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CROSS-MODALITY MATCHING OF LOUDNESS TO BRIGHTNESS FOR FLASHES OF VARYING LUMINANCE AND DURATION

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CROSS-MODALITY MATCHING OF LOUDNESS TO BRIGHTNESS FOR FLASHES OF VARYING LUMINANCE AND DURATION

I. The Problem.

The current study is directed to 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. At threshold the effect of flash duration is well known: threshold for detection of light flashes is a function of flash energy [the product of flash luminance (L) and duration (t)] for all flash durations below some critical duration. This relation is known as Bloch's law. At durations exceeding the critical duration, the threshold for detection is a function of luminance. The aim of this study is to establish the effective brightness of flashes *above* the threshold for detection.

A large number of experiments have been devoted to the Broca-Sulzer effect, a phenomenon in which the apparent brightness of a light flash of suprathreshold luminance does not increase monotonically with duration, but rather passes through a maximum and then decreases to a steady-state value. The effect has been described by Stevens[1,2] as a 2-dB hump that occurs between 30 and 300 msec., the duration at which the maximum brightness is reached tending to decrease systematically as flash luminance is increased. Typically, the effect is measured by having subjects adjust the luminance of a fixed-duration flash to match the brightness of flashes of varying duration and fixed luminance, although Katz[3] assessed the phenomenon by having subjects adjust the luminance of flashes of varying duration to match the brightness of a flash of fixed duration and fixed luminance. Aiba and Stevens[4] utilized both procedures in their determination of the effect. In either case the measurement of apparent brightness was accomplished by use of a visual comparison stimulus.

Attempts to obtain brightness functions without use of a visual comparison stimulus have demonstrated that Bloch's law ($Lt=C$) holds (for constant brightness criteria) for all stimulus durations less than some critical duration, t_c; when the duration of the stimulus exceeds the critical duration, brightness is determined solely by luminance.[5,6,7] In a study by Raab, Fehrer, and Hershenson[8] three subjects made brightness estimates to flashes of constant luminance and varying duration; no Broca-Sulzer effect was obtained. The authors hypothesized that Broca-Sulzer maxima may occur only when a visual comparison stimulus is presented along with the test flash instead of being a sole function of flash duration. Of subsequent studies, the results of one[6] were interpreted as supporting this hypothesis, while the results of two others[5,7] were interpreted as providing evidence for Broca-Sulzer maxima in the absence of a comparison stimulus. These studies, discussed elsewhere,[9] used variations of brightness estimation techniques and their results regarding the Broca-Sulzer phenomenon are not unequivocal.

The current study attempts to determine the brightness function using cross-modality matching in which the intensity of an acoustic signal is adjusted until the subject reports that the tone is as "loud" as the flash is "bright." In other words, the subjective brightness of light flashes for observers in night flying conditions is evaluated without the contaminating effects (usually present in laboratory investigations) introduced by having observers make judgments against comparison lights.

II. Method.

A. *Subjects.* Subjects were female student-wives between 21–26 years of age. Both subjects were examined and found to be emmetropes with no color vision defects. Both were paid an hourly wage.

B. *Apparatus.* An optical system was set up to deliver a 0.5° stimulus to the fovea by

Maxwellian view. 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 (Optics Technology & Bausch and Lomb) that were used to control stimulus intensity, a field stop, and a beam-splitter. The subject fixated four red fixation lines through a 2-mm. artificial pupil. Head position was controlled by a chin and forehead rest. Intensity of the fixation lines was controlled by the subject with a rheostat. The glow modulator tube was driven by an Iconix Light Driver; flash durations were controlled by an Iconix 6257 timebase with preset controllers (Iconix 6010) and associated logic. Flashes were monitored by an RCA 1P39 phototube. Temporal characteristics of the waveform of the light flashes showed that, at the current level used (40mA.), rise-time was less than 15 μsec. and decay time less than 25 μsec. Luminance calibrations were made with a S.E.I. exposure photometer by a method described earlier.[6]

Acoustic stimuli were generated by a Krohn-Hite Oscillator (Model 440) and delivered monaurally through a Western Electric headset (#1002F). Voltage through the headset was continuously monitored on a Tektronix type 535A oscilloscope.

C. *Procedure.* Each session was preceded by ten minutes dark-adaptation. The subject was then required to adjust the intensity of the fixation lines, using the rheostat, until the fixation lines were just visible. The experimenter then read the following instructions to the subject:

"When you hear the ready signal, sight through the tube and fix your gaze on the center of the cross. When ready, press and hold down the switch. Every twenty seconds you will hear a tone and see a flash in the center of the cross. Using the large knob, adjust the intensity of the tone until it is as loud as the flash is bright. Not all the flashes are the same brightness or duration. Try not to allow the flash duration to influence your judgment. When you have achieved a satisfactory match release the switch."

