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## CRITICAL DURATION FOR THE RESOLUTION OF FORM: CENTRALLY OR PERIPHERALLY DETERMINED?<sup>1</sup>

DANIEL KAHNEMAN, JOEL NORMAN, AND MICHAEL KUBOVY

*Hebrew University of Jerusalem*

Bloch's law is shown to hold for a visual acuity task with monocular and binocular viewing as well as in a condition where the target was presented to the right and left eyes in immediate succession. The critical duration ( $t_c$ ) in the latter condition was found to be approximately double the  $t_c$  in the other experimental conditions. It is concluded that  $t_c$  for the resolution of form is not determined at a visual station where binocular summation occurs, i.e., a station in the visual cortex. Moreover, the hypothesis that  $t_c$  corresponds to a central "moment" fails to be supported.

Bloch's law is the basic formulation that describes the role of stimulus duration in vision. Many types of visual response have been found to depend only on the total amount of stimulating energy, provided that this energy is delivered within a certain critical duration ( $t_c$ ): a short and intense stimulus produces the same result as one longer and weaker. A question which has not yet been satisfactorily answered is that of the locus at which, and manner in which,  $t_c$  is determined. In view of recent findings this question should be posed separately for the perception of brightness and the perception of form.

It has been shown that temporal integration follows different rules in the resolution of form than in the percep-

tion or discrimination of brightness. On the one hand,  $t_c$  in an acuity task is considerably greater than  $t_c$  for the brightness sensation (Kahneman, 1966; Kahneman & Norman, 1964); and, on the other,  $t_c$  for the resolution of form varies as a U-shaped function of stimulating energy (Kahneman, 1964), while  $t_c$  for brightness decreases monotonically with increasing energy (Graham & Kemp, 1938; Herrick, 1956; Keller, 1941). It seems fairly clear that  $t_c$  for the brightness process should be attributed to peripheral mechanisms: the characteristics of temporal integration in these functions are quite similar to those of the b wave of the ERG (Alpern & Faris, 1956; Biersdorf, 1958). As to the form process, no retinal correlates have been reported. Moreover, Kahneman (1964, 1966) noted that reciprocity sometimes holds in acuity

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performance up to a  $t_0$  of 500 msec. or more. In the light of Hubel and Wiesel's (1962, 1965) finding that form-specific activity in single visual units of the cat first becomes detectable at the cortical level, the suggestion that  $t_0$  for form resolution corresponds to a centrally determined "moment" (Boynton, 1961; Kolars, 1963; Stroud, 1956) appeared quite plausible.

The present experiment utilizes binocular summation in acuity performance to investigate the hypothesis that  $t_0$  for the resolution of form is centrally determined. This design assumes that the enhancement of acuity in binocular viewing is due to cooperation of monocular messages at some central station. An early model of binocular acuity (Bárány, 1946) provides fairly accurate predictions of binocular acuity from monocular performance by assuming that the superiority of binocular acuity is entirely due to probability summation. However, the adequacy of this model has been questioned on logical grounds (Eriksen & Lappin, 1965), while very recent empirical evidence (Campbell & Green, 1965) clearly points to summation effects in excess of what should be expected from probability summation. This is in accord with findings indicating that impulses from the two eyes cooperate in determining the detectability of light (Collier, 1954; Matin, 1962), its apparent brightness (Leibowitz & Walker, 1956), and the detectability of flicker (Peckham & Hart, 1960). This conforms with Hubel and Wiesel's (1962, 1965) observations that about 85% of those cells in the visual cortex which are active in the detection of form manifest binocular synergy.

The following design is used: A Landolt C is briefly presented to the two eyes, either simultaneously or in immediate succession. A number of

settings of intensity and duration are selected all providing the same amount of total flux to each eye. The critical duration ( $t_0$ ) is identified as the duration of exposure (or successive exposures to the two eyes) beyond which performance deteriorates. It is assumed that if  $t_0$  represents a scanning period, or some other characteristic of a central station of the visual system, it should also appear as the upper limit of the capacity to utilize without loss inputs arriving *successively* from the two eyes. Thus, if  $t_0$  for the perception of form is centrally determined, the critical duration obtained for the successive condition should be equal to that obtained for the simultaneous condition.

#### METHOD

*Subjects.*—Three highly experienced Ss participated. The vision of two of these was fully corrected, while the vision of the left eye of the third S (DK) was corrected for spherical aberrations, but not fully corrected for optimal acuity.

