Spatio-temporal interaction and brightness judgments in sequentially presented, partially overlapping rectangles*

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Ss made magnitude estimates of brightness to three areas within a display consisting of two sequentially presented partially overlapping rectangles of light. The three areas were the singly stimulated region of the rectangle presented first (the trailing flank), the doubly stimulated overlap region, and the singly stimulated region of the rectangle presented second (the leading flank). The stimuli were presented in right-left or left-right order with stimulus onset asynchronies (SOAs) of 0, 25, 50, 75, 100, and 125 msec. A further condition was flank width. The results indicated that the apparent brightness of the overlap region decreased with increasing SOA. The leading flank was judged to increase in apparent brightness, while the trailing flank remained constant.

Brightness at any point in the visual field depends on the relationship among intensities in the field rather than simply upon the absolute intensity of light at that point. Both simultaneous contrast (Heinemann, 1955) and the Mach-band effect (Ratliff, 1965) provide evidence for the importance of spatial relationships between intensity differences within the visual field. Metaccontrast and related effects (Kahneman, 1968) depend upon both spatial and temporal relationships between inputs to the visual system.

Stanley, Finlay, and Bartlett (1971) reported that when two spatially overlapping rectangles of light are presented sequentially, with a stimulus onset asynchrony (SOA) of 25 msec, the resulting percept is of a brighter region in the portion of overlap. This bright portion is flanked by narrow dark bands. With increasing SOA, the region of the display judged brightest shifts location from the position of overlap toward the nonoverlapping section of the rectangle presented second (the leading flank). The area reported darkest also shifts from two bands flanking the overlapped portion to a single dark region involving the whole of the area of overlap.

The authors related this shift in the areas judged brightest and darkest to Békésy's (1960, 1967) ideas on funneling, whereby a "deviation of the sensory magnitude from the distribution of the stimulus may be achieved by a funneling action in which the sensory magnitude of the

weaker section is always depleted in augmenting the stronger section [Békésy, 1960, p. 628]." It was assumed that at longer SOAs, the overlap region became the "weaker section" because of the temporal growth of inhibitory processes associated with the first rectangle, resulting in a funneling of brightness toward the leading section of the second stimulus. This explanation assumes a brightness enhancement in the leading flank as stimulus-onset asynchrony increases. However, the distributions of "brightest" and "darkest" judgments could also be obtained if the brightness of the leading flank remained and the flanking region of the rectangle presented first (the trailing flank) decreased in brightness.

The present study was designed to provide data on changes in relative brightness magnitude of the three display areas as stimulus-onset asynchrony is increased. It was expected that for short SOAs the region of overlap would appear brighter than the two flanking regions which should appear equally bright. It was further expected that as the SOA increased, the apparent brightness of the overlap region would decrease and that of the leading flank would increase.

In the present study, the relative brightness of the three regions was determined by the method of magnitude estimation (Stevens & Galanter, 1957). This method, although not as direct as matching techniques, avoids the complication of a variable stimulus in the test field. Brightness exponents determined for each S were used to transform magnitude estimates made to the three display areas. This was done to achieve a comparability between Ss not inherent in magnitude estimates.

Magnitude estimates used consistently by individual Ss may differ among Ss primarily from differences in the use of numbers in making estimates. Using exponents derived from a closely matching stimulus task, a mapping of subjective magnitude back onto a relative physical scale should be possible. Other transformations have been used to equate the data of individual Ss (Donchin & Lindsay, 1965).

METHOD

Subjects

Eight undergraduates with normal or corrected-to-normal vision served as paid Ss. A Titmus vision tester was used for screening Ss.

Apparatus

A three-channel Scientific Prototype (Model GB) tachistoscope was used. One channel presented a red fixation point (FP), 3 mm in diam, 20 mm below the FP and 20 mm apart, and a modulus 30 mm above the FP, 50 mm long x 8 mm high. The measured luminance of the modulus was 10 cd/m².

To determine each S's exponent for brightness, 30 x 8 mm stimuli were presented 30 mm below the FP. Stimulus intensities were varied with Kodak N.D. filters. The density values used were 0.2, 0.57, 0.72, 0.81, 1.03, 1.17, 1.40, 1.60, and 1.97. The measured luminance with N.D. 1.03 was 10 cd/m². The stimuli were presented for 25 msec. The test stimuli were two pairs of rectangles (60 x 8 mm, 40 x 8 mm) viewed from a distance of 1,050 mm. Spatial overlap for both pairs was 20 mm, with 40-mm flanks for the larger pair and 20-mm flanks for the smaller pair. Between trials, the two lower spots delimited the region of overlap from the flanking regions. The measured luminance of each rectangle was 10 cd/m².

For a given pair of stimuli, the rectangles were presented sequentially with SOAs of 0, 25, 50, 75, 100, and 125 msec. The stimulus duration for each rectangle was held constant at 25 msec.

A further condition was order of presentation. Either the rectangle in the right field was presented first and then the rectangle in the left field (the R-L condition) or the order was reversed (L-R condition).

Viewing for all conditions was binocular.

