The latency of response in relation to Bloch's law at threshold[1]

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Bloch's law failed to hold for latencies of response in a threshold experiment where frequencies of response did, nevertheless, obey the law. Dark-adapted Ss were instructed to respond as soon as they detected flashes of various luminances and durations. The frequency of response increased with increases in stimulus energy (luminance times duration); it was constant when energy was constant. The latency of response, measured from stimulus onset, varied inversely with energy; it also varied inversely with the luminance of flashes that were constant in energy. The results were consistent with data from earlier threshold and simple reaction time experiments.

Luminance-duration reciprocity has been observed in numerous visual threshold experiments since Bloch's classical work nearly a century ago (Sperling & Jolliffe, 1965). It is well documented that constant behavioral effects are obtained with various luminances L and durations T of stimuli that are both constant in energy (LT) and briefer than a critical duration T_c. Stimulus energy, or more properly the time integral of stimulus luminance, appears to be the only stimulus quantity of significance to response determination when durations are briefer than T_c (Graham, 1965, p. 77). The rate at which energy is delivered, or stimulus luminance, appears to have special importance only when stimulus durations exceed T_c and luminances are low (Bartlett, 1965, p. 170). Nonetheless, the luminance of stimuli that are briefer than T_c may have behavioral effects that are distinguishable from those of energy in a threshold experiment–judging from certain reaction time data, which may at first appear to be irrelevant.

Bloch's law failed to hold for simple reaction times in the parametric study by Raab and Fehrer (1962), whose purpose was to determine the range of flash durations which influence reaction time. Latencies varied inversely with the energy in brief suprathreshold flashes (i.e., up to 20 msec) and, for a given energy, varied inversely with flash luminance. Lewis (1964) proposed that the constant-latency for constant-energy relation required by Bloch's law did not occur because of response biases, which arose when luminance was fixed during each session (but durations were randomized). In a limited test, two flashes of equal energy were interspersed randomly among the trials of an experiment, which yielded reaction time distributions that were not significantly different from each other. Thus Lewis concluded that Bloch's law is valid for reaction time. The present paper concerns a plausible alternative interpretation that is consistent with the results of both studies.

The idea is that reaction times do not generally obey Bloch's law and deviate more from the law, the lower the stimulus energy. That alternative raises the question, whether reaction times for suprathreshold stimuli are a legitimate basis for predicting how response latencies vary near absolute threshold. An answer is given by the present study, where the frequency and the latency of positive response ("yes") are determined together, as joint functions of luminance and duration; Ss are required to respond as soon as they see the flash stimulus. These modified threshold experiments are designed to show whether Bloch's law fails for the latency of response (following the pattern in the data of Raab & Fehrer) even though the frequency of response to the same stimuli conforms with the law. Such an outcome would be particularly interesting, because Bloch's law has proven to be valid for an impressive variety of subject tasks and response measures (Aiba & Stevens, 1964; Kahneman & Norman, 1964).

METHOD

Apparatus

Stimuli were produced with a fluorescent lamp (Sylvania F4T5/CWX) that was switched on electronically by a gating circuit that applied 400 V dc between the lamp filaments. The filament attached to the negative terminal of the 400 V supply was heated continuously with 10 V dc. The circuit produced nearly rectangular stimulus waveforms which closely resembled those obtained by Gerbrands and Stevens (1964) with a similar circuit. Stimulus duration, given in terms of the interval between the half-power points of the stimulus waveform, was controlled with the 50 V gate of a Tektronix Type 162 generator. Stimulus luminance was controlled with neutral density filters.

The stimulus field was circular, subtended 0.5 deg, and appeared to be white when transilluminated by the lamp. A fixation device was located in the plane of the stimulus. In Experiment 1, it was a dim red light that subtended 10 min and was 3 deg below the stimulus. In Experiment 2, it was a pair of dim red lights, each subtending 0.5 deg, which were located 2 deg on either side of the stimulus. The S sat in a dark booth and viewed binocularly. Head position was controlled with a chin and forehead rest. The response button was a sensitive microswitch (Unimax 2HBJ-1).

Subjects

Two male college students were paid Ss. Both HH and JS served in Experiment 1, and then JS served in Experiment 2.

Procedure

During each block of trials, luminance was fixed while durations were randomized. The durations used at each luminance ranged from relatively brief exposures, which were detected rarely, to long exposures, which were always detected. The one exception was the highest luminance in Experiment 1, where durations were selected so that they would be detected on nearly all trials. In preparation for formal runs, Ss were trained to respond rapidly to dim flashes, but not to respond on blank trials–i.e., trials on which no flash was presented.

