Orientation effects on line afterimages*

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Lines of various orientations were viewed as prolonged afterimages in six experiments. The duration of unitary appearance was not influenced by line orientation for monocular afterimages, but there was a marginal effect for afterimages generated binocularly; vertical and horizontal lines tended to be visible for longer than did 45-deg lines. Measures of fragmentation frequency and the latency to the first disappearance did not vary reliably with orientation under any conditions. Binocular afterimages lasted longer than did monocular ones, but generally showed the same pattern of fragmentations. These results are compared with those from experiments using optical stabilization and steady fixation, in which orientation differences have been reported.

Lines viewed under steady fixation, optical stabilization, or as afterimages tend to appear and disappear in a unitary manner (Evans, 1967; MacKinnon, Forde, & Piggins, 1969; Pritchard, Heron, & Hebb, 1960). Notwithstanding the problems associated with making inferences from such perceptual functioning (Weinstein, 1969), it remains popular to attribute these effects to the operation of linear analyzers in the human visual system, the presence of which is inferred from neurophysiological experiments with cat and monkey (Hubel & Wiesel, 1962, 1968). A somewhat less speculative approach relates to the differential response in the human visual system to patterns of different orientation (Campbell & Maffei, 1970; Maffei & Campbell, 1970): the average evoked potential to oscillating gratings is greater when they are vertical or horizontal than when they are at 45 deg. This orientation selectivity in the EEG response would appear to correspond to the selectivity that has been found in a range of perceptual tasks (see Howard & Templeton, 1966). Assuming that both the disappearance of lines and the pattern of EEG responses reflect the operation of some hypothetical "units" in the human visual system, it is then of interest to find out if the former displays the orientation selectivity evidenced by the latter. The work to date on this question is equivocal. Evans (1967), using one well-trained S, failed to find any differences in the duration of visibility of line afterimages oriented at 0, 30, 60, and 90 deg. Atkinson (1970), on the other hand, found marked orientation differences using a wider range of line orientations: vertical and horizontal lines were visible for longer than

intermediate orientations, the shortest duration being at around 45 deg. This result was obtained for three Ss viewing parafoveal and two Ss viewing foveal afterimages. The complexity of the situation is increased when the work on optical stabilization is consulted; Schmidt, Fulgham, and Brown (1971) reported that horizontal lines disappear less frequently than either vertical or 45-deg lines. Furthermore, there were no differences in the duration of disappearance with orientation (Cosgrove, Schmidt, Fulgham, & Brown, 1972). This discrepancy between the results with optical stabilization and afterimages is rather puzzling in view of MacKinnon et al's (1969) comparison and equation of these two procedures with respect to the pattern of fragmentation of outline figures. It is also surprising that such large differences were found between vertical and horizontal lines because almost every other orientation task shows these to be similar, as do the EEG recordings. The closely related disappearances that occur under steady fixation yield similar results for horizontal and vertical lines (Craig & Lichtenstein, 1953; Goldstein, 1967).

The present experiments examined the effect of line orientation on afterimage duration and, in some cases, fragmentation. The first two experiments involved afterimages produced monocularly, while the second two generated them binocularly; these different viewing conditions were compared in two further experiments.

EXPERIMENT 1

Atkinson (1970) found the greatest duration differences between 0-deg (vertical) and 45-deg lines, and these were used in this experiment, together with a horizontal line. Both Atkinson and Evans recorded the duration of visibility of the afterimages for 1 min only, as this was said to be the period

in which they were clearly visible. They reported that the afterimages often lasted considerably longer than 1 min. Here the inspection period was 100 sec.

Method

Apparatus. Afterimages were produced by the discharge of a Mecablitz 502 flashgun, the output of which was 120 J with a duration of 1 msec, according to the manufacturer's specifications. The face of the flashgun was located 57 in. from S's eye; masks with central apertures of 2 x 1/8 in. were placed directly against the face so that the light passing through the aperture provided the only source of stimulation upon discharging the flashgun. The aperture orientations were 0, 45, or 90 deg, each of which subtended 2 x 1/8 deg at the eye; they were surrounded by luminous paint so that S could readily locate the position at which to fixate in the darkened room. A chin and forehead support roughly controlled the position of S's head. A microswitch operated by S's right hand was connected to a timer that recorded the cumulative switch depressions.

The apparatus was situated in a dark room.

Subjects. Fifteen Ss from an introductory course in psychology participated. In this and subsequent experiments, those Ss who normally wore corrective spectacles did so during testing.

Procedure. The instructions to S were to depress the switch for the period that the whole line was visible; the possibility of line disappearance and reappearance was mentioned, and it was stressed that the switch depressions should correspond to the visibility of the whole line. The inspection period was 100 sec, during which S viewed the afterimage with eyes closed.

