Fragmentation of monocular afterimages in individuals with and without normal binocular vision

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Monocular afterimages of a vertical line were generated in each eye of binocularly normal individuals and of those lacking binocular single vision or stereopsis as a consequence of childhood strabismus. Fragmentations and disappearances of the afterimages occurred less frequently in the strabismic than in the normal subjects; they were also less frequent in the dominant (nonamblyopic) eyes of the strabimics than in their amblyopic eyes. The afterimages remained visible for longer when presented to the dominant eyes of the strabismic subjects, and a similar effect was found between the sighting dominant and nondominant eyes of normal subjects.

Prolonged afterimages of line patterns undergo sequences of fragmentations into component parts, disappearances and reappearances. The characteristics of such sequences differ under monocular and binocular observation. Afterimages that are generated binocularly are more stable than those produced in one eye (Forde, 1971; Owen & Chalfant, 1970; Wade, 1972): they remain visible for longer before the first fragmentation, tend to undergo fewer fragmentations, and have a longer overall duration of visibility. Forde (1971) has suggested that this pattern of results reflects the origin of the fragmentation effects in the binocularity of the visual system.

Forde provided support for this suggestion by examining subjects who had a history of strabismus (squint) and were functionally monocular. Afterimages of a single vertical or horizontal line were observed in the nonamblyopic (dominant) eyes of seven strabismic subjects, and also in one eye of eight binocularly normal subjects. Disappearances and reappearances were reported by all the binocular subjects, but they occurred rarely, if ever, in the strabismic subjects. Thus, it seems that the inappropriate stimulation of a functionally binocular visual system by a monocular afterimage leads to the higher degree of fragmentation. For the strabismic subjects, lacking any binocular integration, a monocular stimulus is adequate as indexed by its stability.

The experiment reported herein examined the visibility of a vertical line afterimage in normal and functionally monocular subjects. The afterimages were generated in each eye separately. This enabled a comparison between the dominant and nondominant eyes of both groups of subjects.

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METHOD

Six normal subjects were tested. All had at least 20/20 visual acuity in each eye and had good stereopsis.

Eight subjects with a history of strabismus participated. Seven of the subjects had reduced visual acuity (strabismic amblyopia) in one eye. Data from a ninth subject were discarded because she had virtually no pattern vision in her amblyopic eye, and could not see an afterimage presented to that eye. All but one of the subjects had simultaneous binocular vision, but none had any evidence of either binocular single vision or stereopsis. That is, contours within one eye were suppressed permanently by competing contours within the other eye.

Those subjects who had correcting lenses wore them during testing.

Apparatus

Afterimages were generated by the discharge of a Multiblitz Report flash gun, with an output of 120 J in 2 msec, according to the manufacturer's specifications. Black masking card with a vertical aperture was mounted in front of the flash gun 28.5 in. away from the subject's eyes. The vertical line subtended $2 \times \frac{1}{4}$ deg at the eye. Two switches were positioned in front of the subject, and these activated timers and separate channels of an event recorder. The apparatus was situated in a darkened room.

Procedure

All subjects were given visual screening tests, and they were assessed for sighting dominance. They were then dark-adapted for 10 min, after which an afterimage of the vertical line was generated in one eye. The subject's task was to depress one switch when the afterimage was visible in its entirety (referred to as the whole category) and the other switch when it was partially visible. Neither switch was depressed when the afterimage disappeared completely. A trial lasted for 2 min, and the intertrial interval was 3 min. Each eye was simulated alternately, and there were eight trials in all—four for each eye. The afterimages were viewed with the eyes closed.

The normal subjects were tested in a single session, and the strabismic subjects were tested in 1, 2, 4, or 8 sessions, according to availability.

RESULTS AND DISCUSSION

The data were analyzed in terms of the total durations of whole and partial visibility, and the duration of disappearances before the final fading of

Table 1
Response Measures for the Whole and Partial Visibility and Disappearance of a Line Afterimage in Strabismic and Normal Subjects

		Strabismics		Normals	
		Dominant Eye	Non-dominant Eye	Dominant Eye	Non-dominant Eye
Duration (sec)	Whole	53.2	32.8	66.3	47.4
	Partial	29.6	24.4	15.4	12.7
	Disapp.	11.5	15.8	14.0	16.4
Frequency	Whole	2.7	3.2	6.1	5.9
	Partial	2.1	3.2	3.8	3.9
	Disapp.	2.5	3.7	4.3	4.6
Period (sec)	Whole	27.0	15.2	12.9	11.6
	Partial	7.0	8.0	4.1	3.1
	Disapp.	3.7	4.0	3.2	3.4
Latency from flash to first appearance (sec)		4.1	6.5	2.6	2.3
Time to first fragmentation (sec)		36.6	19.6	23.5	23.8
Time to first disappearance (sec)		46.9	27.4	42.1	35.2

the afterimage (if this occurred before the termination of a trial). Frequencies and periods (duration/frequency) of visibility and disappearance were also extracted from the records. Further measures in terms of the latency from the discharge of the flash gun to the initial visibility of the afterimage, the duration to the first fragmentation and also to the first disappearance were included. The data are presented for the dominant and nondominant eyes of the subjects, as determined by the sighting test; of course, the nondominant eyes for the strabismic subjects corresponded to those that were permanently suppressed in normal vision. The average values for all the above measures are given in Table 1.

Considering first the duration measures, the afterimage remained visible for longer when presented to the dominant eye than when presented to the nondominant eye for both groups of subjects. The effect was shown by all the strabismic subjects and all but one of the normal subjects. It is of interest to note that the overall durations of afterimage visibility (whole plus partial durations) are very similar for the dominant eyes of the strabismic and normal groups. In comparing the strabismic and normal subjects, it is clear that a greater proportion of the visibility time was taken up by seeing part of the line for the former. The afterimage disappeared completely for similar durations under all conditions. The disappearances were longer in the nondominant eyes of five of the strabismic subjects.