On each trial during formal runs, the S depressed the response button with the index finger of his right hand and then, with his left hand, threw a switch that started the timing of the foreperiod. His task was to release the button as soon as he saw the flash, but to continue depressing it if he did not. If the button was released within 1 sec after the end of the foreperiod, the action was regarded as a response, and its latency, measured from stimulus onset, was recorded to the nearest msec. If no release occurred during the 1 sec interval, the trial was ended and no latency was recorded. The S was told that blank trials sometimes occurred, but he was not told that a trial had been blank unless he responded when one occurred. One such response was made by HH; JS made none. Thirty sec after the end of a trial the S received an auditory signal that informed him he might begin a new trial as soon as he wished.

Experiment 1 was a survey over wide ranges of luminances and durations. There were four luminances, A, B, C, and D. In log ft-L (logarithm to the base 10), their values were -2.82, -1.81, -0.81, and -0.07, respectively. There were 12 sessions, and one luminance was used in each, in this order: A B C D D C B A A B C D. A session was made up of 10 blocks of trials with rests between blocks. A block consisted of a trial at each duration (values will be apparent in the figures that display the results) and three blank trials, all in a random order. In the whole experiment, a S received each luminance-duration pair on 30 trials and blanks on 120 trials. Thirty min were allowed for dark adaptation. The foreperiod was 4 sec.

Experiment 2 had fewer stimulus values but yielded more data per value. There were two luminances, A and B, whose values were, respectively, -1.77 and -1.24 log ft-L. In the first of the 14 sessions, the sequence of blocks of trials was: AB-BA-AB-BA-AB, where a hyphen represents a rest period. In the next session the positions of A and B were reversed; in the next they were reversed again; and so on. A block consisted of a trial at each duration and a few blanks (three for A and four for B), all in a random order. In the entire experiment the S received each luminance-duration pair on 70 trials and blanks on 490 trials. Ten min were allowed for dark adaptation. The foreperiod was 2.8 sec.

RESULTS

Three measures of the S's behavior are considered: the percentage of trials on which a response occurred; the median of the response latencies; and the semi-interquartile range of the response latencies. Each measure is examined to see whether it obeyed Bloch's law—that is, whether the measure is constant when the product of luminance (L in ft-L) and duration (T in msec) is constant.

The upper panels of Figs. 1, 2, and 3 show that the percentage of responses (P) increased with increases in flash duration for a fixed luminance. At each luminance, values are plotted only up to the duration at which the percentage response first reached and remained at 100%. No points are plotted for -0.07 log ft-L in Experiment 1, because percentages were 100% at all durations. Figure 1 shows that 50% responding occurred when durations were approximately 60, 6, and 0.6 msec; as Bloch's law would require, the respective luminances were increased by factors of 10. Other percentages also occurred in accord with the law, as indicated by Fig. 4 (left panel: HH1). It shows that the curves in Fig. 1 approximate a single curve when percentages are plotted as a function of the product of luminance and duration, or energy. The same interpretation is consistent with the functions in Figs. 2 and 3, for JS in Experiments 1 and 2, respectively. These, too, merge when plotted against energy in Fig. 4. In all three cases, the agreement with Bloch's law is just as good as could be expected with 30, or in Experiment 2, 70 binary choice trials per data point. Thus the law held over the full range of response percentages.

The lower panels of Figs. 1, 2, and 3 indicate that the median of response latencies (MDN) decreased with increases in flash duration while luminance was fixed. Medians are plotted only for stimuli to which the S responded on at least 10 trials. The medians are well ordered inverse functions of luminance and duration and show no discontinuities when they are examined with reference to the accompanying response percentages. The inapplicability of Bloch's law to the medians can be seen in Fig. 1. For example, a latency of about 500 msec occurred at -2.82 log ft-L when the stimulus was about 60 msec, but a latency of about 450 msec occurred at -1.81 log ft-L when the stimulus was about 6 msec. The same trend can be found in Figs. 2 and 3, but is indicated more clearly in Fig. 5. It shows that median latencies were a joint function of luminance and energy, even at those low energies for which response percentages obeyed Bloch's law.