Each eye was presented with each line orientation, resulting in six trials. The intertrial interval was 5 min, and, consequently, the interval between flashes was 6 min 40 sec. The afterimages were generated alternately in each eye; the order of presentation of the orientations was randomized for the first three presentations, and this order was repeated for the last three trials. The nonviewing eye was occluded.

Results and Discussion

The mean unitary appearance durations of the lines at different orientations are given in Table 1, together with the standard deviations. The 45-deg line was visible for a slightly shorter period than the 0- and 90-deg lines, with the left eye; but the

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Table 1
Mean Durations (Seconds) and Standard Deviations of Visibility of the Whole Line Afterimage During 100-Sec Inspection Period as a Function of Orientation and Eye Used

	Left Eye			Right Eye		
	Orientation (Deg)					
	0	45	90	0	45	90
Mean	77.3	72.5	76.7	79.2	80.3	78.6
SD	15.3	22.3	14.0	19.2	11.6	19.7

reverse was obtained for the right eye. The afterimage duration did not differ significantly with the orientation of the line ($[F(2,28) = 0.22, p > .05]$, or with the eye used for observation $[F(1,14) = 2.23, p > .05]$. The interaction between eye and orientation was not significant $[F(2,28) = 0.59, p > .05]$.

As is evident from Table 1, the afterimages were visible for a large percentage of the time in unitary form. The relatively small standard deviations indicate the consistency of the effect over Ss. Atkinson (1970) employed only a unitary appearance response category and found a smaller percentage duration for all line afterimages, but markedly so for the 45-deg orientation (about 50%). Evans (1967), requiring unitary and partial responses, reported virtually no unitary disappearances but between 50% and 60% partial disappearances. It is unlikely that the differences in the above studies could be attributed to either the dimensions or luminous flux associated with the primary stimulus: line length has relatively little effect on unitary appearance (Atkinson, 1970; Evans, 1967), as does the luminous flux, which has some small influence on the total duration of the afterimage (Atkinson, 1970; Forde, 1971).

The results of this experiment support those of Evans (1967) in that no differences in the duration of line afterimages were evidenced as a function of line orientation. They do not indicate any pattern of duration differences similar to the fragmentation differences reported by Cosgrove et al (1972) and Schmidt et al (1971).

EXPERIMENT 2

The previous experiment recorded only the duration of unitary appearances, consequently no direct comparison could be made to the investigations using optical stabilization. The present experiment, using essentially the same design as the first, examined both visibility duration and fragmentation frequency. It was noted in Experiment 1 that many of the Ss saw the afterimages for considerably longer than the 100-sec inspection period. Accordingly, the viewing time was increased in this

experiment to 2 min, and the data from the first and second minutes were analyzed separately.

Method

Apparatus. The apparatus¹ was different from that used in Experiment 1 and has been described in detail elsewhere (MacKinnon, 1971). The principle was essentially similar to that outlined above: A Multiblitz IIB flashgun provided a brief (0.3 msec), intense (400 J) flash that passed through a linear aperture subtending $2 \times \frac{1}{4}$ deg at the eye. The stimulus orientations examined were 0, 45, 90, and 135 deg. A microswitch by S's hand activated one channel of an Esterline-Angus event recorder.

Subjects. Four Ss, well-practiced in observing afterimages, took part in this experiment.

Procedure. The flash was initiated by S such that an afterimage was generated in one eye and viewed with eyes closed for 2 min. Disappearances of all or part of the line were indicated by depressing a microswitch, and the switch was not pressed when the whole line was visible. Each line orientation was presented to each eye; the orders were randomized and examined in separate sessions.

Results and Discussion

The duration of visibility and the number of fragmentations of the afterimages were extracted from the records for both the first and second minutes of observation. The mean values for these measures are given in Table 2. The afterimage duration was

not significantly influenced by the line orientation in either the first or second minutes $[F(3,9) = 0.87$ and $2.44, p > .05$, respectively]. The same result was obtained for the number of fades within the first and second minutes $[F(3,9) = 0.42$ and $0.45, p > .05$, respectively). In addition, the eye factor and its interaction with orientation were not significant in any instance ($p > .05$).

These results support those from Experiment 1 in finding no evidence for a difference in the duration of the whole afterimage of a line as a function of its orientation. This applied to both the first and second minutes of observation. Therefore, even when the afterimage is weak or negative it is equally visible in all these orientations. Moreover, the absence of any differences in the fragmentation frequency with orientation is at variance with Schmidt et al's (1971) and Cosgrove et al's (1972) data with optically stabilized lines: they found that horizontal lines disappeared as a whole less frequently than those at either vertical or 45 deg. As mentioned above, this difference in the number of disappearances was not accompanied by any variations in the duration of disappearance (and thus of visibility). However, since a unitary appearance response category was employed here, the results cannot be compared exactly: the stabilized retinal image experiments recorded whole and partial disappearances, whereas this afterimage one recorded whole line visibility alone. The periods in which the afterimage was not seen in its entirety were mainly whole disappearances but included partial line visibility, too. Consequently, it was not possible to dissociate these measures. Nonetheless, because both whole and partial fragmentation show orientation selectivity in the first few minutes of optical stabilization (Cosgrove et al, 1972), a similar effect would be expected for the afterimage disappearance data, too. Such is