*Apparatus.*—The apparatus was designed to present an acuity test target, at predetermined values of intensity and duration, to one or both eyes, simultaneously or in immediate succession. It superimposed two beams of collimated light, which then transilluminated a positive transparency of a Landolt C affixed to a plate of frosted glass which served as a diffusing screen. The target could be presented in four positions by means of a rotating slide holder. The light sources were two Sylvania glow modulator tubes (R1131C), powered and controlled by an Iconix FAST system (Model 6080 Transducer Power and Control; Model 6255 Time Interval Generator/Counter; Model 6010 Preset Controller). The amount of light reaching the screen from each light source was controlled by Ilford neutral density filters. The S's head was immobilized by a bite board 85 cm. from the target. At this viewing distance the Landolt C subtended 25.85' in diameter and 5.17' in critical detail. The illuminated field was circular and subtended 1°20'. Fixation was provided by a square pattern of incandescent wire, subtending 41', which was placed 5 mm. in

front of the screen. Two sets of crossed polaroids ensured that each eye received light from one beam alone. The attenuation of luminance by this cross-polarization was measured at more than 3 log units. Background luminance was determined with a selenium photocell-liquid filter combination possessing a spectral sensitivity curve similar to the photopic response of the human eye.<sup>2</sup> The intensity of each light source was adjusted to a standard level at the beginning of each session by reading the output of a Phillips (90AG) phototube from an oscilloscope.

*Procedure.*—In a preliminary phase of the experiment, a luminance level was selected for each eye of each *S*, to yield a probability of seeing (corrected for chance) of 45–55% with exposure durations of 10 msec. The resulting luminance-duration products (energy levels) were 2.22 m.L. × msec. and 1.56 m.L. × msec., respectively, for the right and left eyes of both *S*s DM and JN. The right and left eyes of the third *S* (DK) required 2.22 m.L. × msec. and 1.96 m.L. × msec., respectively.

Acuity performance was investigated under four conditions: monocular-right, monocular-left, binocular-simultaneous, and binocular-successive (where the right and left eyes are stimulated in immediate succession). For each condition the target was presented 80 times at each of nine settings of duration and luminance. Luminance was adjusted for each duration so as to keep total luminous flux to each eye constant at the value determined in the preliminary phase.

Data for each *S* were collected in four sessions, each lasting about 2½ hr. In each session 20 exposures of the target were presented for each of the nine duration settings in the four viewing conditions. The session began with 15 min. of dark adaptation. The sequence of duration settings was randomly determined for the session and the four viewing conditions were run in immediate succession, in random order. The sequence of gap positions within each series of 20 exposures was also random, with the limitation that each position appeared five times. Following each exposure, *S* was required to report the gap position; he was immediately informed of the correct answer. The 20 stimuli within each series were automatically delivered every 3 sec. A break of at least

15 min. was given after half of the data for each session had been collected.

## RESULTS

Figure 1 shows pooled results for the three *S*s. Data were combined after ascertaining that individual results were essentially identical. Each point in the figure represents the probability of correct identification of gap position (corrected for chance success) for a total of 240 trials. The only exceptions are the 200-msec. duration for the monocular-right, monocular-left, and binocular-simultaneous conditions, and the 400-msec. duration for the binocular-successive condition: No data were obtained for DK at these durations, and his expected performance was interpolated from a plot of his data against exposure duration.

The reciprocity relation is indicated by the horizontal segments of the curves in the figure. No consistent deviations from this relation are apparent in any of the curves, and the critical duration is clear-cut in each case. The critical durations are 125 msec. for the monocular-right presentation, and 160 msec. for both the monocular-left and binocular-simultaneous presentations, while perfect temporal summation holds up to 300 msec. in the binocular-successive condition. The monocular critical durations observed here are relatively short for acuity performance, but they are characteristic of the range of energy and acuity investigated in the present study (Kahneman, 1964).

A significant feature of these data is the similarity in the level of acuity performance under conditions of simultaneous and successive binocular stimulation: equal-energy exposures of a Landolt C for durations up to 150 msec. to each eye produce the same level of acuity performance—regardless of whether the eyes are stimulated

<sup>2</sup> We are indebted to D. Pelli and B. Doron of the National Physical Laboratory of Israel for carrying out the photometric measurements.