Seventy-eight stimuli were presented, ranging in duration from 2 msec. to 1024 msec., and in luminance from 7.9 mL. to 15,850 mL. On a single trial, the flash presentation occurred every twenty seconds until the subject was satisfied with his match. Flash onset occurred 2 msec. after onset of a two-second presentation of the 1000-Hz comparison tone. For subject GW each stimulus was presented twice in each two-hour session in random order; for subject MC, who took longer to complete matches, each stimulus was presented once in each session. Thus a total of 18 matches was obtained for each stimulus from each subject. Each subject was given three practice sessions before the data reported were collected.

III. Results and Discussion.

Figure 1 shows for each subject the Sound Pressure Level of the 1000-Hz tone that matched each flash as a function of flash duration with luminance as the parameter. The ordinate is the geometric mean (dB average) of 18 matches for each flash. At each luminance level, the intensity of the matching tone is an increasing, negatively accelerated function of flash duration. In some of the functions (from subject GW) there are inversions, but these appear to be unsystematic. No evidence of Broca-Sulzer maxima is seen.

Figure 2 shows the same data plotted with points connecting equal energy stimuli. The horizontal functions indicate agreement with Bloch's law. No deviations from Bloch's law that would be consistent with the Broca-Sulzer effect are seen. The descending branches of the functions represent the loss of duration effects beyond the critical duration. For subject MC there appear to be duration effects well beyond the region where the critical duration should be. Similar effects have been observed with one subject using category judgments.[6]

Figure 3 shows the same data replotted with luminance on the abscissa and duration as the parameter (for subject GW). Many of these functions (for subject GW) appear to be linear to a first approximation; but (for subject MC) there is a tendency for some of them to appear negatively accelerated.

The functions of Figure 3 were used to generate a family of constant-response functions that relate flash energy to flash duration. Several horizontal cuts were made through the functions of Figure 3. The log Lt (in msec.-mL.) marked by the intersections were plotted in Figure 4 as functions of log t, and straight-line segments were fitted to the points by the method of averages.

The functions in Figure 4 indicate agreement with Bloch's law: Brightness is determined by flash energy up to the critical duration; for flashes longer than the critical duration, brightness is determined by flash luminance. This result is in agreement with previous studies.[4,5,6,7] In addition, the functions of Figure 4 indicate a change in the critical duration for Bloch's law: As stimulus luminance increases, t_c decreases. The extent of the change in t_c is small when compared with the results of J. C. Stevens & Hall,[7] but the current result is not in disagreement with the results of other studies where a change is reported.[4,5] In one previous study[6] no reliable change in t_c was detected.

Finally, the contours of Figure 4 show no deviations consistent with the Broca-Sulzer effect. This result is in conflict with the interpretive findings of Raab[5] and of J. C. Stevens & Hall,[7] but agrees with the previous findings of Lewis[6] and of Raab, Fehrer and Hershenson.[8] The result is consistent with the hypothesis that the Broca-Sulzer effect occurs only when a visual comparison stimulus is present.