Table 2
Mean Durations (Seconds) of Unitary Visibility and Number of Fragmentations of Line Afterimages Over the First and Second Minutes of Observation as a Function of Line Orientation and Eye Stimulated

TABLE 1. Effect of Lens Orientation and Eye Separation								
	Left Eye				Right Eye			
	Orientation (Deg)							
	0	45	90	135	0	45	90	135
	First Minute							
Duration	43.2	44.9	44.0	47.9	42.9	45.5	45.4	43.9
Fragmentation	3.8	3.8	3.5	4.0	3.5	4.8	3.8	3.2
	Second Minute							
Duration	36.0	41.4	46.9	40.9	36.9	33.9	44.4	41.8
Fragmentation	4.0	4.2	2.8	4.1	4.0	4.8	4.8	4.5

Table 3
Mean Durations (Seconds) and Standard Deviations of Whole Afterimage Visibility for Binocularly Generated Line Afterimages as a Function of Orientation*

	Orientation (Deg)		
	0	45	90
Mean	120.4	111.6	119.6
SD	37.2	42.8	34.4

*The observation period was 3 min.

clearly not the case. For monocular afterimages, the data for both duration and fragmentation are in agreement in showing no dependence upon line orientation.

EXPERIMENT 3

Vertical and horizontal lines fragment less frequently than 45-deg lines when they are viewed parafoveally (Craig & Lichtenstein, 1953). This orientation selectivity is attenuated in Ss having only one eye compared to normally sighted Ss under monocular observation, and the fragmentation frequency is greatly reduced (Goldstein, 1967). Forde (1971) has extended this latter finding by showing that functionally monocular observers evince markedly fewer fragmentations when viewing afterimages. Forde has suggested that certain aspects of stimulation of binocular cells in the visual cortex are necessary for fragmentation to occur. Goldstein, on the other hand, argued that the absence of binocular rivalry in the one-eyed observers resulted in the stability of peripheral targets. This argument can be applied to the disappearance of monocular afterimages: the nonstimulated eye is in rivalry with the stimulated one and, when the former dominates, the afterimage disappears. Since it is well established that a patterned field will tend to dominate an unpatterned one, this would account for the predominance of the afterimage eye, although this factor would clearly interact with the photochemical status of each eye.

It may, then, be more meaningful to search for orientation differences in binocularly generated afterimages. According to Goldstein's view, such afterimages would merely lose contrast and not fragment, since no rivalry would be operating. If such is the case, it is essential to use an inspection period that is sufficiently long to permit disappearance of the afterimage. Preliminary studies had shown that a 3-min viewing period was generally long enough for the afterimage to have disappeared completely.

Method

Apparatus. The apparatus was the

same as that used in Experiment 1.

Subjects. Twenty-four Ss, the majority of whom had had no prior experience with afterimage experiments, were tested.

Procedure. A brief description of the experimental arrangement was given, with instructions to press the microswitch when the line afterimage was visible in its entirety. The S was then dark adapted for 10 min, after which the first afterimage was generated on corresponding areas of each eye. The clearly visible luminous surround to the apertures ensured binocular fusion of the line stimulus prior to generation of the afterimage. The afterimage was observed with closed eyes throughout the following 3 min. The intertrial interval was 5 min, during which S remained in the dark. Each S viewed line afterimages of 0, 45, and 90 deg, the order of which was counterbalanced over the group so that four Ss were tested in each of the six possible orders.

Results and Discussion

The mean duration of visibility of the whole afterimages is shown in Table 3, together with the standard deviations. The vertical and horizontal lines were visible for about 9 sec longer than the 45-deg afterimage, but this difference was not statistically significant [$F(2,46) = 1.20, p > .05$]. Contrary to the predictions of the rivalry hypothesis, there were consistent disappearances reported (although not measured) under this condition. Such disappearances have also been reported for binocular afterimages of vertical and horizontal lines (Forde, 1971).

The results of this experiment, though inconclusive, are more suggestive of orientation selectivity in afterimage duration than those employing monocular observation. This suggestion is reinforced by the consideration of first-presented afterimages only: if the eight Ss who viewed 0-deg afterimages first were compared with those observing the 45-deg and those with the 90-deg lines, the mean durations were 123.5, 92.9, and 102.0 sec, respectively. However, not too much importance should be attached to the comparison of first and later afterimages due to the large individual differences evident in the former condition.

EXPERIMENT 4

The orientation selectivity surmised in Experiment 3 was examined more thoroughly in this experiment. A smaller number of Ss were studied, but each underwent six sessions so that any effects of the order of presentation of the afterimages could be assessed.

