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THE BROCA-SULZER EFFECT IN A GANZFELD

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Abstract—Observers judged the brightness of an infinitely large, contourless field of view (Ganzfeld) illuminated by constant luminance flashes of various durations. A Broca-Sulzer effect was found: 50 msec flashes were judged 30–40% brighter than 500 msec flashes of equal luminance. In a second experiment, the same observers demonstrated a Broca-Sulzer effect in estimating the overall brightness of grating targets. The Ganzfeld results show that neither stimulus contours nor edge effects generated by eye movements are necessary for the Broca-Sulzer effect.

INTRODUCTION

The Broca-Sulzer effect, also known as temporal brightness enhancement, occurs when a light flash of some intermediate duration is perceived to be significantly brighter than either a shorter or longer flash of the same luminance. For example, a flashing beacon light generally appears noticeably brighter than it would if viewed continuously. The effect manifests itself as an overshoot in the brightness-duration curve measured for a target of fixed luminance. In general, such curves rise monotonically at short stimulus durations, reach a peak at an intermediate duration (usually between 50 and 200 msec), and then fall to a lower plateau value for all longer durations.

The Broca-Sulzer effect has been known since 1902. Since then, a remarkably diverse collection of explanations of the effect, many of them mutually contradictory, has been formulated. The following sorts of processes have been postulated to account for the Broca-Sulzer effect: photochemical bleaching (Broca and Sulzer, 1903), statistical neural refractoriness (Bartley, 1969), neural on-responses (Boynton and Kandel, 1957), and backward masking (Raab, 1963). More recently, Arend (1971, 1973) has postulated that the Broca-Sulzer effect is mediated by involuntary eye movements occurring during relatively long stimulus flashes. The eye movements give rise to retinal activity near the edges of a target image, and this activity is assumed to act in such a way as to reduce the target's brightness.

The purpose of the present study was to test an implication of Arend's account, by measuring brightness-duration curves for the Ganzfeld. The Ganzfeld is a spatially homogeneous target, produced by flooding the observer's eye with light so that every retinal area receives the same amount of luminous flux. According to Arend's model, no Broca-Sulzer effect would be expected for a Ganzfeld target because it possesses no contours, whereas a relatively large effect should be found for gratings, especially if they have high contrast and high spatial frequency. As it turned out, the Ganzfeld target produced a Broca-Sulzer effect.

METHOD

Apparatus

Ganzfeld targets were presented by rear projection, using a Kodak Carousel slide projector fitted with a Uniblitz 1 in. diameter electronically controlled shutter. Flash durations were varied by the experimenter in discrete steps by means of a Uniblitz Model 310 shutter-control unit.

The Ganzfeld target was produced according to a method first described by Hochberg, Triebel and Seaman (1951), by a hemisected ping-pong ball. The ball was contoured to fit snugly around the orbit of the viewer's right eye. A bead of white putty was pressed around the edge of the ball to exclude light leaks and to prevent discomfort. The ball was fitted into a hole cut in the bottom of a hollow white styrofoam cone[1] and held in place with transparent cement. About $\frac{1}{4}$ in. of the ball protruded from the bottom of the cup, to produce a close fit with the viewer's eye. A translucent flat plastic plate was cemented to the other end of the cone to serve as an additional diffusing surface. The outside surface of the cone was covered with black electrician's tape to exclude possible shadows. Under continuous illumination this Ganzfeld stimulator produced an essentially infinite and uniform field of view, totally devoid of spatial variations of brightness. Normal eye movements produced no perceptible changes in its appearance.

The grating targets were produced by rear-projection onto a ground glass plate. The plane of projection was baffled by black cardboard except for a circular opening subtending 3.6° in diameter. The viewing distance was 1.25 m. The grating transparencies were 2° × 2° glass-mounted slides, calibrated by the manufacturer to yield undistorted sinusoidal luminance distributions.[2] Three spatial frequencies were used: 1.6, 3.2, and 6.4 cycles per degree (c/deg). All three targets had the same physical contrast of 0.50, and the same overall transmissivity. The mean luminance of the unfiltered gratings was 600 ft-L.

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[1] The styrofoam cone was a 6 oz. coffee cup.

[2] The transparency negatives were procured from Dr. C. F. Stromeyer, III. They were mounted by the authors.

