VISUAL REACTION TIME AND THE HUMAN ALPHA RHYTHM: THE EFFECTS OF STIMULUS LUMINANCE, AREA, AND DURATION [1]

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Human Ss in a visual reaction-time experiment responded to stimuli of systematically varied luminance, area, and duration. Reaction time, EEG alpha blocking latency, and alpha blocking duration were recorded and measured. The major findings were: (a) Over a range of luminances (0.65–10.0 mL.) and exposure durations (10–200 msec.) constant I × t products result constant blocking latencies; i.e., Bloch's law. (b) Constant products of I × A (Ricco's law) do not lead to constant blocking latencies beyond areas of 1°. (c) Reaction time decreases with increased luminance or area under equal-energy conditions and is independent of duration over the range of t employed. (d) Blocking duration increases with stimulus duration but is unaffected by luminance. (e) Correlations between reaction time and properties of the alpha rhythm are determined, in large part, by stimulus variables.

For stimuli subtending small ($\frac{1}{2}$°–1°) visual angles and lasting approximately 100 msec., the visual threshold is dependent solely upon total energy and is independent of the areal, intensive, and temporal characteristics of the flash. The constant visual effects produced by constant products of intensity × duration ($I \times t$) and intensity × area ($I \times A$) are implicit in the well-known laws of Bloch and Ricco, respectively. For larger extrafoveal stimuli and those of longer durations, the relationships are reciprocal in $\sqrt{t}$ (Pieron's law) and $\sqrt{A}$ (Piper's law). Empirical confirmation of these relationships is found in studies of brightness discrimination (Graham & Kemp, 1938), visual acuity (Graham & Cook, 1937), threshold detection (Graham, Brown, & Mote, 1939), infrahuman (*Limulus*) optic fiber discharges (Hartline, 1934), and human electroretinographic records (Johnson & Bartlett, 1956). To this extent, these reciprocal relationships and the ranges over which they persist appear to describe fundamental properties of visual information processing. As such, they provide a meaningful context for studies of the cerebral alpha rhythm (50–100 μv., 8–13 cps) which, since Berger's pioneering studies, has received considerable attention within the context of visual function. Emphasis upon visual aspects derives principally from (a) the relative ineffectiveness of nonphotic stimuli in altering the alpha rhythm (Berger, 1929), (b) the nonhabituating nature of the alpha response to light (Adrian & Matthews, 1934), and (c) reported relations between properties of the alpha response and parameters of the visual stimulus (Cruikshank, 1937). Despite experi-

mental support of a vision-specific interpretation of alpha function, other research suggests diffuse or multisensory functions of the alpha rhythm primarily because of observed correlations with attitudinal, intellectual, and emotional variables (Ellingson, 1956).

Two studies in the reviewed literature are addressed directly to human alpha rhythm variations in response to flashes of controlled intensity and duration (Cruikshank, 1937; Jasper & Cruikshank, 1936). Neither study investigated areal effects but, to control for them, diffuse light was employed. This may well have reduced the temporal range of reciprocity far below the shortest durations (5 msec.) employed as can be inferred from studies of It reciprocity as a function of area (Graham & Margaria, 1935).

The present experiment was undertaken, therefore, to determine the extent to which well-established peripheral relationships in visual information processing are manifested in variations in the human alpha rhythm. Specifically, the research concerns the "blocking" (amplitude reduction and frequency increment) of the alpha rhythm following visual stimulation and the temporal properties (latency and duration) of blocking produced by flashes of different I, t, and A.

In addition to the foregoing, the present research incorporates reaction time as a response indicator because several studies have sought correlations between RT and certain aspects of the alpha rhythm (Callaway, 1961; Lansing, 1957; Stamm, 1952; Walsh, 1952).

METHOD

Subjects.—Two *S*s (W.W. and S.S.), one male, one female, were selected on the basis of strong and reliable EEG activity. The male was a 20-yr.-old college sophomore and the female, a 24-yr.-old graduate student.

