Energy Effects Upon Two-pulse Measures of Temporal Resolution*

Mitchell L. Kietzman

Biometrics Research, New York State Department of Mental Hygiene

*This research was supported in part by post-doctoral fellowships held by the author (USPHS MPD 16, 094 and NSF #42197), and by two USPHS grants. (MH-07776 and 05560). Dr. Samuel Sutton was of fundamental assistance at all stages of the research. Collection and analysis of the data were done by J. Marshall, T. Nilsson, P. Adams and J. Gordon. Help with the equipment was provided by R. Simon and B. Laupheimer. Dr. Joseph Zubin offered helpful comments and encouragement. Thanks to Dr. N. Beckenstein, Director of Brooklyn State Hospital, for providing space for laboratory facilities.
The two-flash threshold has been measured by determining the interval of
time between two successively presented pulses of light that allows a subject to
report having seen two-flashes a certain proportion of the time. This technique,
has been interpreted as providing a measure of temporal resolution or temporal
acuity which has been viewed as a fundamental characteristic of perceptual
behavior (Geldard, 1953; Piéron, 1952).

Mahneke (1958a) systematically investigated two-flash resolution and concluded
that increases in the "quantity of light," i.e., in the total energy, reduced the
two-flash threshold. However, in that study energy increments were obtained by
increasing the duration of the pulses which provides an operational definition
of energy increment but presents certain difficulties. Thus, as the duration
of the light pulses are increased the amount of energy being integrated by the
nervous system is not necessarily increasing since the duration of each pulse
may be longer than the so-called critical duration of Bloch's law.\footnote{Mahneke failed to refer to Bloch's law or to take its implications into
consideration. His use of the quantity of light explanation for his results
suggests that he either considered Bloch's law to be inapplicable (it generally
has been tested at absolute threshold energy levels) or that he considered all
of his stimulus durations to be shorter than the critical duration.}

Also, the fact that longer stimuli sometimes appear dimmer than shorter stimuli of the
same luminance (Broca-Sulzer effect) illustrates that the manipulation of stimulus
duration to increase energy may have complex perceptual results. Experiment I
was designed to investigate further the effects of energy increments on two-
flash discrimination by comparing the effect of alteration in energy obtained by
increasing pulse duration with the effect of alteration in energy obtained by
increasing pulse luminance. Stimulus areas, durations, and luminances were
approximately within the range of those explored by Mahneke.

Experiment I

Subjects and stimuli. Two trained male Os with normal vision, the author
and a college student, served as subjects. For O:MK, the two-pulse stimuli
consisted of seven different intensity-duration combinations which were chosen to allow comparison of the relative effects of manipulating duration and intensity over the same range. For Q:SW, the same seven stimuli plus an additional two intensity-duration combinations were tested. The most intense stimulus tested for both Qs was 612 mL (log relative intensity = 1.79). The log of the exact values used may be seen in the marginal headings of Table 1.

Procedure. All intensities and durations were tested within a single daily session, and three or more such sessions were obtained for each Q. Throughout a session, blocks of 15 trials with a fixed luminance and duration combination were presented in random order. Within each block the interpulse interval values were varied randomly from trial to trial. The exact interpulse intervals employed were different for the two Qs, and for the particular stimulus being tested, but for both Qs the values were changed in 5 msec. steps. The range of intervals was from 6 to 86 msec. for Q:MK and from 16 to 91 msec. for Q:SW. The method of constant stimuli was used. The dependent variable was the frequency of the Q's report of "two flashes" as a function of the interpulse interval. Data were gathered over a minimum of three experimental sessions. Sixteen frequency of seeing curve, one for each duration-intensity combination, were obtained. Each curve was based upon at least 20 stimulus presentations per point and 180 presentations per curve. The slopes of the psychometric curves for each stimulus combination were similar, and therefore the two-flash threshold was specified as the interpulse interval that produced a report of "two flashes" 50% of the time.

