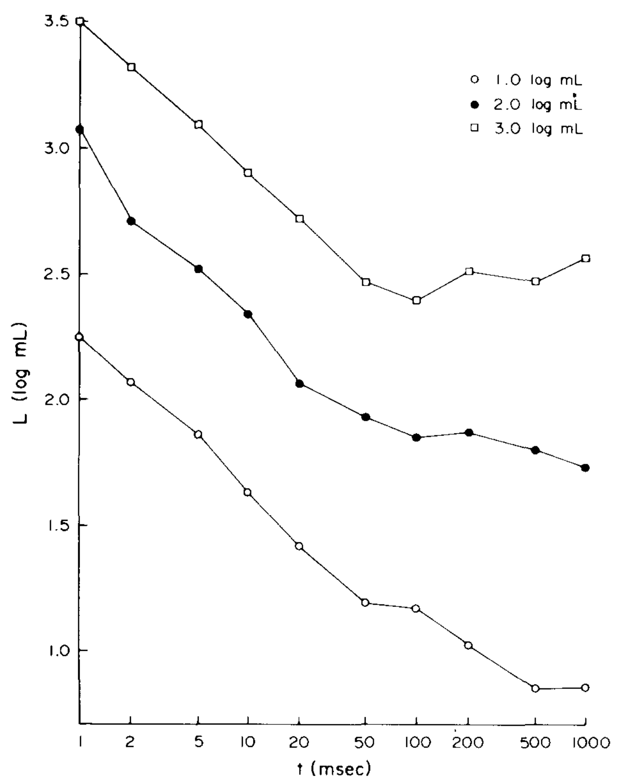

FIGURE 11. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration. Data of the three subjects in the dark-adapted condition are combined.

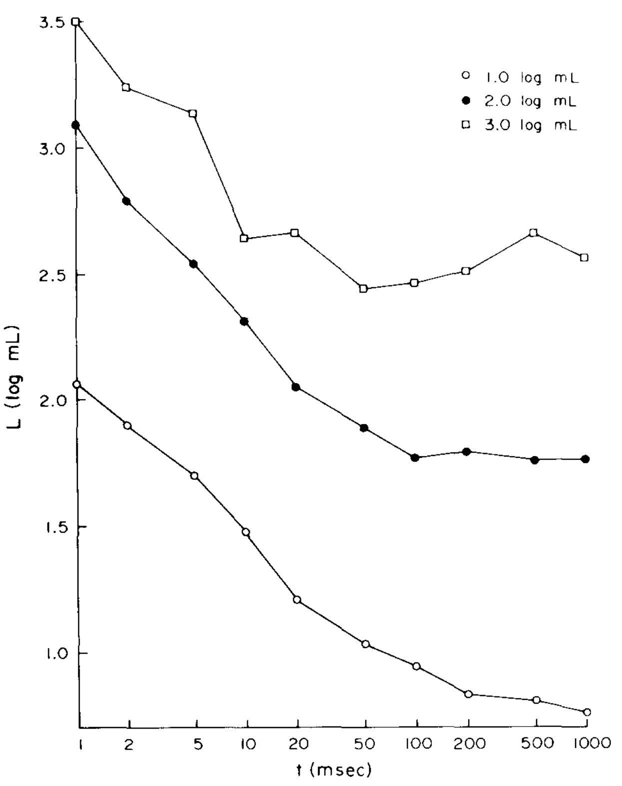

FIGURE 12. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration for Subject BJ in the light-adapted condition. Each mean represents 28 matches.

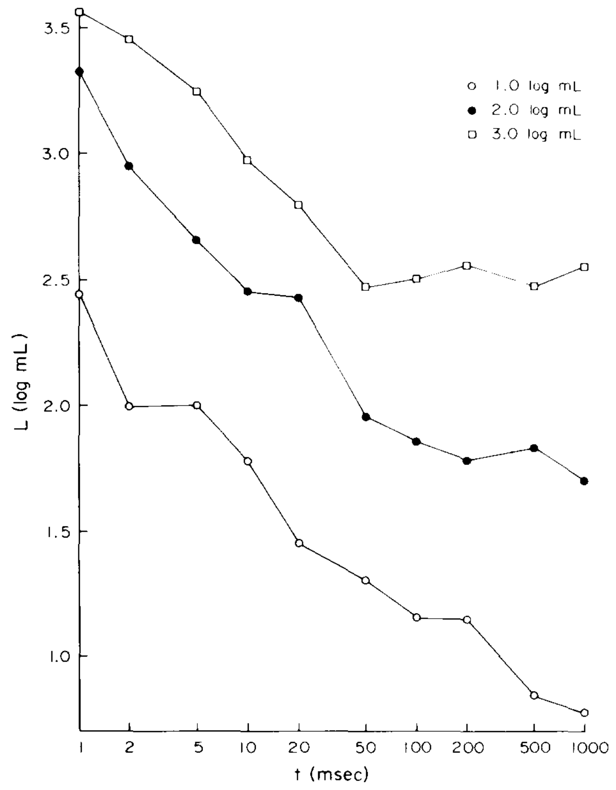

FIGURE 13. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration for Subject KT in the light-adapted condition. Each mean represents 24 matches.

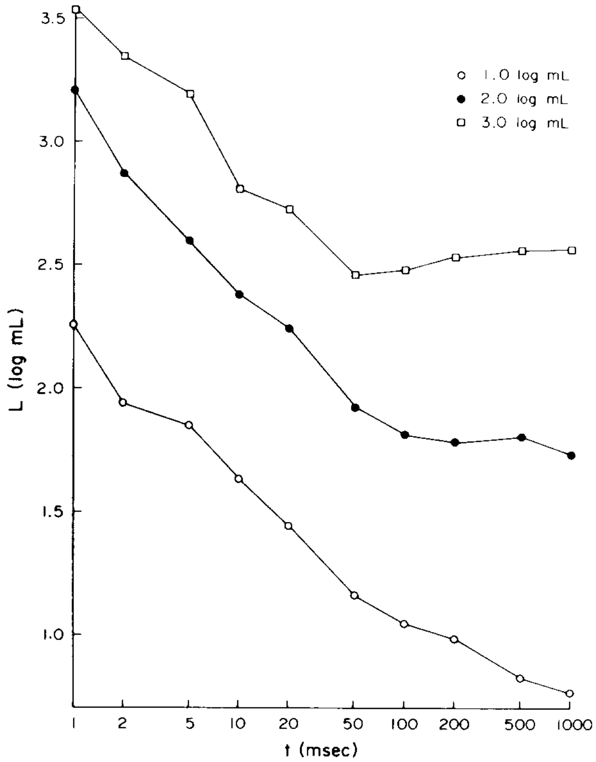

FIGURE 14. Mean test flash luminance required for an intra-modality match to three comparison stimulus brightnesses as a function of test stimulus duration. Data of both subjects in the light-adapted condition are combined.

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