Apparatus.—The stimulus source and duration controls were essentially those used by Raab, Fehrer, and Hershenson (1961). Light was provided by a Sylvania R-1131C glow tube placed behind a 1-cm. aperture covered with an opal diffusing plate and mounted in a light-tight chamber. The tube was placed in series with the plate circuit of a 6L6 with a 45-v. battery used to bias the pentode below cut-off. A Tektronix Model-160 waveform generator and Tektronix 225-v. power supply were used to shape the pulses and control their widths to provide flash durations of 10, 20, 40, 50, 100, and 200 msec. Luminance was controlled with Wratten filters and covered a range from 10.0 mL. at the viewing pupil to 1.2 log units below this in 0.3 log-unit steps. With this source, a collimated beam of light was presented by (*a*) collecting the output flash with an achromatic condensing lens (Edmund Scientific No. 6360) of 55-mm. focal length and (*b*) passing the point-focused light through a wide-angle Erfle eyepiece consisting of three coated achromatic lenses yielding a 32-mm. focal length (Edmund Scientific No. 5160). The collimated output illuminated a circular aperture of 4-mm. diameter placed 18 in. from *S*'s view, hence subtending a visual angle of 30'. A dim red fixation patch consisting of a tinted and masked flash light was positioned 2.2 in. to the left of the aperture relative to *S*. With the red patch (of about 6.5° angular subtense) fixated, source light would fall at a 7° temporal eccentricity on the left eye where relative cone and rod concentrations are about equal and directional sensitivity slight (Pirenne, 1962a, 1962b; pp. 16 and 31, respectively). The left eye viewed through an artificial pupil of 2-mm. diameter mounted in an aluminum hood sprayed with flat black photographic paint. Stray light from any point in the optical path was thereby screened from *S*'s view. The right eye was masked.