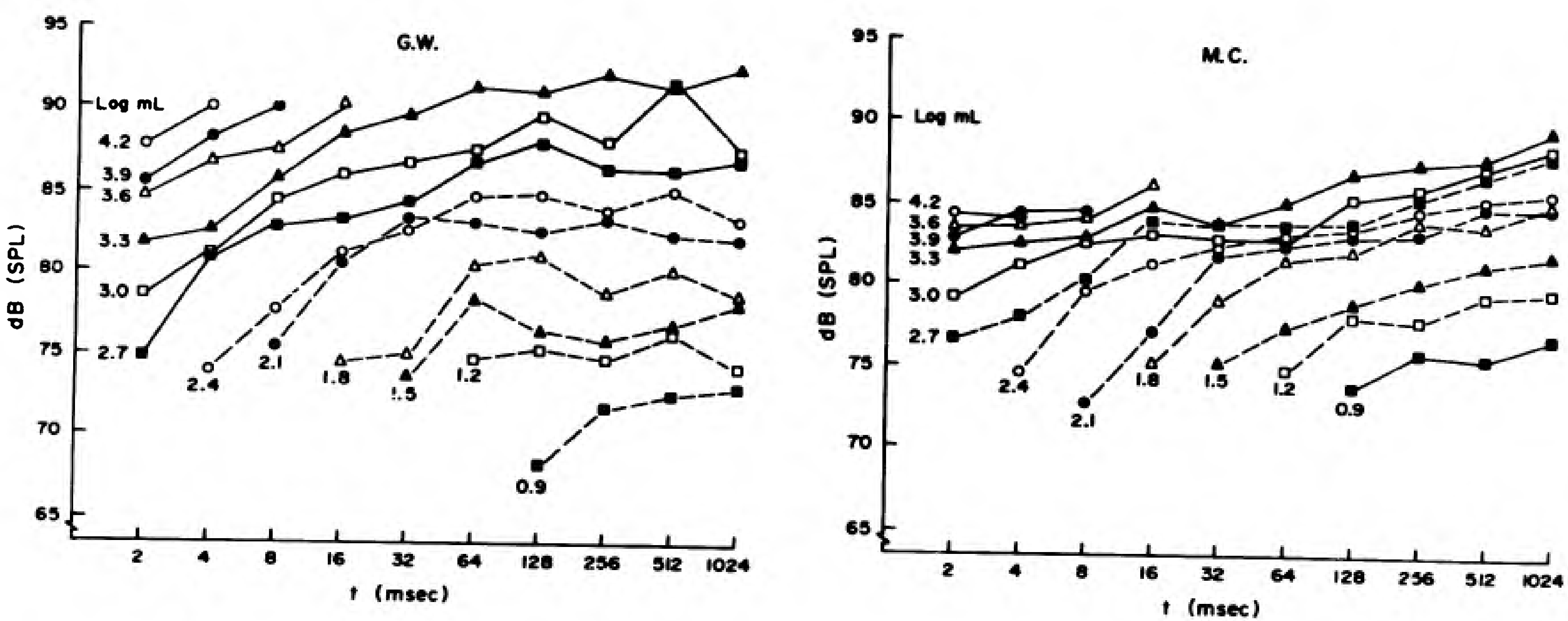

FIGURE 1. Geometric mean intensity (dB average) of matching 1000-Hz tone as a function of flash duration at twelve luminance levels. Data on the left are from subject G. W.; those on the right are from subject M. C.

