"Backward masking" of simple detection latencies¹

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Simple detection latencies were determined with stimuli that comprised two successive flashes. The second flash either equaled or exceeded the first in luminance, duration, or both. When a low-luminance flash preceded either a low- or a high-luminance flash, the flashes summated, yielding latencies that were shorter than the latency for the first flash alone. In the limit, when the second flash was intense and followed the first by a short time, the latency for the paired flashes behaved as if it was determined by the second flash alone. This limit was analogous to the retroactive interference in studies of the neurophysiological concomitants of backward masking. However, the S in masking studies detects the first flash despite interference by the second, whereas the present S detected the onset of the stimulus light. The need for an analysis of the S's response under masking is thus indicated.

In visual-detection studies of backward masking (the most recent review is by Kahneman, 1968), the S is required to discriminate an initial low-luminance flash, the test, despite the interference exerted by a subsequent high-luminance flash, the mask. The analogue of that discrimination in studies of the neural correlates (Donchin & Lindsley, 1965; Schiller, 1968) is a computation that estimates the role of the test from the response to the test plus the mask. Strictly speaking, however, the neural response to a two-flash stimulus is more analogous to the behavioral response in studies of temporal summation. There the S is required to detect a stimulus light, that is, either one or both of the equally intense flashes in the stimulus (e.g., Grossberg, 1970; Ikeda, 1965). Summation also occurred at short interflash intervals in Schiller's (1968, determination a) neural experiments when the two flashes were equal in luminance, but little or no summation occurred when the first flash was less intense than the second. In the latter case, the response to the paired flashes equaled the response to the second flash alone, as if the second flash had "displaced completely the response to the first flash [Donchin & Lindsley, 1965, p. 332]." The purpose of the present experiments is to see whether an analogous result occurs at the behavioral level.

In particular, the S's task is to respond

as soon as he detects the onset of a stimulus that comprises two spatially superposed flashes, the second of which either equals or exceeds the first in luminance, duration, or both. The interval between given paired flashes is varied over a wide range of values while the latency of response is recorded. These stimulus conditions favor backward masking (Battersby & Wagman, 1959, 1962; Schiller, 1966) and resemble the conditions used in the neural experiments. This determination is also quite similar to an earlier determination of simple detection latencies (Grossberg, 1970), where the stimuli comprised pairs of identical low-luminance flashes.

Previously, flashes separated by intervals of less than 50 msec summated, yielding latencies that were shorter than the latency for the first of the flashes alone. Thus, when a weak flash precedes a stronger flash by a short time here, the flashes may be expected to interact in determining the detection latency. The form of the interaction is uncertain, however. Do the flashes summate, with each contributing visibly? Or does the second flash displace the first, as in the neurophysiological studies?

METHOD

Apparatus

Stimulus presentation and response measurement were controlled automatically with relay equipment that implemented stimulus schedules that were coded on punched paper tape. The stimulus was produced by transilluminating a circular 20-min field with two electronically gated Sylvania fluorescent lamps (F4T5/CWX). The lamps were located in adjacent compartments at the rear of a light-tight box. Light first passed through separate filter channels, then through a common filter channel, and finally impinged on the white diffusing plate that formed the stimulus field. The respective stimulus flashes were set at different luminances with neutral density filters. The order in which the lamps flashed, the interval between the flash onsets, and the durations of the flashes were controlled with relays and resistance-varied Massey Dickinson interval timers (Type dt-17). The foreperiod was controlled with a Cramer interval timer (Type 412E-60S). Fixation in the darkened

room was guided by two dim red 23-min lights that were 135 min to either side of the stimulus field. The field was straight ahead of the S, at eye level, and was viewed binocularly with natural pupils from a headrest. The S responded by means of a sensitive microswitch (Unimax 2HBJ-1) and the latency of response was measured with a Hewlett Packard electronic counter (Model 522B).

Subjects

One highly trained S, the author, served.

Procedure

In programming a two-flash stimulus, it was necessary to specify the luminance and the duration of the first and second flashes, as well as the interval between the flash onsets. The two lamps were set to produce two flash luminances, a low and a relatively high value, respectively, during each session. The two luminances were to be paired in three two-flash sequences: (1) low preceding low, (2) low preceding high, and (3) high preceding high. Latencies obtained with the equally intense flashes of the first and third sequences were to be used in analyzing the latencies obtained with the second sequence. In order to perform that analysis, it was necessary to equate all other factors. Therefore, the three sequences were always used with the same flash durations and the same interflash intervals. Furthermore, all the two-flash stimuli that produced the functions for a given analysis (i.e., the latency as a function of the interflash interval, with flash luminances and flash durations as parameters) were presented during each hour-long session, with equal frequencies and in random order. In each experiment, a given two-flash stimulus was presented a total of 30 trials. Two experiments were conducted consecutively.