EEG apparatus.—An Offner six-channel electroencephalograph with associated preamplifiers and amplifiers sensed EEG signals and drove two pens of an Offner Dynograph six-pen ink recorder. Surface electrodes consisted of hand-made solder disc of 1-cm. diameter. Micro-ohm electrode jelly was used to lower scalp resistance and Bentonite paste served as the conductive medium at the scalp-electrode interface. Two electrodes were secured to the occipital protuberance with gauze and collodion solution and were placed about 5 cm. apart. Preliminary efforts
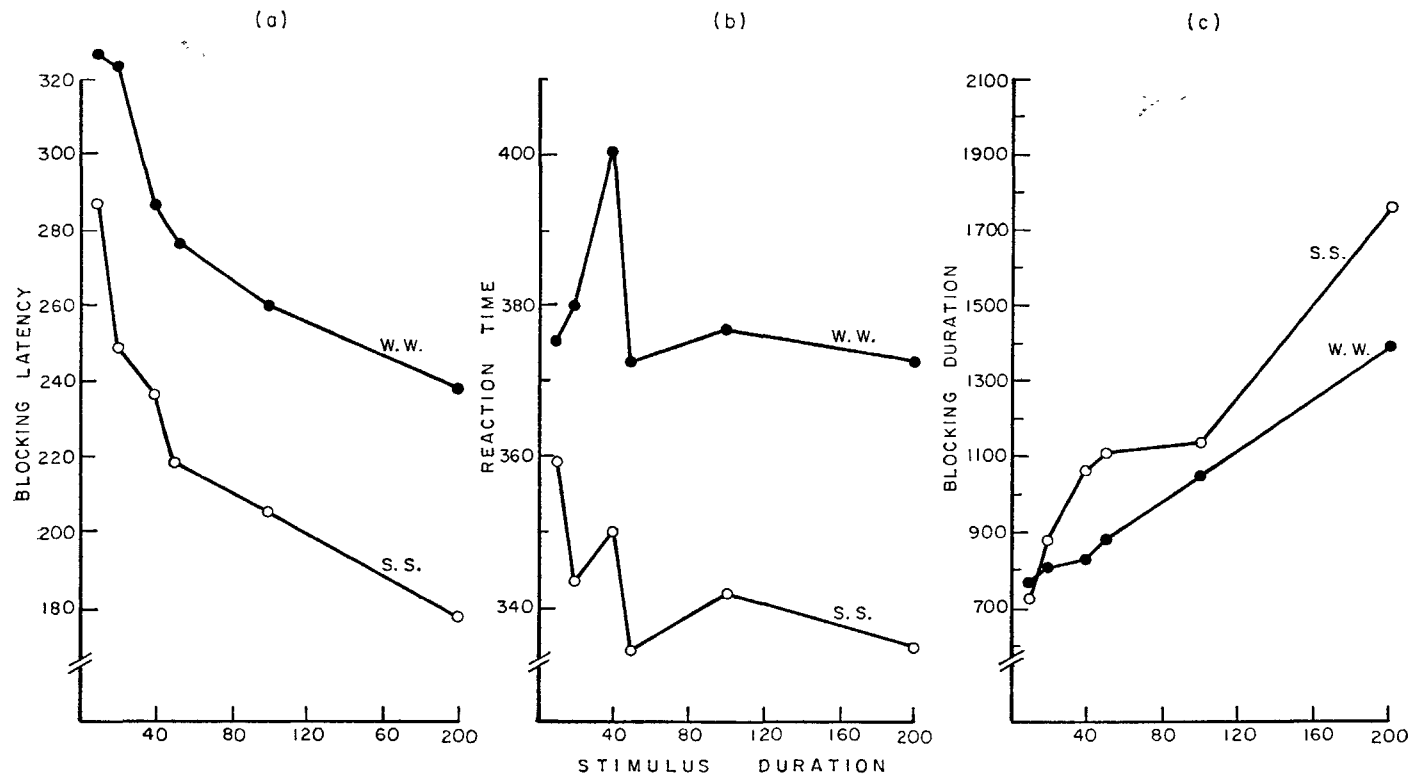
FIG. 1.   Main effects of flash duration upon (a) blocking latency, (b) reaction time, and (c) blocking duration for the two Ss.   (Each point is the mean of 125 trials.)

indicated these to be preferred placements. An ear electrode was used for ground. All recordings were bipolar, measuring the potential differences between disparate loci across the occiput. Efforts to secure motor alpha variations were unsuccessful, presumably because of their low amplitude (usually less than 10 μv.; Bates, 1951).

The RT key employed required a rather large displacement such that a constant 120 msec. was subtracted from obtained reaction times. This constant corresponded to the difference between RTs observed in pilot research using a small displacement key and those observed using the different response key in the present experiment.

Procedure.—Six durations and five luminances provided 30 combinations of $I \times t$. Each S was given 25 trials for each of these combinations and an additional 25 trials at each of two other values of stimulus area. Trials were distributed over three sessions. At a given luminance, t was varied randomly (random-number table) from trial to trial. After each block of 50 trials, S was given 2–3 min. rest. Stimuli were presented at variable intervals from 5 to 20 sec. Consequently, each session lasted about 2 hr. and 30 min. The Ss were dark adapted for about 10 min. prior to testing and 10 practice trials were given at the lowest energy before each session.

The conditions employed were as follows:

1. *Durations:* 10, 20, 40, 50, 100, and 200 msec.

2. *Luminances:* 10, 5, 2.5, 1.25, and 0.625 mL.

3. *Areas:* (a) 0.5° under each of the foregoing 30 conditions. (b) 1° for 25 trials under the 5.0-mL. conditions ($t = 20$ msec.). (c) 4° for 25 trials under the 1.25-mL. condition ($t = 20$ msec.).