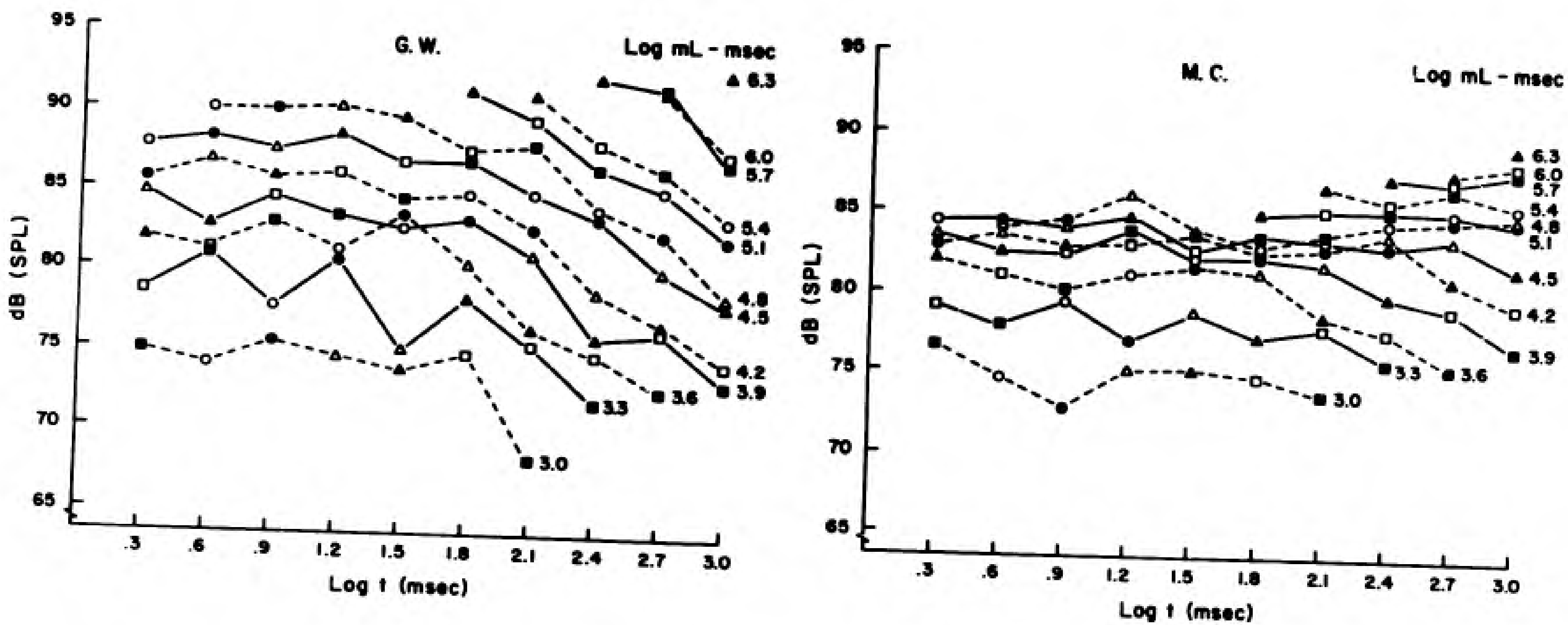

FIGURE 2. Geometric mean intensity (dB average) of matching 1000-Hz tone as a function of flash duration at 11 energy levels. Data on the left are from subject G. W.; those on the right are from subject M. C.

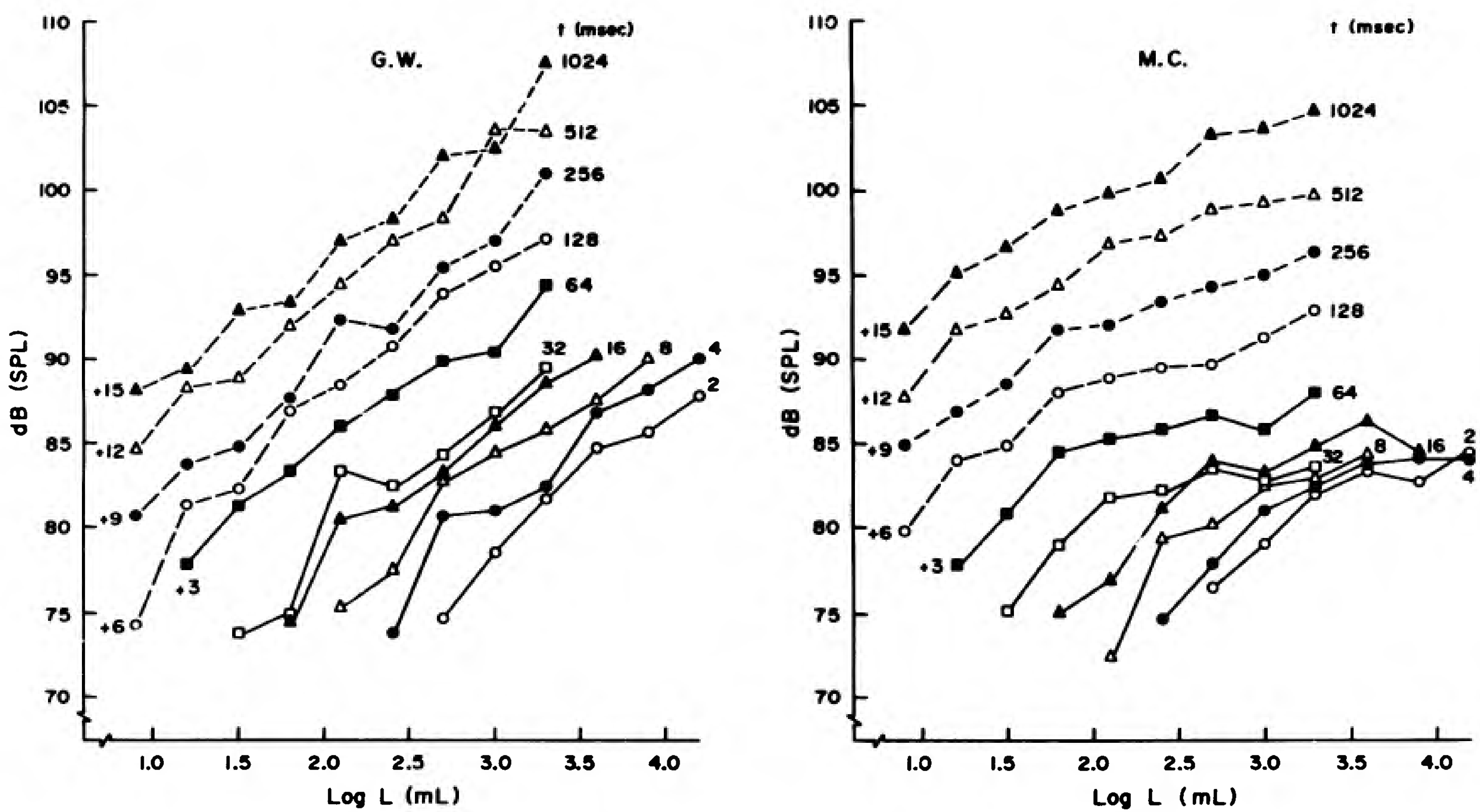

FIGURE 3. Geometric mean intensity (dB average) of matching 1000-Hz tone as a function of flash luminance at ten durations. Data on the left are from subject G. W.; those on the right are from subject M. C. For greater clarity, functions for durations 64–1024 msec. have been shifted along the ordinate by amounts indicated to the left of the functions.