At the beginning of a session the Q was dark-adapted for at least five minutes in a light-tight booth. Then he was given a warning signal that the experiment was to begin and that he could trigger the stimuli at any time. To prepare for the stimuli he fixated on four red dim fixation lines through a 3 mm. artificial pupil. His head position was fixed by use of a bite board and
## Table 1
Two-flash Thresholds as a Function of Different Duration-Intensity Combinations for Two Subjects

(Log of the relative energies shown in parentheses)

<table>
<thead>
<tr>
<th>LOG DURATION (msec.)</th>
<th>0.6</th>
<th>1.43</th>
<th>1.79</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.43</td>
<td>80 (2.03)</td>
<td>57 (2.86)</td>
<td>36 (3.22)</td>
</tr>
<tr>
<td>1.79</td>
<td>80 (2.39)</td>
<td>55 (3.22)</td>
<td>-</td>
</tr>
<tr>
<td>2.0</td>
<td>-</td>
<td>53 (3.43)</td>
<td>31 (3.73)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOG RELATIVE INTENSITY</th>
<th>0.6</th>
<th>1.43</th>
<th>1.79</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.43</td>
<td>72 (2.03)</td>
<td>39 (2.86)</td>
<td>20 (3.22)</td>
</tr>
<tr>
<td>1.79</td>
<td>70 (2.39)</td>
<td>37 (3.22)</td>
<td>-</td>
</tr>
</tbody>
</table>
a chin and forehead rest. Intertrial time was approximately 5 to 8 seconds, depending upon how quickly the Q triggered the stimuli following the warning signal.

**Apparatus.** A one-channel optical system provided a monocular Maxwellian view of a image of the crater of a glow-modulator gas-discharge tube (Sylvania R 1131C). The white-appearing target was determined by a circular field stop. It subtended a visual angle of 20 minutes and was foveally fixated. The duration, slope, and intensity of the light pulse were continuously monitored by use of two photomultiplier tubes (RCA 1P21) whose spectral sensitivities were corrected by filters (Kodak 106) to approximate the C. I. E. photopic luminous efficiency curve. Light intensities were controlled by neutral density filters (Kodak, No. 96) calibrated in the laboratory to an accuracy of 5%. The glow-modulator tubes were electronically gated. The duration of the pulses and of the dark intervals were controlled by a transistorized, nine-channel multivibrator timer with an indeterminancy of 1 part in 10,000. Temporal characteristics of the waveform of the light pulses showed that, at the current level used (23 milliamperes), rise time was approximately 40 microseconds and decay time was approximately 20 microseconds.

**Results.** Table 1 shows the two-flash thresholds of both Qs for the different stimulus intensity-duration combinations. The columns correspond to the different log durations and the rows to the different log relative intensities. The two-flash threshold values (in m sec.) appear in the cells with the log of the relative energy (intensity x time) expressed in arbitrary units shown in parentheses below each threshold value. The same energy value may appear more than once because it was obtained with different intensity-duration combinations. A comparison of threshold values for equal-energy pairs shows them to be quite different with the lower thresholds of the pair always being obtained with the
longer duration stimuli. For both Qs, as the duration of the stimulus is increased for a fixed intensity (reading horizontally) the threshold drops rapidly. In contrast, as the intensity of the stimulus is increased for a fixed duration (reading vertically) the thresholds decrease only slightly. Even an additional increase in intensity for Q:SW (log 2.0 relative intensity) fails to produce threshold shifts that are comparable to those obtained by changes in duration.

A comparison of the difference between duration and intensity effects for both Qs is shown in Fig. 1 (based on the rows and columns of Table 1 for which there is an entry in all cells). Note that in the figures energy is plotted as a second abscissa. The two upper curves show that as the stimulus duration is increased, while holding intensity constant, there is a marked reduction in the two-flash threshold of 44 msec. for Q:SW and 52 msec. for Q:MK, and this reduction is approximately linear as a function of the log of the stimulus duration. In contrast, the lower curves show that as the stimulus intensity is increased over the same, or even a greater range (Q:SW), while holding duration constant, there is only a slight reduction in the two-flash threshold of 10 msec. for Q:SW and 15 msec. for Q:MK. The fact that the two operations to increase stimulus energy failed to produce the same results brings into question the exact role of energy upon two-flash thresholds. Two-flash thresholds are lowered considerably when energy is increased by lengthening the duration of the two-pulses but they are only reduced slightly when energy is increased by increasing the intensity of the two-pulses of light.