RESULTS AND DISCUSSION

The results of the second experiment are discussed below. The statistical reliability of the findings was based upon Wilcoxon Critical Differences analyses (Wilcoxon, 1949).

Effects of Stimulus Duration

Alpha blocking latency.—Increasing stimulus duration resulted in a decrease in the latency of blocking. The relationship was observed at all luminance levels. Both Ss showed reductions in blocking latency as duration was increased. For one S (S.S.), mean latencies were significantly shorter at $t = 200$ msec. ($p < .01$) and $t = 200$ msec. ($p < .05$) than at $t = 2$ msec. For the second S (W.W.), the same significance levels were observed except at $t = 10$ vs. $t = 200$ where differences were significant beyond $p = .01$.

Reaction time.—The effects of stimulus duration upon reaction time were unsystematic. For one S (S.S.), mean reaction times were lower at the highest durations than they were at the lowest durations. However, no systematic and significant reductions were observed as a function of stimulus duration. The results of a Wilcoxon Critical Differences analysis of this S's data indicated that RT means at $t = 50$ and $t = 200$ were significantly shorter ($p < .05$) than at $t = 10$. For the second S (W.W.), a similar analysis of reaction-time data did not show any significant variations. Reaction time for S.S. appears to shorten systematically at the lowest luminance from $t = 10$ to $t = 50$. This is the only point at which this occurred.

Alpha blocking duration.—Increments in blocking duration resulted from increases in stimulus duration for both Ss.

Main effects.—The main effects of stimulus duration (averaged across all luminances) upon the three dependent variables are shown in Fig. 1.

