The detectability of a brief gap in a pulse of light as a function of its temporal location within the pulse*

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A signal detection experiment was carried out to test the hypothesis that the detectability of a brief gap of fixed duration in a pulse of light would vary with its temporal location in the pulse. For five of six Os, as the gap occurred later and later in the pulse, gap detectability increased until just prior to the end of the pulse, where a sharp decrease was found. The finding was replicated in a seventh O, and the decrease in detectability near the end was found to be attributable to the temporal proximity of the end of the pulse. The results are interpreted in terms of the effects of light adaptation and masking.

Varying the duration of either the first or second or both flashes affects the two-flash threshold (Dunlap, 1915; Mahneke, 1958; Keitzman, 1967; Purcell & Stewart, 1971). Thus, it would appear that the total duration of the stimulus package, consisting of two light flashes and a dark interval, is an important variable in two-flash threshold research. The usual dependent variable in two-flash threshold research has been the duration of the dark interval necessary to achieve some criterion level of performance, such as perceiving two flashes 50% of the time. Thus, studies of the effects of the flash duration variable on the two-flash threshold confound the variables of flash duration and the total duration of the stimulus package.

This problem can be seen in a recent study of the two-flash threshold by Purcell and Stewart (1971) and in a study by Mahneke (1958). These investigators report that, with relatively long first flashes, the effect of decreasing the duration of the second flash is to increase the two-flash threshold. They also report that increasing the duration of the first flash, while holding the duration of the second flash constant, reduces the two-flash threshold. However, because the duration of the dark interval was the dependent variable in both of these studies, the total duration of the stimulus package varies from condition to condition, making it difficult to interpret these findings.

A possible way of deconfounding the above findings is to study the detectability of a fixed duration gap (temporal discontinuity) in a pulse of light of fixed duration as a function of

the temporal location of that gap within the light pulse. The results cited above imply that the detectability of a fixed duration gap will increase as the gap occurs later and later in the pulse, until some point at which the detectability of the gap will decrease as the remainder of the pulse gets shorter and shorter. If this conjecture is confirmed, Purcell and Stewart's conclusion rejecting Mahneke's (1958) total light hypothesis will be reinforced.

A further feature of the experiments to be described is that by employing the techniques of signal detection theory (Green & Swets, 1966) the response bias problems of the traditional psychophysical methods have been avoided. As early as 1915, Dunlap pointed out the problem of response bias in measuring the two-flash threshold, yet all of the studies cited have been subject to response bias by virtue of their psychophysical technique.

EXPERIMENT 1

Method

Subjects. Six York University students, all with normal, uncorrected Snellen acuity and paid at the rate of \$2 per hour, were employed as Os.

Apparatus and stimuli. The programming, timing, and lamp drivers were all standard Iconix, Inc., equipment.

The stimulus display was a disk of white light, subtending 10 min of visual angle, centered in a diamond-shaped fixation pattern consisting of four dim red spots of light. The brightness of the fixation pattern was under the control of the O, who set it to be just barely visible. The photometric luminance of the stimulus disk was 3.00 fL. The light stimulus was produced by a glow modulator lamp (Sylvania R1131C) projecting through a neutral density filter and a piece of milk glass

appropriately masked to produce a disk of white light.

Procedure. All viewing was monocular with the preferred eye. O sat in a dark room. His head was fixed in a chin and forehead rest attached to a table, on which were placed the intensity control of the fixation pattern and a panel of pushbuttons with which O indicated his response on each trial.

After 10 min of dark adaptation, the discrimination session began. A session consisted of four blocks of 100 trials. There was a 30-sec rest between blocks.

O's task was to discriminate the presence or absence of a brief fixed duration gap in a 500-msec pulse of light. Each trial consisted of a 500-msec auditory warning signal, immediately followed by a 500-msec pulse of light, followed by a 2,500-msec response period. Thus, the total time in the dark between light pulses was 3 sec. On a randomly determined one-half of the trials in each block, the light pulse was interrupted by a brief, fixed duration gap. O responded during the next 2.5 sec by rating his confidence that a gap had occurred by pushing one of the four pushbuttons on the panel in front of him. No feedback about the correctness of responses was provided. His responses were cumulated on electromechanical counters located (with the control apparatus) in an adjoining room. The data were accumulated in the standard manner; receiver operating characteristics (ROCs) were constructed and d'_e was estimated (cf. Green & Swets, 1966) for each condition.

Each O was run in all five conditions, one condition per session. The order of conditions was different for each O. The five conditions varied the temporal location of the gap within the 500-msec pulse. The gap was centered around the temporal point occurring at 50, 150, 250, 350, or 450 msec. The gap duration employed for each O was chosen to yield a d'_e approximately equal to 1.00 under the 250-msec condition employed during two preliminary sessions. The gap duration employed in all conditions for Os 1 to 6, respectively, was 10, 10, 16, 14, 16, and 10 msec.

Results and Discussion

Figure 1 shows d'_e as a function of gap location for each O. For four of the six Os, the pattern of results is as predicted, i.e., d'_e increases monotonically as the gap occurs later and later in the pulse and then takes a sharp drop when the gap to be detected is close in time to the end of the pulse. O 5 shows a minute

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Fig. 1. Detectability of a brief gap in a pulse as a function of its temporal location for each of six Os.

Fig. 2. Detectability of a brief gap in a pulse as a function of its temporal location for two pulse durations.

deviation from monotonicity between the 150- and 250-msec conditions which may safely be attributed to chance. The sixth O shows an increase in d'_e between the 50- and 150-msec condition and remains at essentially the same level for the 250- and 350-msec conditions, but shows a drop under the 450-msec condition, as did the other Os.

d'_e was chosen as the dependent measure, since the ROCs were satisfactorily linear in normal deviate coordinates, but their slopes tended to decrease as detectability increased, as is usual in visual detection experiments employing signal detection procedures (Green & Swets, 1966).