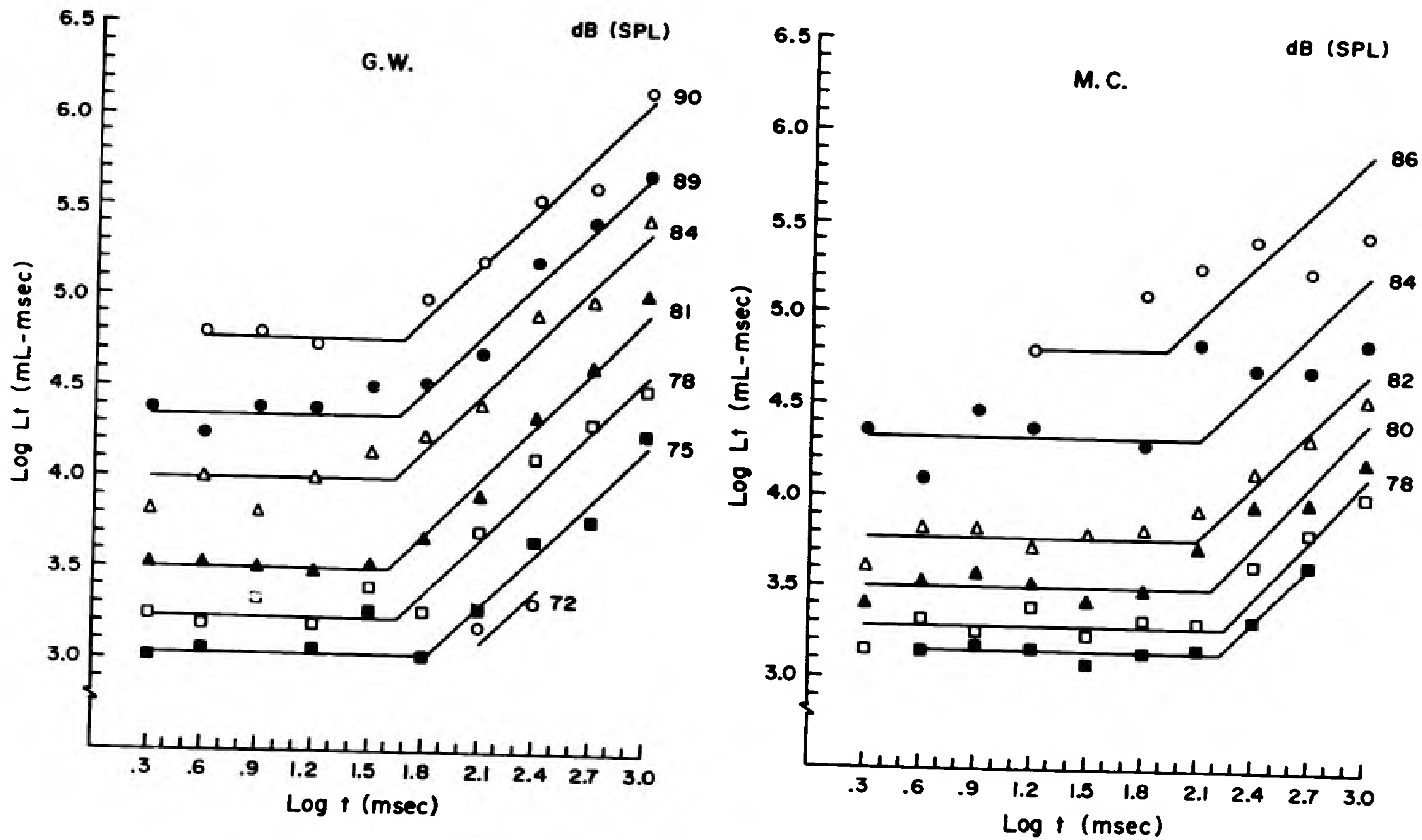

FIGURE 4. Equal-brightness functions relating flash energy (log mL.-msec.) to flash duration (log msec.). Data on the left are from subject G. W.; those on the right are from subject M. C. The points were obtained by making horizontal cuts through the functions of Figure 3 at the intensity levels of the matching tone indicated above by the parameter.

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