Table 4
Means for the Duration (Seconds), Number of Fragmentations, and Time to First Fragmentation for Binocular Line Afterimages as a Function of Orientation During 3-Min Inspection

	Orientation (Deg)		
	0	45	90
Duration	130.5	119.1	125.0
Fragmentation	4.57	4.55	4.52
Time to First Fragmentation	82.4	82.2	82.7

Method

Apparatus. The apparatus was the same as that used in Experiment 1, with the addition of a Miniscript chart recorder that gave a complete profile of the pattern of switch depressions.

Subjects. Six Ss, well-practiced in observing afterimages, participated.

Procedure. The procedure was essentially similar to that of Experiment 3, except that each S was tested in six separate sessions, one for each of the possible orders of presentation.

Results and Discussion

The results, averaged over sessions and Ss, are given in Table 4, both for the whole duration of visibility and for the number of fragmentations. The order of presentation did not significantly influence afterimage duration [$F(5,25) = 0.04, p > .05$], but the orientation of the lines was significant [$F(2,10) = 7.73, p < .01$]. Line orientation did not have any effect on the fade frequency [$F(2,10) = 0.14, p > .05$]. A further measure, the time to the first fragmentation, was also extracted from the records, and its mean values are shown in Table 4. This factor showed no orientation selectivity [$F(2,10) = 0.13, p > .05$].

The pattern of results is very similar to that of Experiment 3, merely the duration of each afterimage is longer. The difference in duration between the 0- and 90-deg-line afterimages and the 45-deg one is about 8 sec. This difference was found to be significant in the present experiment due to the greatly reduced variance consequent upon repeated testing of well-practiced Ss.

As a methodological point, it is of interest to note that in this experiment, which yielded a significant orientation effect for afterimage duration, no similar differences were evidenced by the other response indices—particularly fade frequency. This is the reverse of the results reported by both Schmidt et al (1971) and Cosgrove et al (1972), in which orientation differences were found for fragmentation but not for duration of optically stabilized lines; the latter situation also holds for

Table 5
Mean Durations (Seconds) and Number of Fragmentations for Monocularly and
Binocularly Generated Line Afterimages as a Function of Orientation

		Monocular			Binocular			Orientation F	Observation F
		Orientation (Deg)							
		0	45	90	0	45	90		
First Minute	Duration	45.2	44.4	46.2	51.7	48.8	52.7	1.07	9.52*
	Fragmentation	4.1	3.6	3.2	1.8	2.0	2.1	0.67	29.46†
Second Minute	Duration	27.4	29.8	33.1	38.9	36.8	42.3	1.72	11.02**
	Fragmentation	4.1	4.1	3.3	3.2	4.1	3.6	1.15	0.10
Third Minute	Duration	12.6	12.7	13.0	20.9	19.7	24.1	0.94	5.94*
	Fragmentation	2.5	2.3	2.4	3.1	2.9	2.9	0.10	1.24
Total	Duration	85.2	86.9	92.3	111.5	105.3	119.1		
	Fragmentation	10.7	10.0	8.9	8.1	9.0	8.6		
Time to First Fragmentation		22.7	29.5	40.4	50.2	47.0	57.2	3.13	10.08**

* $p < .05$ ** $p < .01$ † $p < .001$

Note—The data are given for each minute of inspection separately, together with the total over 3 min. The time elapsing before the first fragmentation is also included. The *F* ratios for the orientation and observation factors are given for each minute of observation.

peripherally viewed lines under steady fixation (Craig & Lichtenstein, 1953).

EXPERIMENT 5

The first two experiments using monocular observation provided no evidence to support the hypothesis that afterimage duration differs with line orientation, whereas the second two, employing binocular observation, yielded more positive indications of such differences. The data from these various experiments cannot, however, be compared directly, due to the subject and procedural differences involved. This experiment was designed to compare the effects of monocular and binocular observation under the same conditions and in the same Ss. If the above results are borne out, it would be predicted that no orientation selectivity would be found with monocular viewing, but that the 45-deg afterimage would be visible for a shorter period than those at 0 and 90 deg under binocular observation. Statistically, this prediction would be corroborated by a significant interaction between observation conditions and afterimage orientation in the analysis of variance.

Method

Apparatus. The apparatus was the same as that used in Experiment 1, with the addition of a Rustrak event recorder.

Subjects. Twelve Ss took part in this experiment. Most of them had previous experience of observing line afterimages.

Procedure. The procedure was essentially similar to that of Experiment 3. The aperture orientations were 0, 45, and 90 deg, and the inspection period was 3 min. Preliminary dark adaptation was for 15 min, and the intertrial interval was 5 min. Each S was tested in two sessions, one for monocular and one

for binocular observation. The order of these factors was counterbalanced over Ss, as was the presentation sequence of the orientations.