Procedure

Flashes of seven durations (5, 10, 20, 50, 100, 200 and 500 msec) were presented in random order. Each session consisted of presenting a specific target a total of three times at each duration and at each of two luminance levels 1 log unit apart. Luminance was controlled by interposing a 1.0 log unit neutral density filter, mounted as a 2 × 2 transparency, in the projector. Without the filter, the luminance of the Ganzfeld target was 500 ft-L. Luminances were measured using a solid state photometer (Tektronix J-16) fitted with a narrow angle luminance probe (J6523).

Brightness judgments were obtained by the method of free magnitude estimation. A standardized instruction message was read to each observer, specifying that he assign a number to each flash in proportion to its perceived overall brightness. No standard flash was shown, nor was any numerical modulus suggested to the observer. Subjects were instructed to respond only to brightness and to disregard possible differences in the perceived duration of the flashes. Furthermore, they were instructed to ignore any spatial inhomogeneity ("blotchiness") in the Ganzfeld target, and to ignore the presence of striations in the grating targets. For the Ganzfeld condition, subjects were instructed to maintain a "straight-ahead" gaze and a relaxed accommodative state ("imagine you are looking far out into the distance"). All observers were able to comply with these somewhat stringent response requirements without apparent difficulty.

Neutral density filters were mounted as slides in the projector. The experimenter manipulated stimulus luminance by operating the slide-changing mechanism with a remote-control switch. Stimulus duration was varied in discrete steps by changing a multiple-position switch on the shutter-control unit. The dark inter-trial interval was approximately 3 sec.

In both grating and Ganzfeld conditions, both luminances and all seven durations were randomized together. This was done independently for each of the four stimulus conditions. Each of the fourteen luminance/duration combinations was presented three times, yielding a total of 42 trials per condition. The first brightness estimate made for each luminance/duration combination was discarded, and the geometric mean of the second and third estimates comprised the raw data for each observer. This procedure, and details of subsequent data analysis, follow the method described by Stevens (1961).

Observers

Twelve volunteer undergraduate psychology students served as observers. All were naive with regard to the purpose of the study, and none were practiced in the magnitude-estimation procedure. Observers who wore corrective glasses removed them in order to view the Ganzfeld target.

RESULTS

Ganzfeld condition

Log brightness estimates were averaged across all observers and are plotted as a function of log stimulus duration in Fig. 1. The upper and lower curves represent the 500 and 50 ft-L stimulus luminance conditions, respectively. Variability is indicated by vertical error-bars representing 1 standard error above and below each data point. Standard errors were calculated from the logarithms of the individual observer's estimates (mean of two individual judgments), after correcting for between-subject differences in numerical moduli. This was done by adding or subtracting a constant from each observer's score to compensate for the difference between the average of all his scores in a given experimental condition and the grand mean over all observers for that target condition. Since there was no systematic change in data variability across target duration, luminance level, or spatial frequency, overall variability can be estimated by averaging across these variables. The average standard error was 0.038 log units (approximately 9%) indicating that, for the Ganzfeld, the obtained Broca–Sulzer effects are statistically reliable.

Grating condition

Figure 2 is a complete display of data for the grating targets, plotted as log brightness vs log duration curves. Plotted brightness responses are averaged over all twelve observers. The two curves at each spatial frequency are based on measurements made within a single experimental session. Each curve represents the brightness responses to a grating of constant space-averaged luminance: 600 ft-L for the upper curves and 60 ft-L for the lower curves. Note that the pairs of curves are not parallel, but tend to be further apart at short target durations than at long ones. All six curves vary non-monotonically with respect to target duration, indicating a Broca–Sulzer effect at all three spatial frequencies and at both luminance levels. There is no systematic change in the overall shapes of the curves with respect to spatial frequency, but the location of the peak brightness re-

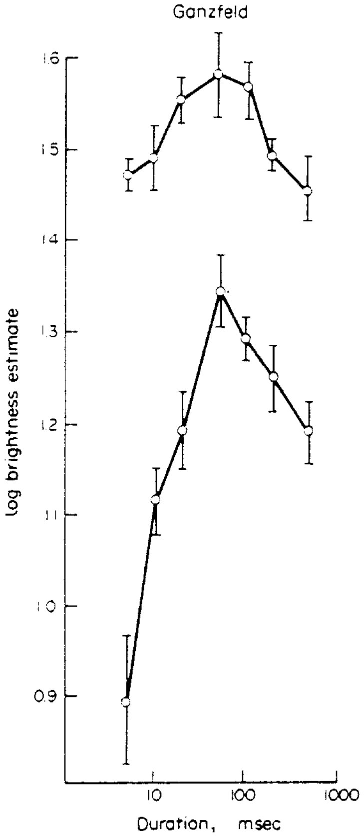

Fig. 1. Log brightness estimates for Ganzfeld target, as a function of log target duration, in msec. The upper and lower curves represent 500 and 50 ft-L stimulus luminances, respectively. Error bars represent 2 standard errors. Enhancement ratios for the Ganzfeld curves are 1.43 for the upper curve and 1.33 for the lower curve.

