Fig. 2. Typical patterns of fragmentation reported by subjects viewing Fig. 1, under intermittent illumination.

decreased again to 1 c.p.s. The frequency of intermittent illumination was held constant while subjects made their reports. Typically, a complete trial lasted 8 to 10 min. Intermittent illumination was produced by placing the outline figure shown in Fig. 1 before a General Radio Company 'Strobotac' type 1531-AB, operating with a Mazda FA/7/s flash tube (standard fitment). The spectral output of this source was continuous within the visual spectrum. Flash duration was rated at 3 μs for frequencies from 2 c.p.s. to 11·5 c.p.s., and at 1·2 μs for frequencies above 11·5 c.p.s., power rating at 0·35 W. The geometrical figure was drawn in black Indian ink on white translucent paper. To ensure an evenly illuminated stimulus, a sheet of white translucent plastic was placed between the geometrical figure and the strobotorch. The diameter of the circle subtended a visual angle of 3° and the line width of 7 min of arc, when viewed at optical infinity. A condition of optical infinity was produced by instructing subjects to wear their corrective lenses if normally worn for distance and to view the geometrical figure through a convex lens of focal length 50 cm. The plane of the stimulus was situated in the focal plane of the lens. Viewing was monocular, the non-viewing eye being occluded.

The only illumination present during the experiment was that provided by the strobotorch. All subjects were experienced observers and had prior knowledge of the phenomenon. To minimize any unpleasant effects which might have been induced by the intermittent illumination, the visual field was restricted to that immediately surrounding the geometrical figure. This was achieved by placing a circular aperture in the stimulus plane. At optical infinity the diameter of the aperture subtended a visual angle of 11½°. The stimulus was centrally placed with respect to the aperture.

All subjects reported fragmentation of the stimulus. Some typical observations are shown in Fig. 2. These observations are consistent with those reported when usual methods of producing retinal image stabilization were used. All subjects also reported distortion of the figure, a finding also consistent with previous reports[10]. Although there seem to be qualitative similarities of fragmentation between this method and those described previously, it remains to be seen whether there are also quantitative similarities. Strong qualitative and quantitative similarities have already been demonstrated for geometrical figures viewed by steady fixation, with a contact lens and as a prolonged after-image[6,7,11,12]. Subjects' qualitative observations showed that generally fragmentation occurred between 2 and 16 c.p.s. But there were strong indications from subjects' reports that more fragmentation took place between 6 and 10 c.p.s. than at other frequencies.

This possibility was investigated. Four subjects who had previously reported fragmentation qualitatively reported the occurrence and duration of fragmentation by pressing a button. These responses were recorded on an Esterline-Angus events recorder. The stimulus conditions were those already outlined, except that subjects viewed the geometrical figure at six specific frequencies of intermittent illumination: 3, 6, 9, 12, 15 and 40 c.p.s. Subjects reported fragmentation for 3 min at each frequency. Frequencies were chosen to cover the range within which fragmentation had been reported to occur, qualitatively. A frequency of 40 c.p.s. was chosen because, being well above each subject's C.F.F. for central vision, it simulated a steady fixation viewing condition. The results are shown in Table 1.

Table 1. TOTAL DURATION OF FRAGMENTATION REPORTED BY FOUR SUBJECTS AT FREQUENCIES OF INTERMITTENT ILLUMINATION OF 3, 6, 9, 12, 15 AND 40 C.P.S.

	(c.p.s.)					
Subject	3	6	9	12	15	40
1	75·0	109·0	154·75	60·0	53·25	16·50
2	3·75	13·5	16·25	17·50	7·0	3·75
3	1·75	84·25	167·50	8·75	1·25	0·00
4	24·75	128·50	171·0	86·0	44·50	45·25

Figures are given in seconds. Total viewing time at each frequency for each subject was 180 s.

Table 1 shows the total time for which each subject reported fragmentation occurring at each frequency of presentation. For three subjects the amount of fragmentation was frequency dependent, that is, it occurred maximally at 9 c.p.s., and took up progressively less of the viewing time at greater or smaller frequencies. One subject reported a similar amount of fragmentation at all frequencies of presentation.

In summary, it can be said that viewing a geometrical figure in conditions of intermittent illumination provides a new method of producing fragmentation. Because these preliminary findings indicate that the amount of fragmentation is dependent on the frequency of presentation, this method may provide a means of investigating temporal factors underlying the phenomenon.