Procedure

The Ss were tested individually for five 1-h sessions. Two sessions were used to familiarize Ss with the tasks. In the third 1-h session, data were

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Fig. 1. Average transformed magnitude estimates (percent "relative luminance") as a function of stimulus onset asynchrony. The points plotted are means derived from summing scores across Ss, two rectangle widths, and presentation order. The inset shows the stimulus position in relation to the reference and fixation points.

collected for determination of exponents. Ss were instructed to fixate and to make magnitude estimates of the variable stimuli in terms of the modulus. Twenty estimates were made to each luminance value, 180 trials in all.

Magnitude estimates of the apparent brightness of the three areas, the overlap area and the two flanks, were obtained after the eight Ss were randomly assigned to two groups of four. One group viewed stimuli presented from left to right (L-R group) and the other from right to left (R-L group). Each S made 10 estimates for each treatment combination of SOA x flank width x display region. A trial began by E's indicating to which of the three regions of the display the S had to

respond. For all conditions, Ss were tested individually.

Analysis of Data

Brightness exponents for each individual were calculated from a linear regression analysis (Ferguson, 1959). Logarithms of the geometric mean magnitude estimates were plotted against the logarithms of the actual physical intensity. The exponents for brightness for each S were as follows: 0.35, 0.22, 0.75, 0.92, 0.39, 0.23, 0.24, and 0.35.

Using these exponents, magnitude estimates made to the three regions within the overlapping rectangle display were transformed from being data of subjective magnitude into data of relative physical magnitude using the relationship $\psi = k\phi^n$. Stevens's

power law holds that ψ , the subjective magnitude, is a function of the physical magnitude, ϕ , raised to the power n . It can be readily seen that $\phi = c\psi(1/n)$, where c and k are both constant and relate to scaling factors.

Transformations were carried out using calculated exponents, because it has been shown that the value of an exponent varies with the range of stimuli used (Poulton, 1968), the duration of the stimuli (Aiba & Stevens, 1964), and the state of adaptation of the eye (Stevens & Stevens, 1963). Obtaining exponents from a small range of stimuli comparable to that expected in the stimulus situation under identical adaptation and exposure conditions avoids these problems.

To make the scales of relative physical magnitude comparable among Ss (that is, to have the scales for all individuals starting at unity), the transformed estimates for the overlap region for SOA = 0 were arbitrarily selected as the units of the scales. Each S's transformed estimates were divided by the exponentiated geometric mean for the overlap region for SOA = 0. This was done for both 40- and 20-mm flank conditions and L-R, R-L presentation orders for all SOAs for each S. Both the transformed and untransformed data were analyzed, using a split-plot design for one between factor (direction of presentation) and three within factors [length of flanking region, three regions of interest within the display, and SOA (Kirk, 1968)].

RESULTS

The data analysis of the untransformed geometric mean estimates resulted in a significant main effect for region within the display [$F(2,12) = 8.38, p < .01$]. Interaction terms significant were Region of Interest by SOA [$F(10,60) = 14.39, p < .01$] and Region of Interest by SOA by Flank Width [$F(10,60) = 2.57, p < .01$]. The third-order interaction term, Region of Interest by SOA by Flank Width by Direction of Presentation, was also significant [$F(10,60) = 2.18, p < .03$].

Analysis of variance of the exponentiated data resulted in two significant main effects for critical regions within the display [$F(2,12) = 9.28, p < .01$] and SOA [$F(5,30) = 3.23, p < .02$]. The interaction term of Region of Interest by SOA was also significant [$F(10,60) = 31.53, p < .01$].

The trends of the data can be clearly seen in Fig. 1. The graph shows the transformed data plotted against SOA for the three regions of interest. The data points represent means for scores summed across Ss, degrees of

flank, and presentation order. The trends for the unexponentiated data are essentially the same.

Over the range of SOAs used, it is clear that the apparent brightness of trailing flank remains fairly constant. The apparent brightness of the double stimulated overlap region decreases markedly until, at SOAs of 100 and 125 msec, it approximates the brightness of the trailing flank. The leading flank is clearly judged to increase in apparent brightness as SOA increases.

DISCUSSION

The results obtained support the idea that brightness enhancement is occurring in the leading flank region for the longer SOAs.

The apparent brightness of the overlap region, for all SOA values, is predictable from a consideration of temporal luminance summation. That is, at short SOAs, the two stimulations to this region summate, but with increasing SOA, summation is incomplete and the apparent brightness of this region decreases.

When the two stimuli are presented simultaneously (SOA = 0 msec), the stimulus display closely matches the paradigm of simultaneous contrast (Heinemann, 1955). However, when the two stimuli are presented asynchronously, a temporal variable is introduced into the spatial interaction domain.

The increasing apparent brightness

of the flanking region occurs only in the flank appearing simultaneously with the second stimulation to the overlap region. The flank preceding this second stimulation to the overlap region, the trailing flank, does not exhibit any increase in apparent brightness. This is consistent with the idea of a conjoint action of inhibition and excitation, resulting in a funneling of brightness away from the overlap region into the leading flank (Békésy, 1967).

A further enhancement effect involving spatial and temporal factors has recently been reported (Shchadrin & Bongard, 1971). They reported that the apparent brightness of a dim chromatic test field, viewed eccentrically, increases considerably if a brighter annular surround is briefly added. The brightness of the test field increases to approximately that of the surround.

The extent to which these two effects, both demonstrating a lateral facilitation phenomenon, have a common basis is not clear. Before a model can be proposed that will account for these effects, further parameters will need to be investigated.

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