Experiment II

In Experiment I, increasing the intensity, and therefore the energy, of the stimulus by a little over one log unit only slightly reduced the two-flash
Fig. 1. Two-flash thresholds as a function of different duration - intensity combinations for two subjects.
threshold. In the present experiment the effect of increasing stimulus intensity over a wider range was investigated. In addition, a more sensitive psychophysical method was employed. In other research done concurrently with these experiments, we had found that a temporal forced-choice psychophysical method yielded thresholds which were 2 to 3 times lower than those obtained with the constant stimulus method (Kietzman & Sutton, 1966). We, therefore, shifted to a temporal forced-choice method in this experiment under the assumption that it might maximize the opportunity of detecting intensity effects upon threshold measures.

In the temporal forced-choice method, the instructions to the S were to report which one of several sequentially presented stimuli was the different stimulus. This was in contrast to the instructions used in the constant stimulus method of the first experiment where the S was instructed to base his judgment on a predetermined perceptual characteristic -- stimulus "twoness". The difference in the S's task for these two experiments leads us to suggest that they may actually be investigations of different types of thresholds, and as such they require different names. In Experiment I we measured the two-flash threshold, and in the present experiment we measure the two-pulse threshold, a term which takes into account the fact that the method does not instruct S on what to base his discriminations. He need not in fact see two flashes.

Procedure. With the forced-choice method the stimuli were presented in four successive observation periods occurring at one and one half second intervals. Three of the four stimuli, the Comparison stimuli, were identical "double-pulse" stimuli with a zero dark interval, so that they were, in fact, single pulses of light. One of the four stimuli was the two-pulse Test stimulus with a variable

---

2 Our terminology is supported by Bartley's (1958) helpful suggestion that a distinction be made between the terms 'pulse' and 'flash' with the former referring to the stimulus and the latter to the response.
dark interval. Each pulse of light was 5 msec., so the duration of each Comparison stimulus was 10 msec. From trial to trial, the two-pulse Test stimulus appeared in a different observation period except for the limitation that, as the Q was informed, the Test stimulus never was permitted to appear in the first observation period. For each trial the Q's task was to report the temporal position of the Test stimulus. He was not informed about the accuracy of his responses. His accuracy in discriminating the Test stimulus, adjusted for chance, was the dependent variable.\(^{3}\)

The independent variable of the experiment was the interpulse interval. Values were chosen to insure that the Q's performance would vary over a wide range of discrimination accuracy. The range and absolute values of the interpulse intervals differed for the various Qs. For two Qs, MK and PA, they ranged from 0 to 50 msec. in 10 msec. steps while for Qs: JG and TN, they ranged from 5 to 55 msec. in 5 msec. steps.

\(^{3}\) The formula used to correct for chance was:

\[
P_{\text{adj}} = \frac{P_{o} - P_{c}}{1 - P_{c}}
\]

Where

- \(P_{o}\) = proportion of obtained accurate discriminations
- \(P_{c}\) = proportion of accurate discriminations, expected by chance
- \(P_{\text{adj}}\) = accuracy of discrimination, adjusted for chance

The fact that a Comparison always was presented in the first observation period does not modify the proportion of responses obtained by chance alone. This proportion is determined by the number of observation periods in which the Test may be presented. In the experiments reported here it was 0.33 since the Test was presented only in the second, third or fourth observation periods.
The experimental parameter was the luminance of the two-pulse stimulus, and each Q was tested on three different luminance values. For three of the Qs the luminances used were 612, 40, and 2.5 mL. The remaining subject, Q:MK, had the same luminances except that a 62 mL stimulus was substituted for the 40 mL stimulus. These luminance values overlap with those used in Experiment I, with the additional range of Experiment II being obtained by having a less intense stimulus than was used in Experiment I.