Results and Discussion

The data for the duration of visibility and the number of fades were averaged over the first, second, and third minutes of the inspection period separately. These values are given in Table 5, together with the total whole duration and number of fragmentations. The mean times from the flash to the first fragmentation are also included. Analyses were carried out on the data for each minute separately, and the *F* ratios for the orientation and observation main effects are appended in Table 5. In no instance was either the duration of visibility of the afterimages or the fragmentation frequency significantly influenced by the line orientation. Binocular afterimages were visible in complete form for significantly longer than those generated monocularly in each minute of inspection. There were significantly fewer fragmentations in the first minute for binocular afterimages, but not in subsequent minutes. The latency to the first fragmentation was not differentiated by line orientation, but it was significantly longer for afterimages generated binocularly. In no single analysis did the interaction between orientation and observation conditions achieve statistical significance.

It is clear from Table 5 that the results for monocular observation support those of Experiments 1 and 2 in providing little indication of orientation selectivity in either duration or fade frequency. Moreover, the binocular orientation selectivity evidenced in Experiments 3 and 4 was shown in this experiment, too; the total duration difference between the 45-deg line afterimage and the average

of the 0- and 90-deg ones is approximately 10 sec. Similar, but smaller, differences were evident in each minute of observation, but the interactions between orientation and observation conditions were not statistically significant.

Binocular afterimages were visible for longer than monocular ones for each minute of observation. This might have appeared obvious simply on the grounds of imparting twice as much energy to the visual system in the binocular condition. However, variation in the luminous flux of the primary stimulus to one eye does not markedly affect the pattern of fragmentation or the duration of afterimages (Atkinson, 1970; Forde, 1971). Duration differences between monocular and binocular afterimages were significant in each minute of inspection, whereas there were fewer binocular fragmentations only in the first minute. This indicates once more the superior sensitivity of duration over fragmentation measures. This factor may have been confounded in part by the increased duration of the binocular afterimages, although this was also the case in the first minute.

EXPERIMENT 6

All the previous experiments utilized the unitary response category alone. This experiment was addressed to the same problem as the preceding one, but required both whole and partial responses. In order to compare monocular and binocular viewing within the same session, only two orientations, 0 and 45 deg, were examined.

Method

Apparatus. The apparatus was similar to that used in Experiment 5. The face of the flashgun was located 28.5 in. from S's eyes. The aperture orientations were 0 and 45 deg,

Table 6
Means for Whole and Partial Durations of Visibility (Seconds) and Fragmentations for 0-Deg and 45-Deg Line Afterimages Generated Monocularly and Binocularly

			Monocular		Binocular			
			Orientation (Deg)					
			0	45	0	45	Orientation F	Observation F
Whole	First Minute	Duration	26.4	24.4	36.6	36.6	0.23	35.96†
		Fragmentation	2.4	2.0	2.2	2.2	1.36	0.00
	Second Minute	Duration	7.9	5.7	9.2	9.0	0.27	1.50
		Fragmentation	0.8	0.6	1.2	1.3	0.01	5.90*
	Third Minute	Duration	0.8	1.5	3.1	4.0	1.84	2.82
		Fragmentation	0.2	0.3	0.5	0.3	0.19	1.88
	Total	Duration	35.1	31.6	48.9	49.6		
		Fragmentation	3.4	2.9	3.9	3.8		
Partial	First Minute	Duration	21.4	21.3	18.0	18.3	0.01	1.96
		Fragmentation	2.3	2.0	1.9	1.8	1.03	1.06
	Second Minute	Duration	21.9	17.3	25.8	21.4	3.10	2.44
		Fragmentation	1.6	1.2	2.2	1.7	4.69*	3.61
	Third Minute	Duration	7.5	4.2	8.6	6.6	1.86	1.86
		Fragmentation	0.6	0.5	0.9	0.6	2.11	1.69
	Total	Duration	50.8	42.8	52.4	46.3		
		Fragmentation	4.5	3.7	5.0	4.1		
Whole Line Disappearance	First Minute	Duration	12.2	14.3	5.2	6.1	1.17	9.89**
		Frequency	2.4	2.3	1.4	1.3	0.37	11.02**
	Second Minute	Duration	30.1	37.0	24.8	29.6	4.03	3.48
		Frequency	1.8	1.6	2.5	2.5	0.18	9.96**
	Third Minute	Duration	51.7	54.3	48.2	49.5	1.00	7.89*
		Frequency	0.8	0.6	1.0	0.6	2.71	0.66
	Total	Duration	94.0	105.6	78.2	85.2		
		Frequency	5.0	4.5	4.9	4.4		
Time to First Fragmentation			16.9	18.4	22.7	26.7	1.49	11.22**

* $p < .05$ ** $p < .01$ † $p < .001$

Note—The data for each minute of inspection are given separately, together with the totals over 3 min. The number of whole line disappearances are appended, as are the times taken to the first fragmentation. The *F* ratios for the orientation and observation factors are given for each minute of observation.

subtending angles of $2 \times \frac{1}{4}$ deg at the eye. Two microswitches were connected to two timers and also to separate channels of the Rustrak event recorder.