The results of the experiment confirm the prediction that the detectability of a gap in a pulse of light will increase as a function of increasingly later temporal location within the pulse until just prior to the end of the pulse, where the predicted decrease in detectability was found in all of the six Os. The increase in detectability which is found as the gap occurs later and later in the pulse is consistent with the findings of Dunlap (1915), Mahneke (1958), Keitzman (1967), and Purcell and Stewart (1971), all of whom found a decrease in the two-flash threshold when the duration of the first flash was increased. The decrement in the detectability of the gap when it occurs near the end of the pulse is consistent

with the results of Mahneke (1958) and Stewart and Purcell (1971), who found that decreasing the duration of the second flash increased the two-flash threshold. Note, however, that Mahneke's (1958) total light hypothesis predicts that sensitivity will not vary as a function of the temporal location of the gap within a fixed duration pulse inasmuch as the total light reaching the eye is the same under all of the conditions of this experiment. This hypothesis is clearly disconfirmed by the present results.

Purcell and Stewart (1971) argue that the decrease in the two-flash threshold found when the duration of the first flash is increased is due to an increase in lateral inhibition due to the first flash. They argue further that the second flash must either be separated by a sufficient time interval or of sufficient magnitude to overcome persisting inhibition from the first flash. The present data can be taken to support such an argument.

An alternative explanation, which does not involve the extension of lateral inhibitory interaction to the temporal domain, is possible. Previous investigations (Dunlap, 1915; Purcell & Stewart, 1971) have demonstrated that light adaptation, in general, reduces the two-flash threshold, the exception being that Purcell and Stewart (1971) found that, with a 90-msec first flash and a 2-msec second flash, light adaptation

increased the two-flash threshold. If we assume that the effect of placing the gap in successively later temporal positions within the pulse is to allow the eye to become increasingly more light adapted by the pulse prior to the occurrence of the gap, we can attribute the rising portion of the functions of Fig. 1 to the changing adaptive state of the eye.

To what, then, can we attribute the decrease in the detectability of the gap when it occurs 450 msec into a 500-msec pulse? The most obvious explanation is that the decrease is due to the temporal proximity of the end of the pulse, which may modulate sensitivity. One of two things may be happening: either the first part of the pulse forwardly masks the second flash or the darkness following the final offset of the pulse serves to backwardly mask the occurrence of the gap.

The backward masking interpretation is particularly attractive as a hypothesis in light of the recent work of Holzworth and Doherty (1971) on backward masking by light offset. In interpreting their experiment, they argue that the "off" discharge, attributable to the dark mask, backwardly masks a luminous target. It would appear that the same phenomenon has occurred in the present experiment. The fact that in the present experiment the masking effect occurs over a longer time period

than Holzworth and Doherty observed it over, is possibly due to the fact that, under a backward masking interpretation of the present experiment, the target stimulus was also a period of darkness.

EXPERIMENT 2

In order to test the hypothesis that the temporal proximity of the end of the pulse caused the decrease in gap detectability, a second experiment was carried out on a seventh O. A further purpose of this experiment was to demonstrate the same phenomenon at a higher luminance level.

Procedure

The O was a male, with normal Snellen acuity.

The apparatus and procedure were as in the previous experiment, as were the task and the trial structure. There were three changes from the previous experiment: (1) the luminance of the pulse was increased to 30 fL; (2) the response period was lengthened to 6.5 sec to allow more time for the eye to redark adapt between flashes; and (3) only 300 trials per condition were run.

The experiment consisted of two sets of conditions. The first set was a replication of the previous experiment, but at the higher luminance. The second set, run after the first set was completed, was run using a 700-msec pulse duration, again at the higher luminance. There were five gap locations, 250, 350, 450, 550, and 650 msec into the pulse. Each gap location was run for one session, and the gap duration employed for all

conditions was 8 msec.

Results and Discussion

Figure 2 presents the data for both the 500- and 700-msec pulse durations. The form of the function found in the first experiment was replicated under the 500-msec pulse duration condition of this experiment. The slightly negative value of d'_e observed at the 50-msec gap location in the 500-msec condition is most probably a chance deviation from a 0.00 value of d'_e .

Note that, under the 250- and 350-msec gap location conditions in the 700-msec duration condition, the estimates of the detectability of the gap are virtually identical with those obtained with the gap in the same temporal location under the 500-msec duration condition. With the gap in the 450-msec location, detectability continues to increase under the 700-msec condition but decreases sharply in the 500-msec condition. At the 550- and 650-msec gap locations in the 700-msec pulse, a decrease in detectability is observed.

The above results support the hypothesis that the decrease in detectability observed at the 450-msec gap location in the first experiment was due to the temporal proximity of the end of the pulse. They are consistent with the interpretation of the decrease as a masking-like effect. The present data are not sufficient to distinguish whether the masking is forward or backward. Research is currently under way which should clarify this.

The results of Experiment 2 suggest

that the increase in the two-flash threshold under light adaptation conditions with a relatively long first flash and a brief second flash found by Purcell and Stewart (1971) may be attributed to the same kind of masking process. If the effect of light adaptation is to render the eye more sensitive to brief offsets of a light, it is not unreasonable to assume that light adaptation makes the final offset of the pulse a more effective masker of a previously occurring brief offset.

As a general conclusion, it appears that there are at least three factors which will influence the detectability of a brief gap in a pulse of light: (1) the duration of the gap; (2) the adaptive state of the eye at the time of the gap's occurrence; and (3) the temporal location of the gap relative to the end of the pulse.

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