In a daily experimental session, two blocks of 20 trials each were randomly assigned to each intensity. Within each block the interpulse interval values were varied randomly. Data were collected for at least five experimental sessions. The data were plotted initially as psychometric curves showing the relationship between interpulse interval and the accuracy of discrimination with stimulus intensity as a parameter. The interpulse interval that produced a 50% correct response level, adjusted for chance, was chosen as the measure of the two-pulse threshold. The visual angle subtended by the circular target was 30 minutes.

Four trained Qs with normal vision, three men and a woman, Q:PA, served as subjects.

**Apparatus.** The same as in Experiment I, except as noted above.

**Results.** Fig. 2 shows the two-pulse threshold values of all stimulus intensities for all Qs. No systematic change is evident in the thresholds as a function of increased luminance, even when it is varied over a range of 2.4 log units. The average threshold across subjects is shown by the stippled curve. These thresholds all fall within a five msec. range. One subject, Q:JG, did show a slight reduction in the two-flash threshold of 5 msec., but this was even a smaller change than had been found in Experiment I. The results of Experiment II also show, as expected, that the threshold values obtained by the forced-choice method were more than two times lower than those which were obtained by the constant stimulus method (Experiment I). This fact is demonstrated particularly...
Fig. 2. Two-pulse thresholds as a function of the stimulus intensity.
by the data for Q:MK who participated in both experiments.

Discussion

Taken together, the results of these two experiments strongly suggest that energy increments, per se, do not change the two-flash or two-pulse threshold. This conclusion is based upon the finding that in Experiment I, equal energy stimuli failed to give the same two-flash thresholds, apparently because the effect of changing stimulus duration upon the threshold is greater than the effect of changing stimulus intensity. Furthermore, in Experiment II, little, if any, systematic change was noted when energy was increased by manipulating stimulus intensity over 2.4 log units. Despite the fact that we were able to replicate Mahneke's finding of a linear relationship between the stimulus duration and the two-flash threshold, even though there were procedural and apparatus differences, our results do not substantiate Mahneke's "quantity of light" hypothesis.

Other two-pulse studies which are procedurally comparable to the present, and to Mahneke's, experiment also fail to lend support to the "quantity of light" hypothesis (Dunlap, 1915; Obert-Thorn, 1962; Venables, 1964) although, admittedly, these studies were not addressed to the specific question of the effect of intensity increments. Dunlap concluded that the effects of brightness are variable. Venables reported that changes in stimulus intensity over a 1.6 log unit range failed to produce shifts in the two-flash threshold. Obert-Thorn found no significant difference between two-flash thresholds for two intensity conditions, separated by 3 log units.\(^3\) Unfortunately, the most complete investigation of the

\(^3\) Although Obert-Thorn did not study equal intensity pulses, one of his conditions involved a second pulse which was 0.2 log units less intense than the first pulse. It is assumed that these pulses were sufficiently close to equality to allow the results to be compared with the results of the present study which used equal intensity pulses.
effects of intensity upon the two-flash threshold has only one condition comparable to those used in the present experiments (Ireland, 1954). In that investigation, monocular two-flash thresholds were obtained for five subjects under two intensity conditions, one log unit apart. The group average for the subjects showed a 10 msec. lower two-flash threshold for the higher intensity condition. This result corresponds quite closely to the result of Experiment I when intensity was changed over approximately the same range. Of the five subjects tested in Ireland's study, two were unaffected by change in intensity. On the basis of his intensity comparisons for both foveal and peripheral retinal regions, Ireland (1954, p. 106) concluded that:

"Certain properties of the critical two pulse interval [two-flash threshold] were found to differ from those of the critical flicker frequency. For example, neither monocular nor binocular critical two pulse intervals seemed to follow the familiar f = log I [Ferry-Porter law] relationship approximated by CFF."