Effects of Flash Luminance

Blocking latency.—Both Ss showed statistically significant reductions in mean blocking latencies as flash luminances were increased. For S.S. latencies were significantly longer at $I = 2.5$ mL. ($p < .05$) and $I = 1.25$ mL. ($p < .01$) than at $I = 10.0$ mL. For W.W., latencies were significantly
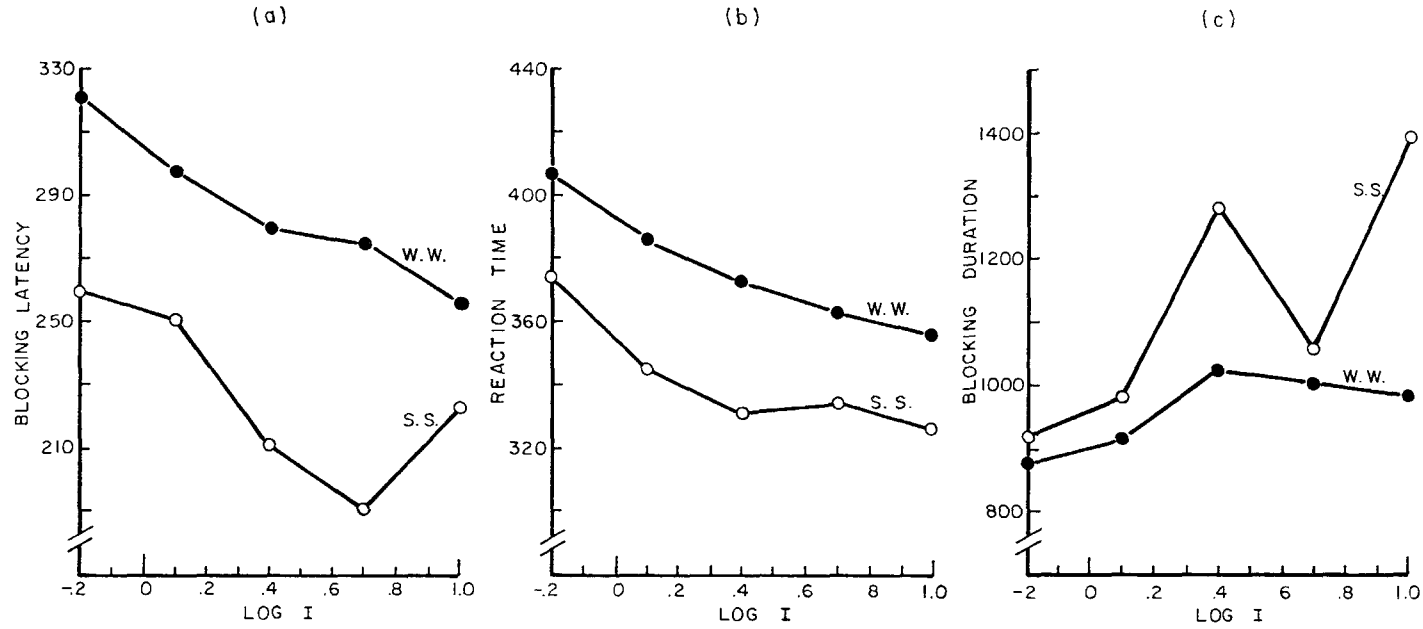
FIG. 2. Main effects of flash luminance upon (a) blocking latency, (b) reaction time, and (c) blocking duration for the two Ss. (Each point is the mean of 150 trials averaged across all durations.)
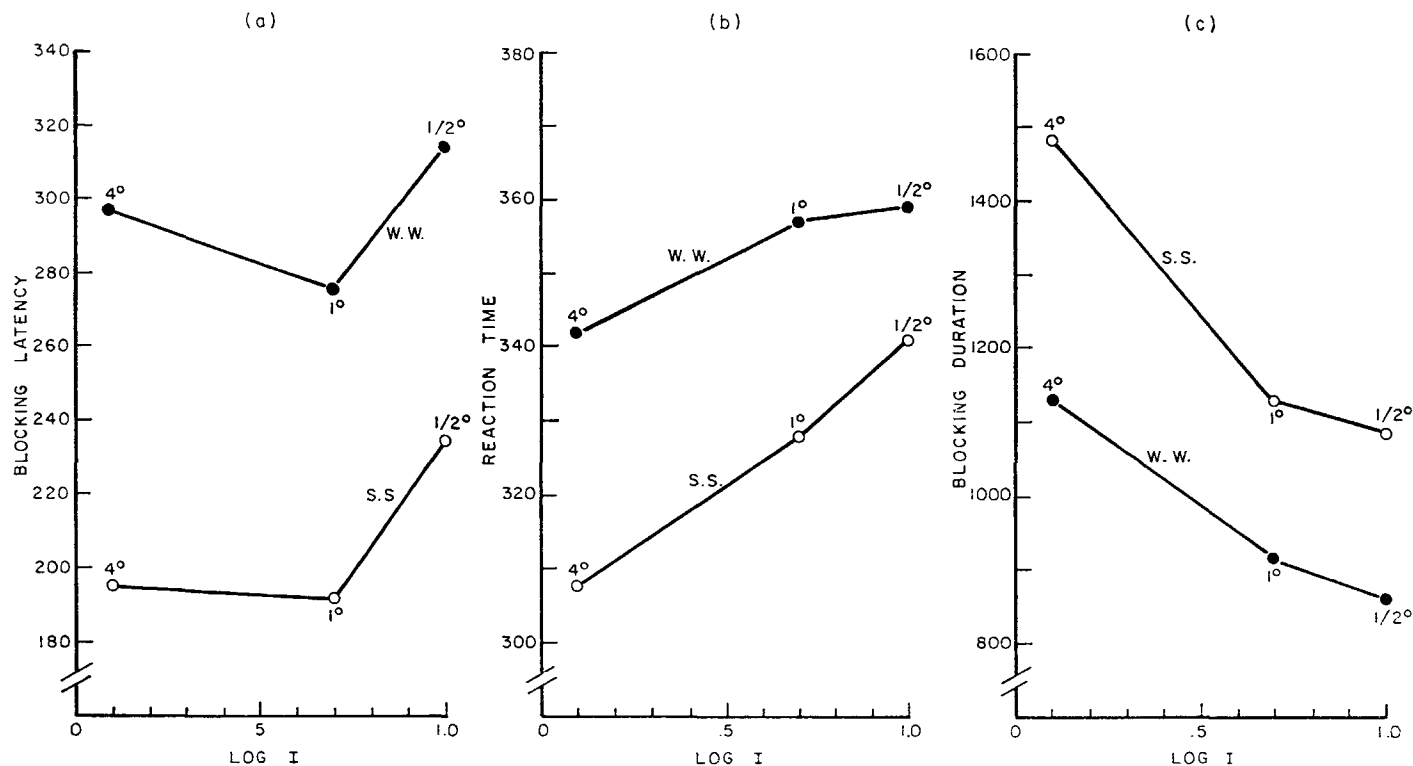
FIG. 3. Effects of areal variation upon (a) blocking latency, (b) reaction time, and (c) blocking duration for the two Ss. (Each point is the mean of 25 trials. Stimuli were of equal energy; i.e., areal increases were compensated for by commensurate reductions in luminance. Flashes were of a constant 20-msec. duration.)