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Mislocation of Test Flashes during Saccadic Image Displacements

IF a stationary source of light is flashed briefly during or just before a saccadic eye movement, it is less easily detected than when the eye is stationary[1-3], and its location relative to a fixed background is misperceived[4,5]. These phenomena have sometimes been taken to support the theory that an efferent signal from the oculomotor system actively modifies the visual input signal during a voluntary eye movement so as to "cancel" the visual effects of the movement[6], with a view to maintaining the stability of the perceived world. On this theory one would not expect to observe such perceptual anomalies if the eye were held stationary and the retinal image moved in saccadic fashion by external means.

I have reported recently[7,8] that the threshold for perception of faint flashes can be elevated to about the same extent by passive as by active image displacement. A further series of experiments using the same apparatus have now confirmed that illusory displacement of a flash also occurs in relation to a saccadically displaced field in the absence of oculomotor activity. These experiments have made it possible to study the effects of the time interval between flash and image displacement, and of the speed of displacement, on the magnitude of the illusion.

A horizontal luminous scale subtending 11° was used as the moving field. Its image (white on a dark ground) was projected with a luminance of 1 log foot Lambert on a vertical screen 1 m from the observer in a dark room. It could be rapidly displaced horizontally up to 4° in either direction by means of a mirror mounted on an electroencephalogram (EEG) pen motor. The displacement, which was free of overshoot, could be set to occupy 8 ms or 40 ms, and took place at randomly varied intervals in the neighbourhood of 4 s, the return stroke coming 2 s later. A triangular arrow, which could be illuminated by an electronic flash tube, was arranged so that its image was deflected with the scale and always coincided objectively with the central scale division.

The timing of the flashes was varied randomly in a range of either 100 or 200 ms about the time of onset of the field displacement, and the subject was asked to report the position on the scale that the flash appeared to occupy. To eliminate cues from a stationary fixation point, the subject was instructed to fixate the central scale division in its initial position. Any reflex response to scale movement would have a latency of the order of 100 ms, and so could be discounted[9].

Typical results are shown in Fig. 1, in which perceived flash location is plotted against the time between flash and onset of field displacement. It is clear that mislocation is confined chiefly to flashes presented in the 50 ms or so before and during displacement, the error curve rising to a maximum at time of onset. Field displacements to left and right produce illusory shifts of similar magnitude in opposite directions.

The effect of increasing the time of displacement from 8 ms to 40 ms is shown in Fig. 2. At the slower speed both the magnitude and time range of illusory displacement were considerably diminished. The position of the peak was not affected, although the "overshoot" error in the opposite sense reached its maximum later—that is at the end of the displacement. Not all subjects experienced this "overshoot".

An interesting anomaly was reported spontaneously by some observers. The flash (which was practically instantaneous) sometimes appeared to have two locations in succession, as if onset and offset happened at different times. Where this ambiguity arose, the subject was asked to report the "earlier" perceived location. Successive "ghost" images in response to transient stimulation are not uncommon[13], and are perhaps attributable to the oscillatory impulse-response of the visual system[14]. The same explanation may account for the "paradoxical double localization" occasionally found by Bischof and Kramer[5] for flashes presented during saccadic eye movements.

Localization errors when a test line was briefly illuminated against a moving background have been reported briefly by Sperling and Speelman[10], who gave no figures, but stated that "localization during eye movement usually can be predicted from localization during object movement". Taken together with my results (especially Fig. 2), this suggests that some correlation might be expected between the magnitude of the illusory displacement observed with saccadic eye movements and the speed of these movements. In any event, although my results do not conclusively exonerate the oculomotor system, they show that it need not be implicated in order to account for mislocations during saccadic movement. I have argued elsewhere that visual stability during eye movements does not require a "cancellation" mechanism[11].

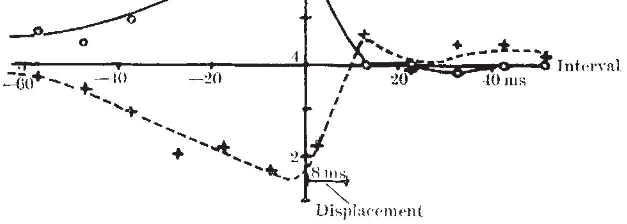

Fig. 1. Perceived location of flash on scale as a function of time interval between flash and onset of displacement. Actual location was fixed at 4. Displacement took 8 ms. Measured displacement to L was slightly larger (2·8 divisions) than to R (2·4 divisions). (○) Left; (+) right.

