The effect of stimulus duration on the persistence of gratings

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The persistence of gratings varying in spatial frequency and exposure duration was measured using a stimulus-blank alternation method. Persistence was found to lengthen with increasing spatial frequency and to shorten with increasing exposure duration. For each spatial frequency, persistence decreased linearly with a slope of approximately -0.75 as duration increased for short stimulus durations. For longer stimulus durations, the rate of decline in persistence with increasing duration was reduced, the slope being approximately -0.13 . The stimulus duration at which the change in slope of the persistence-duration relationship occurred was shown to increase with increasing spatial frequency and was approximately equivalent to the critical duration for each spatial frequency. The data were consistent with an interpretation of persistence in terms of a temporal integration component and a second, possibly cortically located, component.

It has been shown, in a range of experimental situations, that the visual response to a stimulus frequently outlasts the actual duration of the stimulus (Efron, 1970a; Haber & Standing, 1969, 1970; Sperling, 1960). This continuation of a response after the offset of a stimulus is known as visual persistence (Briggs & Kinsbourne, 1972) or visual information store (Meyer, Lawson, & Cohen, 1975). Persistence, which appears to result from neurological activity in the retina and/or visual cortex is influenced by stimulus variables in a manner similar to other temporal and spatial properties of the visual system. Its duration is increased by decreased adaptation level (Haber & Standing, 1969, 1970), luminance (Bowen, Pola, & Matin, 1974; Efron, 1970b), and contrast (Bowling, Lovegrove, & Mapperson, 1979). Persistence duration is also lengthened by increasing the spatial frequency of grating stimuli (Bowling et al., 1979; Meyer & Maguire, 1977) and by decreasing the duration of the stimulus (Efron, 1970a, 1970b; Haber & Standing, 1970). The relationship between the effects of the duration and spatial frequency of gratings upon persistence was the subject of this investigation.

Haber and Standing (1970) found that the persistence of a letter array stimulus declined with increasing stimulus duration, decreasing to nearly zero for stimulus durations longer than 350 msec. Efron (1970a, 1970b) obtained a similar result with a low-intensity (8.8 cd/m^2) colored circular field on a dark background. In all of these experiments, the total apparent duration of the stimulus remained constant for stimulus durations ranging from near 0 to over 100 msec. For durations within this range, the duration of persistence decreased linearly with a slope of -1.0 as stimulus duration increased. Once the duration of the stimulus exceeded 100-200 msec, however, either negligible persistence was observed (Efron, 1970b) or the duration of per-

sistence remained constant with increasing stimulus duration (Efron, 1970). The stimulus duration at which the change of slope in the persistence by duration relationship occurred was called the "critical duration" and was estimated to be about 130 msec (Efron, 1970a, 1970b). The data of Haber and Standing (1970), with a letter array stimulus and light pre- and postadapting fields, indicate that the critical duration is approximately 200 msec under these conditions.

Data obtained by Di Lollo (1977) and Di Lollo and Wilson (1978) also indicate that an inverse relationship between persistence and stimulus duration exists for stimulus durations up to 100-130 msec when the stimuli are light pulses presented on a dark background. The stimulus durations for which this relationship holds are similar to the durations over which time-intensity reciprocity (Bloch's law) occurs under low illumination. The critical duration over which temporal integration occurs is approximately 100 msec under this condition (Barlow, 1958; Roufs, 1972). It is hypothesized that the inverse relationship between stimulus duration and persistence is due to the limited temporal resolution of the visual system, the response to a brief stimulus persisting because it is "smeared" over the period of temporal integration of the visual system. Consequently, at least one component of persistence may be identified with temporal integration. Further evidence for this identification may be obtained from the observation that variables which affect integration time affect persistence similarly. The durations of both temporal integration and persistence increase with decreasing illumination (Bowen et al., 1974; Efron, 1970b; Roufs, 1972) and with increasing spatial frequency of grating stimuli (Breitmeyer & Ganz, 1977; Bowling et al., 1979; Legge, 1978; Meyer & Maguire, 1977).

Many measures of persistence duration indicate that this is often considerably longer than the critical duration (Bowling et al., 1979; Haber & Standing, 1969, 1970), presumably indicating that factors other than integration time may contribute to persistence. Appreciable persistence may also be observed for stimulus durations exceeding the critical duration under some circumstances (Efron, 1970a). A second persistence component, which possibly occurs at the cortical level, is hypothesized to exist in addition to temporal integration at the periphery (Breitmeyer & Ganz, 1976; Eriksen & Schultz, 1978). There is some evidence that cortical elements are involved in persistence (Haber & Standing, 1969; Meyer, 1977; Meyer et al., 1975).