Subjects. Twenty naive Ss were employed in this experiment.

Procedure. The Ss were given a brief description of the experimental arrangement, and instructed to press one switch (the right-hand one) when the whole line was visible, the other for the visibility of part, but not all, of the line, and neither when no part of the line was visible. In order to facilitate comprehension of the instructions and to familiarize S with the response system, a practice trial was given, which was followed by 10 min of dark adaptation. The two afterimages for a given observation condition were presented successively; otherwise, the orders for eyes and orientations were counterbalanced. The inspection period was 3 min, and the intertrial interval was 5 min. For the monocular condition, the right eye was used and the left eye was occluded.

Results and Discussion

The means for the whole and partial

durations and fragmentations for each minute of the inspection period are shown in Table 6, taken over the two orientations and observation conditions. Also included are the whole line disappearance durations and frequencies and the latency to the first fragmentation. The *F* ratios for the orientation and observation main effects are given in the right-hand columns. No orientation effects were found for whole responses. The complete line afterimage was visible for longer when generated binocularly than when generated monocularly in the first, but not the following, minutes. Binocular fragmentations were more frequent in the second minute, even though the durations were longer. Partial durations and fragmentations were relatively insensitive to orientation and observation effects. The only significant difference concerned fragmentation frequency in the second minute: the partial visibility of 0-deg afterimages changed more frequently to whole visibility or invisibility than did 45-deg lines. Whole fade duration and frequency were not influenced by orientation, but did show some significant observation effects. The whole line

disappeared for longer in the first and third minutes for monocular afterimages. An interesting pattern of fragmentations was produced in the first and second minutes: in the first, monocular whole fades were significantly greater than binocular ones, whereas the reverse effect was found in the second minute. As in Experiment 5, the interactions between orientations and observation failed to reach significance in every analysis.

The results of this experiment provide statistical support for those of Experiment 5. The effect of orientation was not significant, nor were the orientation-observation interactions. However, certain differences in the magnitudes of the effects are readily evident. The total whole durations are virtually identical for the binocular condition, which produced a difference of 6 sec in Experiment 5. The monocular difference was 3.5 sec for the whole duration, favoring the vertical orientation, whereas it was slightly in the reverse direction in the previous study. Nonetheless, the statistical evidence is consistent: 45-deg line afterimages are visible in their entirety

Table 7
Conditional Probabilities that an Event (N) is Followed by Another Event (N + 1) for 0-Deg and 45-Deg Line Afterimages Generated Monocularly and Binocularly

p (N+1/N)	Monocular		Binocular	
	Orientation (Deg)			
	0	45	0	45
p (D/C)	.45	.43	.44	.37
p (P/C)	.55	.57	.56	.63
p (D/P)	.69	.81	.58	.65
p (C/P)	.31	.19	.42	.35
p (C/D)	.28	.36	.23	.49
p (P/D)	.72	.64	.77	.51

Note—The three possible events are complete line visibility (C), partial visibility (P), and total disappearance (D).

for as long as, and fragment in a similar manner to, vertical afterimages. The increased duration of binocularly generated afterimages was further attested here, although this was not accompanied by a corresponding decrease in the number of fades in the first minute of observation.

The only significant orientation difference involved partial fades, and this favored the 45-deg afterimage, i.e., they showed fewer partial fragmentations than did verticals in the second minute of observation. One point that should be borne in mind when considering partial fades is that this category includes the changes from visibility of part of the line to complete disappearance and also to whole line visibility. This point will be dealt with in more detail below.

Extraction of whole disappearance frequency, the measure found to be most sensitive to orientation by Cosgrove et al and Schmidt et al, yielded no such indication of orientation selectivity for afterimages. However, whole disappearance duration tended to be longer for the 45-deg afterimages. One general point of agreement between the results from optical stabilization and afterimages concerns the relative sensitivity of partial and whole response measures: both whole line visibility and whole line disappearances yielded consistent observation differences which were not evident from the partial data.

The whole durations recorded here were considerably shorter than those of the previous experiment, which was conducted under similar conditions. This may have resulted from the inclusion of the partial response category, although the participation of naive Ss in the present experiment may also have been a contributive factor.

The use of whole and partial visibility indices enabled stochastic analyses of the afterimage fragmentation data in terms of the

probabilities that a given event will be followed by one particular alternative. The three possible events are the complete visibility of the line (C), its partial visibility (P), and its total disappearance (D). The conditional probabilities for the occurrence of each of these events contingent upon the others are given in Table 7 for each line orientation and observation condition. The frequency with which the visibility of the entire line was followed by a fragment of it was slightly greater than that for its total disappearance. Partial visibility of the line was followed most frequently by total disappearance, an effect evident somewhat more strongly for 45-deg lines and also for monocular afterimages. In a similar manner, the likelihood that a total disappearance would be followed by partial visibility was greater than that for its complete visibility; this was more pronounced for vertical than for 45-deg lines. Apart from the points noted above, the pattern of results is not greatly affected by either the observation conditions or line orientation.