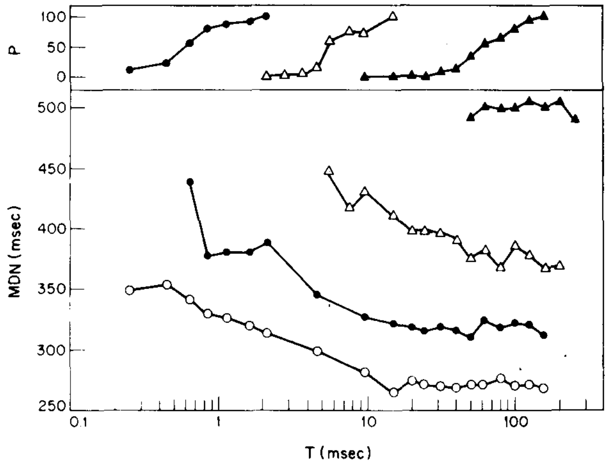

Fig. 1. The percentage of trials on which a response occurred and the median of response latencies, as functions of flash duration at four flash luminances (filled triangles -2.82, open triangles -1.81, filled circles -0.81, and open circles -0.07 log ft-L). Experiment 1: HH.

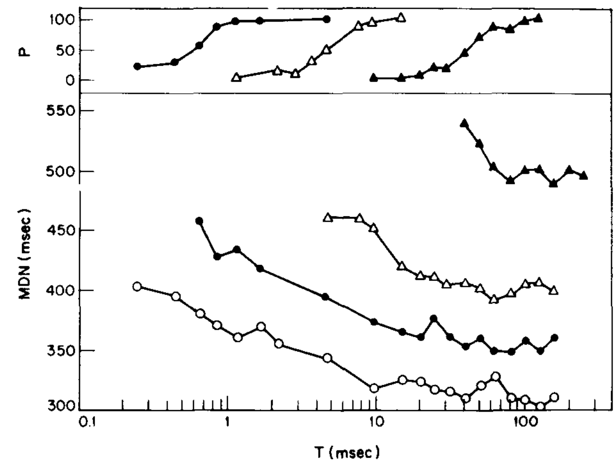

Fig. 2. The percentage of trials on which a response occurred and the median of response latencies, as functions of flash duration at four flash luminances (symbols as in Fig. 1). Experiment 1: JS.

Figure 6 shows that the semi-interquartile range of response latencies Q decreased with increases in flash energy. Ranges were plotted only for stimuli to which the S made at least 10 responses. Because the ranges obtained at various luminances are a crude approximation of a single function, this response measure is not inconsistent with Bloch's law.

DISCUSSION

The task assigned to Ss in this study captured the essential features of performance found in previous studies of frequencies of seeing. Direct comparisons are difficult to make, however. Threshold studies of reciprocity have usually referred to a single behavioral criterion, such as a 50% response probability (e.g., Sperling & Jolliffe, 1965); also they have rarely had flash duration as the independent variable. One exception in both respects is the work reported by Crozier (1950). His S, like the two here, pressed

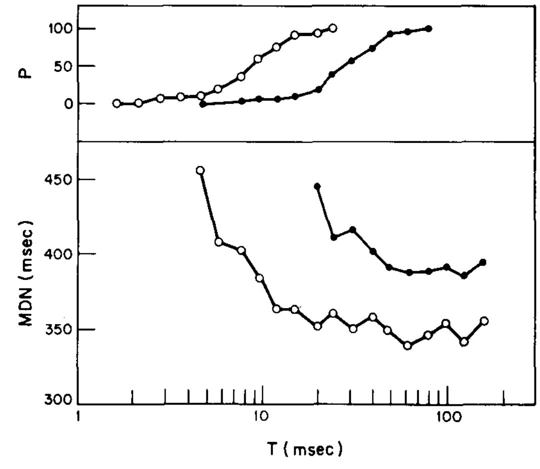

Fig. 3. The percentage of trials on which a response occurred and the median of response latencies, as functions of flash duration at two flash luminances (filled circles -1.77, and open circles -1.24 log ft-L). Experiment 2: JS.

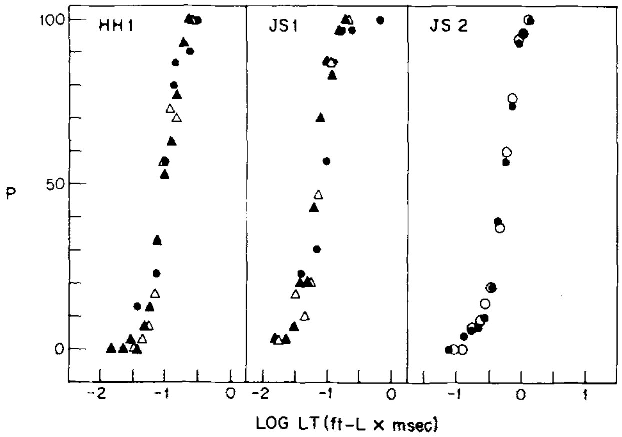

Fig. 4. The percentage of trials on which a response occurred, as a function of the logarithm of flash energy at various luminances (symbols as in Figs. 1-3). The HH1 and JS1 panels are for the two Ss in Experiment 1, whereas the JS2 panel is for Experiment 2.