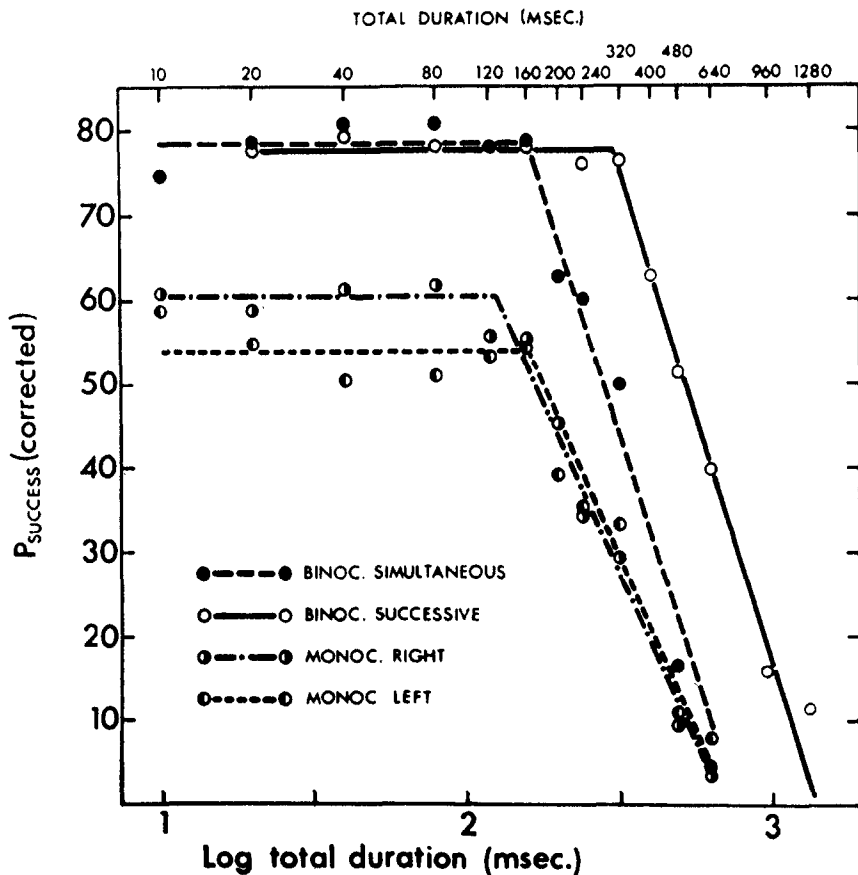


FIG. 1. Probability of identification (corrected for chance success) of the gap in a Landolt C as a function of total duration of equal-energy presentations.

at the same time or in immediate succession.

#### DISCUSSION

With successive presentations, binocular summation is evidently unimpaired over at least 300 msec. This indicates that the structure which is responsible for binocular summation can utilize with complete effectiveness information arriving from the two eyes during this period. Therefore, the deterioration of performance beyond 160 msec. in the monocular and binocular simultaneous conditions cannot be due to limitations of this structure or of any subsequent stage of visual processing. The decrement of simul-

taneous binocular vision for durations exceeding 160 msec. must then be due to the weakening of messages arriving from a more peripheral station along the visual pathway.

These considerations suggest that  $t_o$  for the resolution of form is not determined in the visual cortex, where binocular cooperation appears to be the rule (Hubel & Wiesel, 1962, 1965). Other considerations rule out the primary receptors as the locus where  $t_o$  is determined (Boynton, 1961; Kahneman, 1964, 1966). By elimination, the stations which may determine  $t_o$  for the resolution of form are the bipolar and ganglion cells of the retina, or the lateral geniculate

body, where binocular interaction is probably limited (Bishop, Burke, & Davis, 1959; Erulkar & Fillenz, 1960). The hypothesis that  $t_c$  corresponds to a central "moment" fails to be supported.

An unexpected result of the present study is the finding that binocular summation is the same regardless of whether the target is presented to the two eyes simultaneously or in immediate succession. This is the case in spite of marked differences in the appearance of the target under these two conditions, which are easily discriminable even with relatively short exposures to each eye. The present results suggest that some of the central mechanisms which are involved in the resolution of form have a relatively high capacity for temporal integration. What the limit of their capacity for temporal integration is and whether it corresponds to a psychologically meaningful "moment" remains to be established.

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