These hypotheses may be tested by investigating the effect of stimulus duration on persistence under circumstances in which the integration time of the stimuli can be manipulated. This can be done by varying the spatial frequency of gratings, since the critical duration increases with increasing spatial frequency (Breitmeyer & Ganz, 1977; Legge, 1978). It was hypothesized that the stimulus durations at the change in the slope of the persistence by duration relationships would be similar to the critical durations and increase with increasing spatial frequency. The persistences of gratings varying in spatial frequency and exposure duration were consequently measured. Two linear regression lines were fitted to the data for each spatial frequency, and the points of intersection of these lines were observed for each spatial frequency. The stimulus durations at which the point of intersection occurred (critical duration) were consistent with threshold measures of critical duration, increasing with spatial frequency.

METHOD

Apparatus

The stimuli were presented by means of a Scientific Prototype three-channel tachistoscope (Model GB). The stimuli were three photographic reproductions of oscilloscope-generated sinusoidal gratings subtending spatial frequencies 1, 4, and 12 cycles/deg. The contrast of all gratings was estimated to be .44 from a plot of Michelson contrast against the output level of the oscilloscope (in volts). The space-average luminance of the gratings and of the blank with which they alternated was kept constant at 9 cd/m².

Subjects

Twelve subjects were used. These were volunteers, predominantly postgraduate students and staff of the Psychology Department. Several had participated previously in similar experiments, but the task was new to a number of subjects. All had normal, or corrected-to-normal, vision.

Procedure

Persistence was measured in the same manner as described by Bowling et al. (1979). The grating stimulus was alternated with a blank interstimulus interval (ISI) for 10 cycles. The duration of the ISI was varied in 10- or 20-msec steps, and the subjects were asked to report whether a distinct blank interval was visible between each grating cycle. A double random staircase method was employed

(Cornsweet, 1962). For each block of trials, the initial ISIs of the ascending and descending staircases were chosen so that they were 100 msec apart. The blank was not visible at the initial ISI of the ascending staircase and was clearly visible at the initial ISI of the descending staircase. A few initial trials were generally necessary to establish these starting points. Six threshold reversals were obtained in each block of trials.

A total of 18 blocks of trials, each of which comprised one stimulus condition, was performed on each subject. Each stimulus condition comprised one of the three spatial frequencies (1, 4, and 12 cycles/deg) at one of six durations (50, 75, 100, 150, 200, 300 msec). Two experimental sessions of approximately 1 h duration were employed. An initial practice block of trials preceded the experimental blocks in each session. The order of presentation of the stimulus conditions was randomized, with the constraint that conditions involving each spatial frequency be separated from each other by conditions involving the other two spatial frequencies. This was to minimize possible adaptation effects.

RESULTS

The data are shown in Figure 1. For each spatial frequency, a decline in persistence was observed with increasing stimulus duration. The analysis of variance indicated that the main effect of duration was highly significant [$F(5,55) = 17.08$, $p < .001$]. A highly significant spatial frequency effect was also observed [$F(2,22) = 56.64$, $p < .001$]. Longer persistence was observed with increased spatial frequency at all stimulus durations. A significant Spatial Frequency by Duration interaction [$F(10,110) = 3.02$, $p < .01$] indicated that the rate of decline of persistence with increasing duration differed across spatial frequencies. Two linear regression lines were fitted to the data for each spatial frequency by the method of least squares. The stimulus durations and persistence values of the points of intersection of the two lines were obtained.

These values, together with the slopes of the regression lines, are given in Table 1. There is some variation between the slopes with different spatial frequencies (see Figure 1), but these do not appear to follow a regular pattern. The mean initial slope over the three spatial frequencies was $-.75$, and the mean secondary slope was $-.13$. The values of critical duration derived as indicated in Figure 1 were plotted against spatial frequency (Figure 2). A linear relationship between critical duration and spatial frequency with a slope of 8.3 was obtained.

Table 1
The Slopes of the Linear Regression Lines Fitted to the Data and the Stimulus Durations at the Points of Intersection (Critical Durations, in Milliseconds) for Each Spatial Frequency (in Cycles/Degree)

Spatial Frequency	Slope		Critical Duration
	Initial	Secondary	
1	-.62	-.14	60
4	-.89	-.09	88
12	-.74	-.16	152

Figure 1. The relationship between stimulus duration and persistence for gratings of spatial frequencies of 1, 4, and 12 cycles/deg. The critical duration is obtained from the points of intersection of the two regression lines.

Figure 2. The stimulus durations of the points of intersection of the two regression lines describing the persistence-duration relationships, plotted against the spatial frequency of the gratings.