In Experiment 1, two groups of latency functions were sampled during separate sessions that were alternated. For one group of functions, the low and high luminances were -1.22 and $-0.12 \log fL$ (base 10); for the other, the luminances were -1.22 and $1.06 \log fL$. Other stimulus settings were the same in all sessions. Specifically, the durations of the first and second flashes in each stimulus were 4 msec. In addition, values of the interval between the flash onsets ranged from 10 to 500 msec. Each two-flash

Fig. 1. Medians of response latencies from Experiment 1. Data obtained during the same sessions are represented by the same symbols. The left panel is for paired flashes that were equal in luminance at -1.22 (filled circles and triangles), -0.12 (unfilled circles), and 1.06 (unfilled triangles) log fL. The right panel is for paired flashes that were unequal in luminance, with the first always -1.22 log fL, and the second either -0.12 (unfilled circles) or 1.06 (unfilled triangles) log fL.

stimulus was presented twice during the appropriate session. There were 15 sessions for each group of functions.

In Experiment 2, one group of latency functions was sampled during every session. The low and high luminances were -1.22 and 1.06 log fL, respectively. The first flash in the stimulus was always 4 msec, whereas the second flash was 4, 20, or 40 msec. Values of the interflash interval ranged between 10 and 500 msec. Each two-flash stimulus was presented once per session. There were 30 sessions.

At the start of a session, the S was adapted to darkness for 15 min. Then there were six practice trials. Twenty seconds after each trial, an auditory signal indicated that the S might start the next trial when he was ready with his head in position and his right index finger pressing the response button. He then pressed another button with his left hand and started the 2-sec foreperiod that preceded the stimulus. The S's task was to release the response button as soon as he saw the stimulus, but to continue pressing the button if not. A

button release within 1,000 msec after stimulus onset was regarded as a response. The response latency, measured from stimulus onset, was recorded to the nearest millisecond. In order to check any tendency to respond without attending to the stimulus, responses with latencies of 180 msec or less produced an auditory signal that informed the S he had anticipated. These anticipatory latencies were expected to occur quite infrequently (and did, in fact), but were to be discarded anyway before medians were obtained. On the other hand, if no response occurred within the 1,000-msec period, the trial was ended with a signal and no latency was recorded. Such misses were expected to be quite infrequent (and were, in fact), because both flashes in the stimulus were set at suprathreshold levels.

RESULTS

The results of Experiments 1 and 2 were in excellent agreement and are, therefore, considered together. The median (Figs. 1 and 2) and the semi-interquartile range (Figs. 3 and 4) of the response latencies are plotted as functions of the time that elapsed between the onsets of the paired flashes. Although the response statistics were positively correlated, the analysis is focused on the median, which reflected stimulus control more clearly. However, the median does not provide a very clear picture of whether retroactive interference occurred. This topic is considered last with reference to a derived measure (Fig. 5).

Fig. 2. Medians of response latencies from Experiment 2. The first of the paired flashes was always 4 msec in duration, but the second flash was 4 (triangles), 20 (circles), or 40 (squares) msec. The left panel is for paired flashes that were equal in luminance at -1.22 (filled symbols) and 1.06 (unfilled symbols) log fL. The right panel is for paired flashes that were unequal in luminance, with the first and second at -1.22 and 1.06 log fL, respectively.

Fig. 3. Semi-interquartile ranges of response latencies from Experiment 1. The symbols have the same meaning as in Fig. 1.

First, the latencies for paired flashes of the same luminance are evaluated, because they delimited the range of latencies for paired flashes of different luminances.

When the paired flashes were equal in luminance (Figs. 1 and 2, left panels), the second of the flashes influenced the latency only if two conditions were satisfied: (1) the luminance was $-1.22 \log fL$ and (2) the interval between the flashes was shorter than 50 msec. In that case, the median was decreased either by decreasing the interflash interval or by increasing the duration of the second flash (Fig. 2). Otherwise the medians for the two-flash stimuli were attributable to the first of the flashes. Although the first flash had not been presented alone, its predominance was guaranteed when the interval between the flashes was longer than the accompanying latency (e.g., the 500-msec interval at all luminances), because then the second flash was actually presented after the response had occurred. Since the latencies at -0.12 and $1.06 \log fL$ were not a function of the interval, the latencies were all determined by the respective first flashes; this is also true of the latencies for long intervals at $-1.22 \log fL$.

When a flash of $-1.22 \log fL$ preceded a flash of either -0.12 or $1.06 \log fL$ (Figs. 1 and 2, right panels), the latter had an effect until its onset was delayed by 100 msec. As the interflash interval was decreased from 100 to 10 msec, the median decreased continuously from the long value determined by a flash of $-1.22 \log fL$, and almost reached the short value determined by a flash of either -0.12 or $1.06 \log fL$,

Fig. 4. Semi-interquartile ranges of response latencies from Experiment 2. The symbols have the same meaning as in Fig. 2.

depending on the luminance of the second flash. Within that range of intervals, medians were ordered inversely in relation to the duration of the second flash (Fig. 2), but this relationship appeared to decline in significance as the interval was reduced. The decline would be expected if the second flash were actually displacing the first, rather than summing with it, because there was no duration effect when the first of the paired flashes was $1.06 \log fL$. Another criterion of interference is the rate at which the latency varies as a function of the interval between the flash onsets.