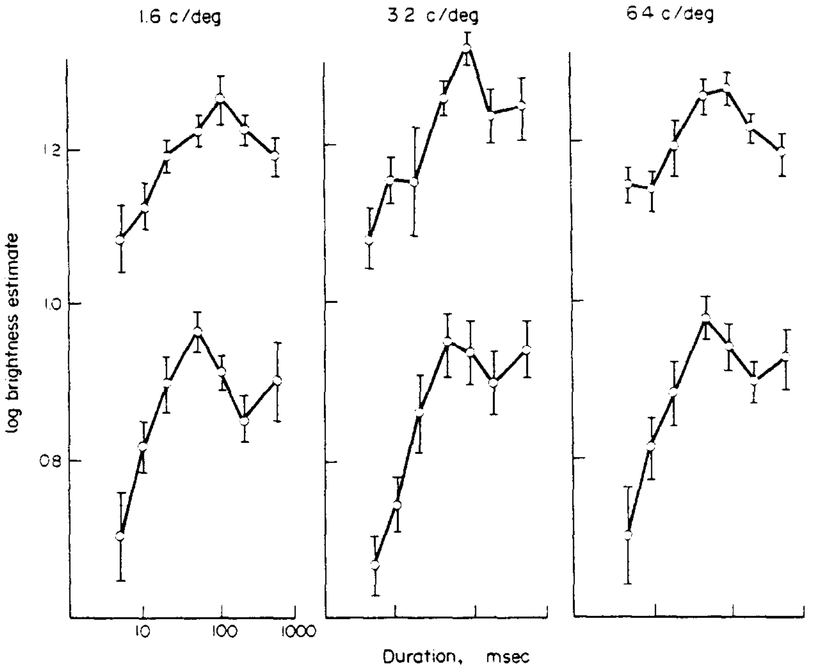

Fig. 2. Log brightness estimates (average of 12 observers) for grating targets, as a function of log target duration in msec. The upper and lower curves represent 600 and 60 ft-L space-averaged stimulus luminances, respectively. Vertical bars represent 2 standard errors, calculated from corrected brightness responses after adjustment for individual variations in moduli. Enhancement ratios for all six curves are approximately 1.2. Each pair of curves was obtained in a single experimental session.

sponse shifts with respect to luminance level: the peak occurs at 50 msec for the lower luminance level and at 100 msec for the higher luminance level.[3] The median standard error is 0.025 log units, or 8%.

The magnitude of the enhancement effect may be specified by calculating the ratio of the maximal response to the response in the plateau region. This was done in the present study by taking the antilog of the difference between tha maximal log brightness response obtained and the smallest log brightness response which occurs for any duration longer than that corresponding to the maximum. Since all responses are expressed as log average brightness estimates, the antilog of this difference yields an enhancement ratio.

All six curves have approximately equal enhancement ratios, with a value of 1.2. There is a tendency for the curves, especially at the lower luminance level, to turn upward at the longest target duration (500 msec). This effect, which was not found for the Ganzfeld target condition, may be related to eye movements. Similar effects are seen in the magnitude-estimation measurements of Raab (1961), who used homogeneous patches of small area as targets.

DISCUSSION

Prior to the present study, the Broca–Sulzer effect has always been measured using homogeneous patches of light presented against a dark or dim background. In the present study, a clear Broca–Sulzer effect was found for a contourless target. This result conflicts with Arend's (1971) findings that the Broca–Sulzer effect exhibited by a sharply focused 1.5° diameter circular test field was abolished when the field was defocused by +3 diopters. It is possible that Arend's results were affected by the difficulty of his dichoptic brightness-matching task. In his sharp-focus condition, the fact that the task was maximally easy when the test and comparison flashes had approximately equal durations may have elevated the brightness match values for durations near 200 msec. And, in the blurred condition, with its added potential for retinal rivalry and other difficulties, it is possible that any Broca–Sulzer effect which may have been present was obscured by high response variability.