DISCUSSION

The data indicate that the persistence of gratings of short exposure duration declines linearly with increasing stimulus duration for each spatial frequency investigated. For long stimulus durations, there was only a shallow decline in persistence with increasing duration. This is consistent with the data of Efron (1970a) and Haber and Standing (1970). The stimulus duration at which the change in slope occurred (the critical duration) was found to increase linearly with increasing spatial frequency (see Figure 2). This increase with increasing spatial frequency is similar to the observed increase in threshold measures of critical duration with increasing spatial frequency (Breitmeyer & Ganz, 1977; Legge, 1978), although the values for critical duration derived in this experiment are somewhat shorter than Legge's (1978) values. Critical duration is known to vary with other stimulus conditions such as luminance (e.g., Roufs, 1972) and may differ for threshold and suprathreshold measurements and for monocular and binocular viewing conditions (Ueno, 1977). Thus, the observed differences between the values of critical duration obtained by Legge (1978) and the values for the stimulus duration at the change of slope do not necessarily invalidate the identification of the latter with critical duration. In addition, it is not claimed that these values represent accurate measures of critical duration under the conditions of the experiment, being only approximate estimates of the duration of temporal integration for the three spatial frequencies employed.

The results of this experiment have indicated that persistence duration is dependent to some extent upon the integration time of the visual system and consequently increases under conditions where the critical duration is increased. The increased persistence of high-frequency gratings observed in this and previous studies (Bowling et al., 1979; Meyer & Maguire, 1977) may thus be partly due to the increased integration times of gratings of these frequencies. The increase in persistence with increased spatial frequency cannot be entirely attributed to longer integration times, however, since this relationship is also observed when the stimulus durations are considerably longer than the integration times of all three spatial frequencies (see Figure 1).

Further evidence that persistence is dependent upon spatial frequency at long stimulus durations can be obtained from a study by Corfield, Frosdick, and Campbell (1978). These authors used techniques similar to those used in this study to measure persistence and showed that "grey-out elimination" increased with increasing spatial frequency for exposure durations of 600-900 msec. The existence of substantial persistence at long durations may be interpreted as indicating that, using the method of measurement reported in this paper, an additional

factor (or factors) may contribute to visual persistence apart from temporal integration. Not all methods of measurement of persistence, however, provide evidence for this factor. For example, Haber and Standing (1970), who used a different technique, found that persistence was virtually zero for long-duration stimuli. In addition, methods of measuring persistence that involve integration of two or more successive stimuli do not provide any evidence for a second component (e.g., Di Lollo, 1977; Di Lollo & Wilson, 1978). It is possible that the characteristics of the second component differ from those of the integration component and that the second component is therefore not detected by all experimental methods. It may originate at later stages of the visual system, possibly as a result of the prolonged activity of sustained cells at the cortical level (Breitmeyer & Ganz, 1976).

Under the conditions of this experiment, the slope of the initial decline in persistence with increasing stimulus duration was found to be approximately $-.75$, instead of -1.0 as expected. This result may have been due to the method of measurement employed, since different subjects tended to adopt very different criteria for detection of the blank ISI. Subjects who indicated that they could identify the blank interval at short ISIs generally showed smaller effects of stimulus duration than subjects who identified blanks at considerably longer ISIs. A supplementary experiment, in which the same procedure was carried out using repeated sessions with a single subject (who adopted a long ISI criterion) indicated that, under these conditions, the initial slope was much closer to -1.0 .

The slope of $-.75$ obtained in this experiment may also possibly be explained by comparison with the results of the temporal integration experiments of Breitmeyer and Ganz (1977) and Legge (1978). In each of these investigations, it was found that perfect temporal integration does not occur when the contrast detection thresholds of grating stimuli are measured. The initial slope of the Log Contrast by Log Duration relationship in these experiments was found to be approximately $-.70$ rather than -1.0 . The relationship between stimulus and contrast at threshold is thus $C \times (t)^{.70} = k$ (Breitmeyer & Ganz, 1977) rather than $C \times t = k$ (Bloch's law). This would cause integration of short-duration stimuli to take place over a shorter period of time than the long-duration stimulus, resulting in the relationship obtained in this experiment. The slope of $-.75$ may thus be due to imperfect temporal integration occurring under the conditions of the experiment.

The results described by this paper are generally in agreement with those obtained by previous investigators when the persistence of stimuli varying in duration was measured. They support the hypothesis that many investigations of persistence apparently include two separate persistence components in the measurement and that the first of these components may be identified

with temporal integration. The nature of the second persistence component has not yet been ascertained, apart from the possibility that it originates in the visual cortex (Meyer, 1977; Meyer et al., 1975).

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