longer at $I = 2.5$ mL. $(p < .05)$, $I = 1.25$ mL. $(p < .05)$, and $I = 0.63$ mL. $(p < .01)$ than at $I = 10.0$ mL. and also significantly longer at $I = 0.63$ mL. $(p < .05)$ than at $I = 5.0$ mL.

Reaction time.—The results of a Wilcoxon Critical Differences analysis of the relationship between luminance and mean reaction time were statistically significant for both Ss. Differences were significant beyond $p = .05$ between 3 of the 10 comparisons and significant beyond $p = .01$ between the most disparate pair of luminances (10.0 mL. vs. 0.63 mL.).

Blocking duration.—Obtained relationships between blocking duration and flash luminance were unsystematic for both Ss and nonsignificant for one S over all luminances. One S (S.S.) demonstrated significantly longer mean blocking durations at the highest luminance than at the lowest $(p < .01)$ or next lowest $(p < .05)$. The other S (W.W.) reflected no significant variation in blocking duration.

Main effects.—The main effects of flash luminance are presented in Fig. 2. The figure contains (a) blocking latency, (b) reaction time, and (c) blocking-duration measures averaged across all durations. Alpha blocking latencies and reaction times decrease systematically with increased luminance. Blocking durations were not systematically affected by variations in luminance.

Areal Effects

Figure 3 presents the main effects of area variations upon (a) blocking latency, (b) reaction time, and (c) blocking duration for the two Ss. As can be seen, mean blocking latencies are longest at the smallest (0.5°) area at which luminance is greatest. For one S (W.W.), mean reaction time is initially reduced from 0.5° to 1.0° and

tends to increase at $A = 4.0°$ (lowest intensity). The other S (S.S.) shows the same reduction from $A = 0.5°$ to $A = 1.0°$ and no significant change beyond that. Reaction time for both Ss increases monotonically with decreasing area. Mean blocking durations are longest at the largest area and decrease at successively smaller areas. Areal effects were not great. For W.W., blocking latencies showed a 5% change, reaction times a 4% change, and blocking durations a 30% change (far less than the effects of stimulus duration). For S. S., blocking latencies showed a 22% change, reaction times a 12% change, and blocking durations a 30% change.

Energy Relations and Alpha Latency

The five intensities and six durations employed in the second experiment provided 30 $I \times t$ energy products, a number of which overlapped with others. Figures 4 (S W.W.) and 5 (S S.S.) are plots of mean blocking latencies as a function of log $I \times t$ with durations presented parametrically. For W.W., there is one point $(I \times t = 2.3)$ at which latency differences are as large as 30% of the entire range of variation. For this S, no other pair of latency measures at a common $I \times T$ product differs by more than 10%. The same is true of S.S.'s data in Fig. 5. It should be noted in both figures, however, that strict It reciprocity would result in a family of functions converging at some particular value of t; i.e., at the critical duration beyond which I alone determines the visual effect.