With hindsight, it is not clear why Mahneke proposed a "quantity of light" hypothesis. It would seem from another study involving multiple pulses of light (Mahneke, 1958b) that he was thinking in terms of an analogy to the Ferry-Porter law for CFF data. He seems to have assumed without evidence that two-flash thresholds are the limiting case of CFF and that, as in CFF investigations, as one increased intensity the two-flash threshold would be reduced. We have shown that this is not so. The analogy between two-pulse thresholds and CFF is in fact contradicted by previous studies (King, 1962; Lindsley & Lansing, 1956). However, having made the assumption that increasing intensity would reduce two-flash thresholds, Mahneke's finding that increasing duration reduced two-flash threshold evidently led him to conclude that an increase in "quantity of light" reduces the two-flash threshold. Whether he assumed that the equivalence of duration and intensity was a reciprocity of the type described by Bloch's law, or whether he thought of the equivalence in terms of alteration in the light adaptation state, is not clear. In any case, the fact that the intensity and duration
manipulations are not equivalent would argue against either type of interpretation.4

A type of experiment which shares with the two-pulse experiment the manipulation of a single dark interval is one in which a light stimulus of an extended duration of one second, or even longer, is interrupted by a single dark interval. As in the two-flash case, the dependent variable is the shortest perceptible dark interval (Clark & Pickett, 1959; Gildemeister, 1915). Under these conditions the higher the luminance of the interrupted light the shorter the perceptible dark interval. In fact, the "quantity of absent light" is a constant. This finding parallels the reciprocity for single light pulses, i.e., Bloch's law. It should be noted that experiments using such long duration light pulses, and also CFF experiments, differ from experiments using two brief light pulses in that the former investigate a light-adapted visual system functioning under nearly steady-state conditions. This is clearly illustrated by the results from CFF studies that vary the total number of pulses presented (Battersby & Jaffe, 1953; Granit & Hammond, 1931; Mahneke, 1958b). Here, as the number of pulses is increased, the CFF increases very rapidly at first, then less rapidly, until an asymptotic CFF value is reached.

The problem still remains of explaining why increasing pulse duration produces lower resolution thresholds. It is tempting to attribute this shift to the increasing time separation of either the "on" or "off" neural processes. Such an explanation would be consistent with the lack of an intensity effect, since altering intensity of both pulses presumably would not alter to any great extent the time between either the "on" or "off" processes. Studies of the neural

4 It is conceivable that reciprocity as described by Bloch's law, might influence two-flash resolution of much shorter pulses than those used by Mahneke. However, evidence (Aiba & Stevens, 1964; Kietzman & Sutton, 1966) suggests that critical duration for suprathreshold stimuli are shorter than most of the pulse durations used by Mahneke.
processes underlying two-pulse stimulation, especially with stimulus intensity and
duration varied so as to yield equal energy, could help to explain the stimulus
duration effect on the two-flash threshold and also help to clarify two-pulse
interactions in general.

Summary

Two experiments tested the hypothesis that an increase in the stimulus energy
would improve two-pulse measures of temporal resolution, i.e., would result in
lower two-flash and two-pulse thresholds. In one experiment a comparison of the
two-flash thresholds obtained by manipulating stimulus intensity and stimulus
duration over the same energy range, showed the thresholds to be quite different;
duration manipulations reduced thresholds much more than intensity manipulations.
In the other experiment, a change of the stimulus intensity over an even greater
range failed to show any systematic shift in the two-pulse threshold. It was
concluded that for the suprathreshold energy range tested, an increased quantity
of light does not modify two-pulse measures of temporal resolution.


Battensby, W. S., & Jaffe, R. Temporal factors influencing the perception of visual flicker. J. exp. Psychol., 1953, 46, 154-161.

Clark, W. C., & Pickett, R. Luminance required to detect the presence of a dark interval between two pulses of light. Amer. Psychologist, 1959, 14, 412. (abstract)


Crain, R., & Hammond, E. L. Comparative studies on the peripheral and central retina. V. The sensation-time curve and the time course of the fusion frequency of intermittent stimulation. Amer. J. Physiol., 1931, 98, 654-663.


Mahnke, A. Foveal discrimination measured by two successive light flashes. Acta Ophthalmologica, 1958, 36, 3-11. (a)

Mahnke, A. Fusion thresholds of the human eye as measured with two or several light flashes. Acta Ophthalmologica, 1958, 36, 12-18. (b)