The present results indicate that inhibitory activity associated with stimulus contours is not required for the Broca–Sulzer effect. Nevertheless, it seems premature to reject models of the effect which postulate a simpler form of lateral-inhibitory activity. Such activity, generated within the stimulus area, would take some time to become effective. Hence short flashes would escape inhibition, whereas responses to longer flashes would be reduced.

Barlow and Verrillo (1976) measured brightness in a Ganzfeld using a magnitude-estimation procedure similar to that used in the present study. They used

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[3] Each of twelve observers produced three brightness–duration curves, one at 600 ft-L and one at 60 ft-L. Of these 36 pairs, the maximal brightness response for the 600 ft-L curve occurred at a longer stimulus duration than did the maximal response for the 60 ft-L curve in fifteen cases. There were five reversals and sixteen ties. A sign test indicates that the peak shift is statistically significant ($P = 0.042$, two tailed).

only three target durations (10 msec, 1 sec, and 5 sec), and found no significant differences among the brightness estimates given to the three target durations. They concluded that "Flash duration has no significant effect on the brightness estimates of Ganzfeld stimuli". The results of the present study demonstrate that this conclusion is not true in general. The present results show some temporal brightness summation up to at least 50 msec, as well as a significant Broca–Sulzer effect, for Ganzfeld stimuli.

For the grating targets, the magnitude of the Broca–Sulzer effect was found to be independent of spatial frequency. The failure to find the expected dependency on spatial frequency may have been due to the narrow range of spatial frequencies used (1.6–6.4 c/deg) or to insensitivity of the magnitude estimation method. Another explanation, however, may lie in the method of stimulus presentation. Gratings were flashed against a dark background. Each grating presentation was therefore accompanied by a transient change in mean luminance. If the temporal brightness enhancement were due primarily to the mean luminance component, then the overshoot would be the same for all gratings, as in fact was the case. This explanation is supported by a more recent experiment (Kitterle and Corwin, 1977) in which gratings were flashed without changing mean luminance. In this experiment the overshoot was indeed greater for lower spatial frequency gratings. However, observers in this study were asked to judge contrast rather than brightness, and so differences in instructions may have affected the outcome. More recent grating experiments in our laboratory suggest that response–duration curves differ in shape according to whether observers are asked to judge the brightness of light bars, dark bars or overall contrast (Corwin, 1978).

The magnitude of the Broca–Sulzer effects found in the present study are in line with those found using conventional (small spot) targets. Raab (1961) was the first to demonstrate a Broca–Sulzer effect using a magnitude-estimation procedure. At luminances comparable to those of the present study, Raab found an enhancement ratio of 1.17 with a maximal brightness response for a 50 msec target duration. These values agree well with the data of Fig. 1 and 2. A similar magnitude-estimation study by Mansfield (1973) also found peak brightness responses at 50 msec durations; he found an enhancement ratio of 1.78 for targets of 40 mL luminance.

The Ganzfeld may be a particularly advantageous stimulus for psychophysical measurements of other temporal effects as well (e.g. flicker, masking, and successive contrast effects), especially for relatively high stimulus intensities. Global changes in luminance may produce a briefer and sharper temporal response than would a merely local luminance change. When a stimulus of limited area is presented, receptors within the target image are stimulated strongly, and those outside the image are stimulated weakly by scattered light. The latter produce relatively small, long-latency responses, which can contaminate the first, direct response to the target. This process renders electroretinographic responses to small-area targets more difficult to interpret than Ganzfeld responses (Gouras, 1970). Use of the Ganzfeld in conjunction with a magnitude-estimation procedure may prove to have similar advantages for psychophysical measurements of temporal variables.

CONCLUSIONS

The present study applied the technique of magnitude-estimation in measuring the brightness/duration relationship for two unconventional types of target: one with no spatial features (the Ganzfeld), and one with considerable spatial complexity (the gratings). Subjects were able to produce reliable brightness estimates for both grating and Ganzfeld stimuli. Temporal brightness enhancement was demonstrated for both target types. In the case of the Ganzfeld, this result rules out all theoretical accounts of the enhancement phenomenon which postulate the necessity for stimulus contours, contrast, or spatial features.

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