These findings are relevant to certain current questions concerning visual information processing.

Effects of Energy

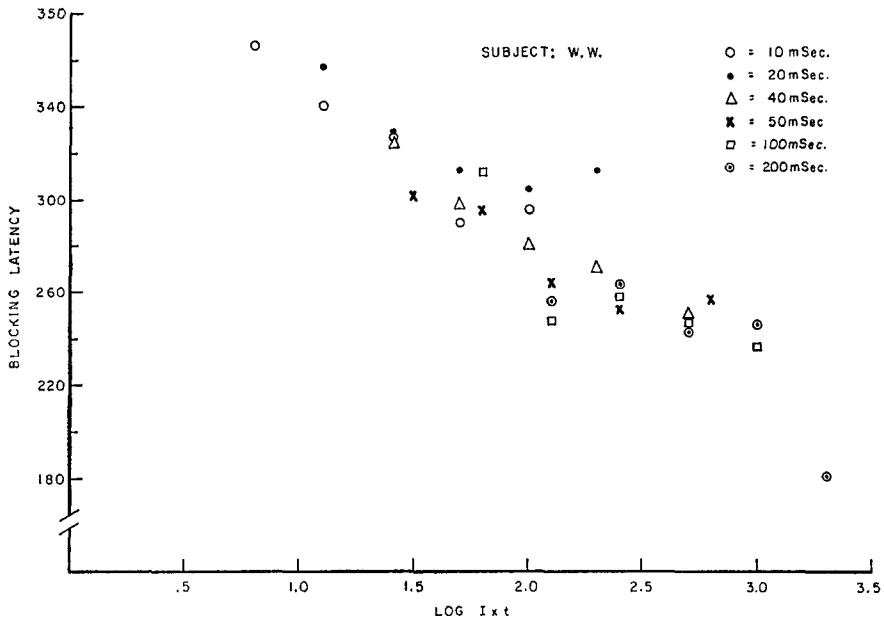Consistent with Raab and Fehrer (1962), RT was found to be luminance dependent and thus probably based upon

FIG. 4.   Alpha blocking latencies at each of the 30 *I* × *t* combinations
for *S* W.W.   (Each point is the mean of 25 trials.)

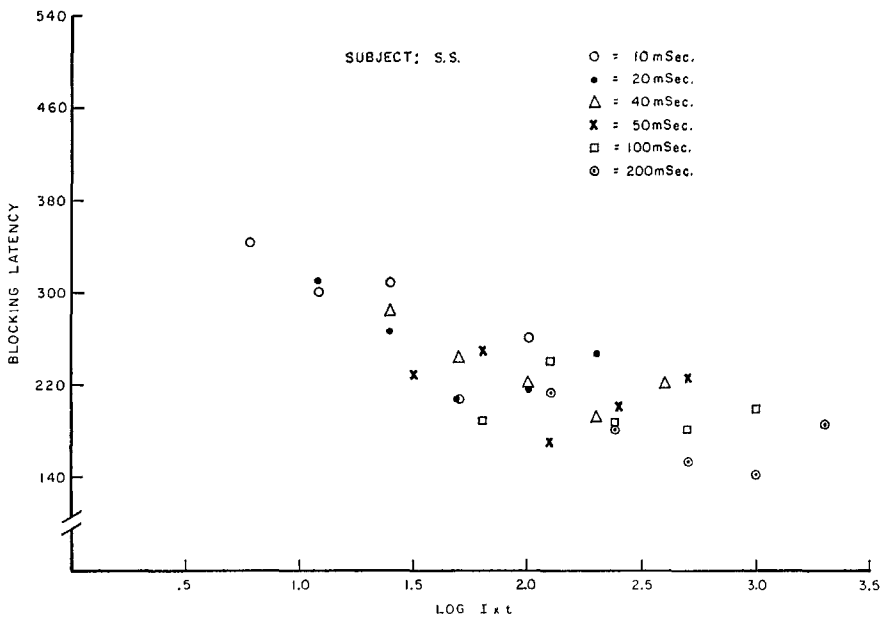

FIG. 5.   Alpha blocking latencies at each of 30 *I* × *t* combinations
for *S* S.S.   (Each point is the mean of 25 trials.)