If interference were complete, the median would decrease 1 msec for each millisecond decrease in the interval (the decrease is slower for pairs of low-luminance flashes; also see Grossberg, 1970), because the median was measured from stimulus onset. In other words, total interference is equivalent to a change in the effective origin of the latency, from the onset of the first flash to the onset of the second. Nonetheless, this change in origin

would not be reflected by the semi-interquartile range, since it is a difference between two latencies that have the same origin. One finds, in fact, that the semi-interquartile range was independent of short interflash intervals, where it took the value obtained with a flash of $1.06 \log fL$ (in Figs. 3 and 4, compare the corresponding unfilled symbols in the right and left panels). The variability thus suggests total interference at short intervals for which the median decreased at a rate that approximated 1 msec/msec. A clearer picture is seen in Fig. 5, which presents a measure that incorporates the change in origin of the median.

Figure 5 shows the extent to which the influence of the initial low-luminance flash, L, was masked by a subsequent high-luminance flash, H. The two plotted measures were obtained by calculating the differences that are specified along the ordinate axes. A difference of zero at a given interflash interval, ΔT , means that the two successive flashes, LH (one of the identifying subscripts), produced a latency that equaled the latency for the second flash alone. The value of the latter was estimated using the latency obtained with the pair of high-luminance flashes, HH (the other identifying subscript), for the same interval and under the same conditions (which are indicated by the same unfilled symbols in the left and right panels of Figs. 1 through 4, respectively). Each function in Fig. 5 is the average for the conditions that are represented in one of the other figures.

The two measures in Fig. 5 are closely correlated functions of the interflash interval. According to both, the latency for

Fig. 5. The degree to which an initial flash of $-1.22 \log fL$ was "masked" by a following flash of either -0.12 or $1.06 \log fL$. The upper and lower panels contain average quantities based, respectively, on the semi-interquartile ranges and medians which are plotted in Figs. 1 through 4. Experiments 1 (squares) and 2 (circles) are distinguished. A value of zero indicates that the result for the pair of flashes equaled the result for the second flash alone (see the Results section for other details).

the paired flashes approximated the latency for the second flash alone when the interval was less than about 50 msec. Within that period of time, the measure based on the semi-interquartile range shows no deviation from 0 msec, while the median-based measure deviates from zero by less than 8 msec, the average semi-interquartile range of the latencies for the second flash alone. However, the latter measure tends to be negative in sign, suggesting that the calculations slightly overcompensated for the actual effect of the second flash, except perhaps at the 10- and 20-msec intervals. Except at those intervals, therefore, it seems unlikely that the latency was initiated by the second flash, as total interference would require. The influence of the first flash was, in any case, negligible at short intervals. Beyond 50 msec, its influence grew rapidly until it alone governed the latency (the continuous decrease in the median-based measure beyond 100 msec was produced by subtracting the intervals in order to change the origin).

DISCUSSION

In agreement with previous determinations of simple detection latencies (Fehrer & Raab, 1962; Grossberg, 1970; Harrison & Fox, 1966; Schiller & Smith, 1966, Experiment I), paired equally-intense flashes summated, with both flashes discernibly influencing the

response, when the flashes were low in luminance and the interval between the flashes was less than 50 msec. When the luminance of the second flash was increased, so that it produced a latency that was about 70 msec shorter than the latency for the initial low-luminance flash, the two-flash interaction changed in two ways. First, it was extended to an interflash interval on the order of 100 msec, illustrating the "overtake" phenomenon that has often been discussed in papers on backward masking (e.g., Battersby & Wagman, 1959; Donchin & Lindsley, 1965; Kahneman, 1968, p. 419). Second, the first flash had no observable effect when the interval between the flashes was less than about 20 msec, providing a behavioral analogue of the retroactive interference observed in neural data (Donchin & Lindsley, 1965; Schiller, 1968, determination a). The response to the two-flash stimulus was then indistinguishable from the response to the second flash alone, as if the response to the paired flashes was initiated and determined by the second flash (cf. Fehrer & Biederman, 1962).

These findings are consistent with the operation of an integrative mechanism that is sensitive to the rate at which stimulation impinges (e.g., Grossberg, 1968, 1970). The retroactive interference would then be a limiting case of temporal integration, in which the second flash is processed at a

rate that allows it to override the influence of the first flash. This interpretation is consistent with the neural data, whose pertinence to formulations concerned with backward masking has been discussed elsewhere (e.g., Kahneman, 1968, p. 420). The present study has helped to reduce the operational distance between the neural studies and conventional behavioral studies of backward masking. However, in contrast with the latter, where the S discriminates whether the stimulus contains the test plus the mask or the mask alone (e.g., Schiller & Smith, 1966, Experiment II), the S in this study discriminated the onset of the stimulus light. Attention is therefore focused on the S's response in the masking situation, particularly its perceptual basis (e.g., Kahneman, 1968, p. 410).

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NOTES

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