The treatment of the temporal fluctuations of afterimage fragmentation permits direct comparison of the monocular data with that of Cosgrove et al, which was similarly analyzed. In brief, they found high conditional probabilities (greater than .7) for the following sequences: a partially visible line followed by its complete visibility; a completely visible line followed by a fragment; and complete visibility following a total disappearance. That is, the pattern of probabilities for fragmentation under optical stabilization differs markedly from that for afterimages, and their relationship tends towards an inverse one. Furthermore, the $p(N-1/N)$ values also differed for the total disappearances: Cosgrove et al reported that complete disappearance of the line was about equally likely to be preceded by partial or total visibility; line afterimages are more likely to disappear following partial than following complete visibility [$p(P/D) = .67$ and $.72$ for 0- and 45-deg lines, respectively]. The occurrence of such large differences in conditional probabilities is rather surprising, as this is the index that led MacKinnon et al (1969) to postulate a single mechanism underlying fragmentation under these two conditions.

GENERAL DISCUSSION

The general conclusion from these experiments is that the duration and fragmentation of line afterimages are not influenced by their orientation. This has proved to be so consistently

for monocular afterimages (Experiments 1, 2, 5, and 6), although the conclusion is a little more tentative for binocular afterimage duration (Experiments 3, 4, 5, and 6). The significant orientation differences found in Experiment 4 correspond quite closely to those nonsignificant ones in Experiments 3 and 5. This duration effect, which was in the order of 7%, cannot be considered in any way as a robust one due to the results of Experiment 6, in which there was no orientation selectivity for the duration of binocular afterimages. It should be noted, however, that the data of Experiment 4 were, by far, the most consistent because of the multiple testing of the Ss; in the other experiments, the individual differences were much more marked. In this regard, the possibility of binocular orientation selectivity cannot be discounted. It is pointless to speculate about the possible basis of the orientation selectivity under binocular but not monocular observation until this issue has been resolved.

The results for monocular observation clearly support those reported by Evans (1967) for his one well-trained S, i.e., orientation does not influence the duration of visibility of line afterimages. The reasons for the discrepancy between these studies and that of Atkinson (1970) remain obscure. The visual subtense of the long dimension of the lines employed throughout the present investigations was 2 deg; Atkinson used a 1.5 x 0.25 deg line, and Evans's stimuli varied in length from 0.67 to 1.5 deg, but were of unspecified width. Since the studies using the shortest and longest lines yielded similar results, it is unlikely that this factor could account for the discordance. It is also improbable that the stimulus intensity would have produced any systematic orientation effects on duration, because the same pattern of results has been evidenced in the various minutes of observation throughout which the afterimage strength was decreasing (Experiments 2, 5, and 6). Other aspects of the above experiments were substantially similar; consequently, the differences may have been due to S sampling. Here, Ss with a wide range of sophistication with respect to afterimage observation were tested, and no indication of monocular orientation selectivity was evident; while some Ss showed an orientation preference for the duration of 0- and 90-deg lines, others exhibited the reverse pattern.

Orientation selectivity with steadily fixated lines and under optical stabilization has been adduced from fragmentation frequencies alone, since fragmentation durations do not yield

such effects (Craig & Lichtenstein, 1953; Cosgrove et al, 1972). Upon this latter point, there is agreement between these studies and the above monocular afterimage experiments, if the complementary measure of afterimage invisibility is considered. With respect to fragmentation frequency, there is no correspondence between the present afterimage experiments and those using steady fixation and optical stabilization; indeed, there are areas of dispute between results of experiments using the last two methods. Craig and Lichtenstein (1953) and Goldstein (1967, 1968) found a cyclic function relating disappearance of any part of or all the line to its orientation: fragmentations were least frequent at 0 and 90 deg and most frequent at 45 and 135 deg. Optical stabilization, on the other hand, produces fewer complete fades for 90-deg lines (i.e., horizontal, though this orientation was labeled 0 deg) than either 0 or 45 deg, which were similar in number (Cosgrove et al, 1972; Schmidt et al, 1971). In almost all other studies of orientation selectivity, 0- and 90-deg stimuli yield similar results. This suggests that some other factor may have been operative to produce the vertical-horizontal difference. One obvious possibility concerns asymmetries in the departures from perfect stabilization. The extent of horizontal lens slippage with similar optical arrangement is in the order of 0.3 min of arc (Riggs & Schick, 1968). If there were more vertical slippages than horizontal, this would account for the increased stability of horizontal lines, since a small vertical slippage would result in stimulation of a new set of receptors for horizontal but not for vertical lines. One factor which may have led to this type of asymmetry relates to S's posture; if the head were upright, the attachment of any device to the eye would have disturbed the fine oculomotor balance, adding to the force required to keep the eye in a given position, which may have increased the amount of vertical nystagmus and lens slippage. It is not stated explicitly by either Cosgrove et al or Schmidt et al what head position was employed, i.e., whether upright or supine; it is assumed that it was the former, because of the use of a biteboard and the optical arrangement employed. Thus, the possibility of greater vertical nystagmus and lens slippage cannot be precluded. Nonetheless, certain aspects of the results argue against this being the single factor operative to produce the pattern of results. Vertical lens slippage would have favored the stability of 45-deg lines and would also have produced more partial fades for