events which occur early in the central response to light. The length of durations over which intensity and time function reciprocally in affecting both EEG and verbal responses to stimuli is long relative to that involved in reaction time. Cruikshank (1937) reported $I \times t$ reciprocity for values of t as long as 640 msec. Reciprocity was observed in the present experiment at the longest t employed (200 msec.). Psychophysical determinations indicate reciprocity up to about 100 msec. (Graham & Margaria, 1935). It is tenable, therefore, that the mechanisms involved in the judgment of brightness are bypassed when RT is the dependent variable. This is suggested by the fact that judgments reflect the outcome of temporal summation while reaction time does not. Neurophysiological support for this view is provided by Wall, Remond, and Dobson (1953) who demonstrate the potentiation of motor cortex excitability by photic stimuli with that effect unchanged by occipital lobectomy. However, lesion of pretectal (ventrolateral geniculate nuclei) area abolished the effect. The authors conclude that, ". . . neither of the two main visual projection systems is responsible for the facilitory effect of visual afferent volleys on the motor cortex [p. 393]."

Therefore, in terms of energy relations between EEG and motor latencies, it is suggested that different functions are being reflected by the respective dependent variables. Reaction time is the outcome of a sequence of events with short time constants, presumably from retina to lateral geniculate nucleus to occipital cortex to motor cortex. Further, it would appear that motor cortex is "readied" by those geniculo-cortical impulses which are initiated by retinogeniculate inputs. Once excited, the motor cortex initiates movement with the arrival of the first impulse(s) from occipital cortex (via the subcortical areas). The sequence may be different and is certainly more prolonged in the judgmental setting. Speculatively, the observed afteractivity may constitute a redistribution of previously synchronized

(10 per sec.) neuronal activity into new and different frequencies, each of which (or each combination of which) carries information regarding separate parameters of the stimulus (intensity, duration, area, wavelength, etc.). Reaction time is over long before the blocked alpha rhythm recovers and, presumably, whatever information is carried by the duration of the blocked alpha would not appear in the RT data.

Effects of Area

Bartley (1935, 1936) has investigated areal effects upon the latency of the cortical evoked potential in rabbits. He has shown that latency is reduced by areal increases up to about 20° visual angle and interprets the finding as suggestive of a cortical analog of peripheral spatial summation. In the present experiment, the reduction in both blocking latency and reaction time with increases in stimulus area may also reflect central visual and motor correlates of areal summation at the periphery.

In this connection it is of relevance to reconsider possible processes involved in the initiation and maintenance of the blocking pattern. That blocking is not initiated simply by the retinal "on" response is clear from the data of the present experiment. The b-wave latency, asserted to reflect retinal "on" activity (Johnson & Bartlett, 1956) does not depend upon total energy but upon flash luminance. Alpha blocking latency does depend upon total energy. It is reported that the b-wave *amplitude* is proportional to $I \times t$ products (Johnson & Bartlett, 1956) and the present data would suggest that the blocking latency is a consequence of response amplitude at the periphery; i.e., a frequency representation of amplitude. It is tenable that the activated peripheral units lead to an interruption of the periodic alpha and that the delay is proportional to the number of impulses impinging upon the cortical region. To this extent, it would not matter whether the number of impulses were achieved by varying the intensity, the duration, or the area of the

exteroceptive stimulus. The reciprocity of I and t in the determination of blocking latency supports this position as does the effect of increased area.

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