The afterimages fragmented less frequently in the strabismics relative to the normals. This applied to each measurement category, but it was most evident for the whole category. Fragmentations and disappearances were less frequent in the dominant

eyes of the strabismic subjects.

The periods of visibility or disappearance of the afterimage represents the average individual phases for which a particular category occurred. Thus, both whole and partial line visibility periods were longer in strabismics than in normal subjects. This is most clearly evident for the whole afterimage visibility in the dominant eyes of the strabismics.

One of the most clearly differentiating features between normal and strabismic subjects was the latency from the discharge of the flash gun to the initial visibility of the line afterimage. This required several seconds longer in the strabismic group. Moreover, this measure also differentiates between the eyes of the strabismic subjects: the latency was longer in the nondominant eye for seven of the eight subjects.

The time from the initial visibility of the afterimage to its first fragmentation was much longer in the dominant eyes of the strabismics than in their nondominant eyes, and also much longer than the equivalent measure in the eyes of the normal subjects. The time from the initial visibility to the first disappearance of the afterimage does not differentiate so clearly between the groups. These last measures indicate that the fragmentations and disappearances are not confined to the final phases of visibility when the afterimage is very weak.

The above results are somewhat at variance with those of Forde (1971). He reported that afterimages disappeared very rarely in subjects who were functionally monocular. Here it was found that subjects lacking binocular single vision and stereopsis do experience fragmentations and disappearances of a single line afterimage. One strabismic subject observed no fragmentations and very rare disappearances, and a second one had no disappearances but did report changes from whole to partial visibility and back again. Otherwise, the strabismic subjects experienced disappearances for about the same durations as did the normal subjects. The frequencies of fragmentations and disappearances, however, were lower in the strabismic subjects.

One of the factors that might have contributed to the disappearances among the strabismic subjects concerns eye movements during observation of the afterimages. When the eye drifts, the afterimage appears to move with it. Several of the strabismic subjects reported difficulty in maintaining their eyes in a fixed position during observation: the afterimage would appear to drift to an extremity of the field and then would be returned to the center. Since it is known that afterimages can be suppressed by such rapid eye movements (Fiorentini & Mazzantini, 1965), this might have led to some of the disappearances for the strabismic subjects. In particular, it might have contributed to the difference in disappearance frequencies between the dominant and nondominant

eyes in these subjects, as it is generally more difficult to maintain voluntary fixation with the latter. This factor is unlikely to be the basis for the discrepancy between Forde's results and those presented here. The same problems were likely to have been operating in both experiments as the observation conditions were essentially similar. Clearly, this problem awaits empirical clarification by the monitoring of eye movements during the observation of afterimages.

Forde did restrict his measurements to the dominant (nonamblyopic) eyes of the strabismic subjects, and this condition produced the smallest number of fragmentations in the present experiment. As such, the results provide general support for Forde's suggestion that the instability of monocular afterimages in normal subjects are due to the inappropriate stimulation of a functionally binocular visual system. Monocular afterimages are more stable in functionally monocular subjects. However, for both of these groups, fragmentations and disappearances of monocular afterimages do occur.

The unexpected difference between the durations of afterimage visibility in the dominant and non-dominant eyes of normal subjects is of particular interest. It is known that single cells in the visual cortices of cat and monkey are coded for eye dominance and that these have a columnar organization (Hubel & Wiesel, 1965, 1968). One could speculate that there is some inhibitory interaction between columns having opposite eye dominances. If there is a difference in the distribution of eye dominance columns corresponding to that for sighting dominance, then such interaction might account for the longer visibility of afterimages presented to the dominant eye. Subjects deprived of binocular vision as a consequence of strabismus are generally considered to be lacking in cells within the visual cortex that can be driven binocularly. It is known that kittens reared with an induced squint have a greatly reduced complement of binocular cells (Hubel & Wiesel, 1965). Consequently, there would

be minimal interaction between the cortical columns that respond predominantly to one eye or the other, particularly since these are likely to be biased in favor of the nonamblyopic eye. Whether the disappearances that occur for strabismic subjects reflect any residual binocularity or are artefacts of afterimage suppression due to eye movements remains to be determined.

In summary, afterimages presented to one eye of subjects lacking normal binocular vision fragment and disappear less frequently than do equivalent afterimages in normally binocular subjects. Afterimages generated in the nonamblyopic eyes of strabismic subjects remain visible for longer than do those in the amblyopic (nondominant) eyes. A similar difference was found in normal subjects with regard to the sighting dominant and nondominant eyes.

REFERENCES

- FIorentini, A., & MAZZANTINI, L. Inhibition of afterimages due to voluntary eye movements. *Atti della Fondazione Giorgio Ronchi*, 1965, **20**, 307-320.
- FORDE, J. *Binocular stimulation and the fragmentation of afterimages*. Unpublished PhD thesis, University of Waterloo, 1971.
- HUBEL, D. H., & WIESEL, T. N. Binocular interaction in striate cortex of kittens reared with artificial squint. *Journal of Neurophysiology*, 1965, **28**, 1041-1059.
- HUBEL, D. H., & WIESEL, T. N. Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology*, 1968, **195**, 215-243.
- OWEN, D. H., & CHALFANT, C. Central integration effects with stabilized afterimages. *Perception & Psychophysics*, 1970, **7**, 284-286.
- WADE, N. J. Orientation effects on line afterimages. *Perception & Psychophysics*, 1972, **12**, 409-416.

NOTE

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