vertical lines, neither of which were evident from the data. Furthermore, the horizontal departures from perfect stabilization are said to have no visual effects (Riggs & Schick, 1968). One additional aspect of Cosgrove et al's and Schmidt et al's reports that is puzzling concerns the durations over which S observed the line stimuli. The reports are not accompanied by any remarks about the reduced contrast of the target under stabilization, an effect otherwise universally noted by workers in this field (see Cornsweet, 1970), nor do there appear to be any of the prolonged disappearances that are again commonly reported. This would tend to support the view that the departures from perfect stabilization were appreciable.

Disregarding the vertical-horizontal difference for stabilized lines, there remain serious discrepancies between the data under optical stabilization and the present afterimage results. The frequency of unitary disappearances was found to be the most sensitive measure of orientation selectivity under the former conditions, although partial fades also differentiate between orientations in the first few minutes of stabilization. With line afterimages, the fragmentation frequency does not reflect orientational differences consistently under any condition except marginally for partial fades, and this measure favored the stability of 45-deg lines. One problem in comparing optical stabilization methods with afterimage experiments is that the former measure disappearance characteristics, whereas the latter are concerned with appearances. Consequently, the whole disappearance data of Cosgrove et al and Schmidt et al can only be compared directly with the whole disappearance afterimage data from Experiment 6. Here it is quite clear that no orientation preference was present in the fragmentation data, although it may be in the whole disappearance duration. This problem is not so acute, because the afterimage durations are all within the period in which both partial and whole fades are orientation-selective (Cosgrove et al, 1972), and therefore this effect would be expected for the whole fragmentation categories employed in Experiments 2, 4, and 5. No such differences were found, not even in Experiment 4, where the afterimage durations differed significantly with orientation. Moreover, the consistent monocular-binocular duration differences were not accompanied by reliable variations in the fragmentation measures.

In the light of these results, it is of interest to examine more closely the equation of steady fixation, optical

stabilization, and afterimage viewing with respect to perceived fragmentation. The unitary disappearances of the sides of an outline square follow similar patterns under the three observation conditions (MacKinnon et al, 1969). It was stated that few partial disappearances occurred. Comparison of Craig and Lichtenstein's, Cosgrove et al's, and Schmidt et al's data with the present afterimage results suggests that such similarity may not prove to be the case for single line stimuli, especially when these are varied over some independent dimension like size or orientation. This view is strongly supported by the discrepancies in the conditional probability values for fragmentation of afterimages and optically stabilized lines (Cosgrove et al, 1972). The temporal fluctuations of the former were such that a completely visible line would fragment or disappear with about equal probability; it is then highly likely that a partially visible afterimage will disappear, and this is frequently followed by reappearance of another part. For the latter, there appear to have been oscillations between partial and complete visibility of the line, with disappearances mostly following complete visibility. These sequential dependencies may have been confounded by the departures from perfect stabilization inferred from other features of the data.

One of the major problems with optical stabilization concerns the feasibility of fitting contact lens devices to more than a small number of Ss. Unfortunately, many of those so fitted are not naive as to the problem under investigation or are tested so thoroughly that referring to them as unaware of the experimental aims would itself appear naive on behalf of the E. Afterimage experiments are not necessarily faced with this dilemma, but all of the methods are presented with the problem of the criteria that Ss adopt for responding in any given category.

As a methodological issue, it is here considered that afterimage duration is a more reliable and sensitive measure of afterimage characteristics than are fragmentations or other indices like the time to the first fragmentation. Clearly, the duration of visibility of a stimulus cannot be compared under the above three viewing conditions, but the comparisons of durations for different stimulus conditions can be made. Furthermore, it is possible to contrast the relative durations for whole visibility of stabilized images with the complementary measure of whole appearance of afterimages.

Binocular line afterimages were visible for significantly longer than

monocular in their entirety (Experiments 5 and 6). This effect has been found by Forde (1971) for the whole visibility of pairs of lines and it does not seem to be related in any simple way to the increased energy imparted to the visual system. Forde has argued that some degree of binocular interaction of a facilitatory nature is evident for afterimages generated simultaneously in both eyes. If such is the case, the basis for the binocular orientation differences (should they be demonstrated to be reliable) may be sought at the level of binocular interaction of the visual input.

The orientation selectivity in the human visual system in response to oscillating gratings is not evident for line afterimages. It may be that the selectivity is dependent upon either a moving or a spatially repetitive stimulus.

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