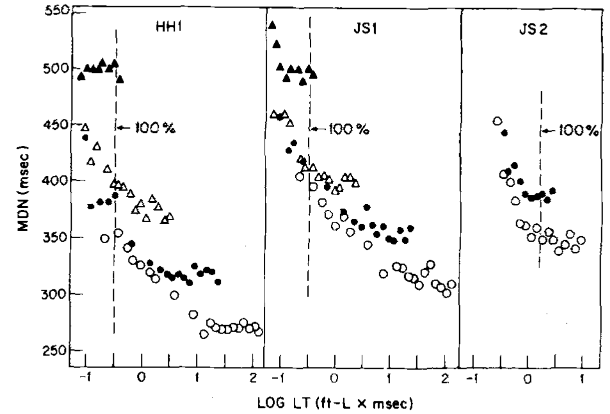

Fig. 5. The median of response latencies, as a function of the logarithm of flash energy at various luminances (symbols as in Figs. 1-3). The panels follow the convention used in Fig. 4.

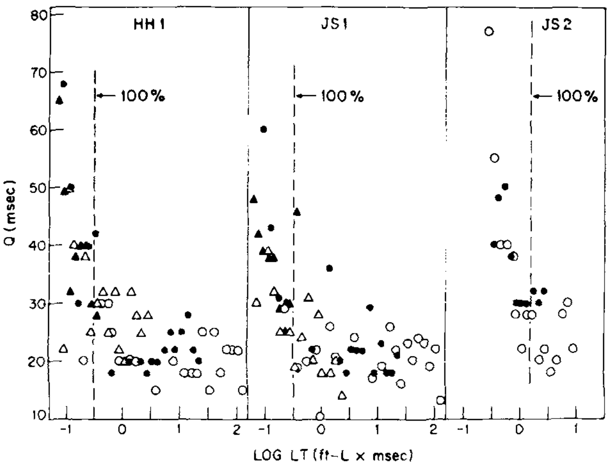

Fig. 6. The semi-interquartile range of response latencies, as a function of the logarithm of flash energy at various luminances (symbols as in Figs. 1-3). The panels follow the convention used in Fig. 4.

a key if she saw the flash and never responded on blank trials. His data (p. 97) may be replotted to show how Bloch's law, "or rather . . . its accurately determined counterpart" (p. 88), applied to frequencies of seeing. For example, 50% was associated with relative log energies of -2.19, -2.44, and -2.39 units for stimuli which spanned almost two log units of intensity. Plotted as a function of intensity times duration, Crozier's three frequency functions would have approximated a single function, as in this study.

Absolute values also agree with those in other contexts. In Experiment 2, viewing was binocular with foveal stimulation, as in Karn's (1936) method-of-limit threshold study and Raab and Fehrer's (1962) reaction-time study. A threshold energy of about zero log (ft-L x msec) was obtained by Karn when the foveal stimulus subtended 20 min. Here in Experiment 2 with a 0.5 deg stimulus, 50% responding was associated with an energy of -0.3 log (ft-L x msec). Raab and Fehrer used a still larger stimulus, 1 deg 10 min, and reported that a luminance of 0.3 ft-L "was below foveal threshold when presented for 0.5 and 1 msec" (p. 326); hence threshold was near -0.5 log (ft-L x msec). Threshold energy values in the three studies were in close accord, allowing for differences in stimulus area and the negligible difference between luminance units. As far as the difference between foveal and extrafoveal stimulation is concerned, the energy associated with 50% responding in Experiment 2 was higher than the analogous energy in Experiment 1. This energy difference is in the direction indicated by threshold studies of retinal position (e.g., Bartlett, 1965, p. 167).

Although Ss' frequencies of response obeyed Bloch's law, their latencies were not everywhere consistent with the law. Median latencies measured from flash onset varied inversely with stimulus luminance when stimulus energy was constant. This failure of Bloch's law, as well as other features of the relationships involving medians, followed the pattern in the data of Raab and Fehrer (1962). The semi-interquartile range of latencies for low energies was, however, consistent with Bloch's law. There are no published data with which the latter interesting finding may be compared strictly.

Had latencies been measured from flash cessation, the resulting median latencies would have obeyed Bloch's law at low energies; however, the form of relationships involving the semi-interquartile range would have been unaffected. This change of origin has formal appeal, because it preserves the invariance of Bloch's law to some extent. But it is only one of a number of conceivable transformations that might be regarded as realistic when viewed in terms of the processes underlying latency of response. Although these experiments raise the question whether latencies should be measured from stimulus onset or from some other point in time, the topic is beyond the scope of this paper.

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NOTES

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