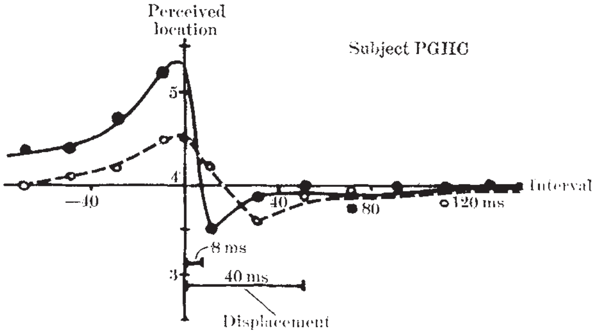

Fig. 2. Effects of duration of image motion on perceived location. (●) 8 ms (500°/s); (○) 40 ms (100°/s).

How then are such mislocations to be explained? The clue seems to be the finding (confirmed in a further series of experiments on fifteen subjects with the assistance of Mr K. Bradshaw) that the most significant errors are confined to the period before and during displacement of the image. The inference seems to be that the location of a flashed image relative to its background involves an interaction between the neural signals generated by each, which interaction takes an appreciable time to complete. If during this time the retinal image of the background shifts to a new position, the integrative process will have two different "background" signals to cope with, each making its own contribution to the total weight of evidence with respect to flash location. The later the flash comes, before the moment of transition, the greater will be the weight attached to the new scale-position as compared with the old. Thus the greater will be the illusory displacement of the flash, which is then objectively at the centre of the old scale-position. When the flash is delayed until after the scale-displacement, it is objectively at the centre of the new scale-position, so that only the residue of the earlier background signal remains to contribute any bias to the computation of relative flash location. This bias would account for the "overshoot" observed with some subjects.

If this explanation is valid, the shape of the error curves in Figs. 1 and 2 should be closely related to the time course of the postulated interaction. The data suggest a duration of the order of 50 ms for the integrative process, which is comparable with that inferred for the flash-detection process in the earlier experiments[7,8]. Retinal ganglion cell discharges of about this duration are typical in response to brief threshold stimuli[12]. The correspondence is at least encouraging; and the strong dependence of the magnitude of the illusion on the duration of the movement strengthens the hypothesis that it depends essentially on the degree of overlap in time between the neural events representing the flash and those representing the scale in its successive positions.

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Test of Gregory's Constancy Scaling Explanation of the Müller–Lyer Illusion

MUCH of the recent interest in geometrical illusions has centred on a size constancy explanation by Gregory[1-3]. Size constancy occurs when the apparent size of an object remains constant, independent of the distance of the object from the observer, even though the size of the retinal image varies with the distance. The mechanism which produces size constancy has been called constancy scaling[2].

In Gregory's theory—a modification of perspective theory[4]—geometrical illusion figures are considered to be similar to two-dimensional projections of three-dimensional figures. As in three dimensions, constancy scaling operates to increase the apparent size of apparently more distant parts of a figure, and to decrease the apparent size of apparently nearer parts. In a two-dimensional figure, perspective features provide the observer with cues for judging the apparent distance of parts of the figure. These perspective features trigger constancy scaling, which affects the apparent size of parts of the figure and produces an illusion, even though the figure need not be seen as having depth.

Gregory's theory cannot account for all illusions because, as Day[5] has pointed out, illusions can be generated by figures without perspective features, such as the dumbbell version of the Müller–Lyer figures. It is still, however, of interest whether illusions in figures containing perspective features can be explained by the operation of constancy scaling. The Müller–Lyer figures seem to have perspective features: the wings and their directions. If Gregory's theory is correct, constancy scaling should thus influence the perception of the Müller–Lyer figures.

Gregory[2] assumes that Müller–Lyer figures are similar to projections of typical three-dimensional objects. For example, Fig. 1*a*—with the wings directed outwards—is similar to a projection of the corner of a room, where the central axis corresponds to the corner and the outside wings correspond to the intersections of the walls with the ceiling and with the floor. Because of the effect of the wings as perspective cues, the central axis is judged as though it were farther away than the wings, that is, as though the figure were a three-dimensional object. Accordingly, constancy scaling operates, and increases the apparent length of the central axis. On the other hand, Fig. 1*b*—with the wings directed inwards—has the perspective cues of a projection of an outside corner of a building. The central axis is thus judged as though closer than the wings and therefore appears too small because of constancy scaling.

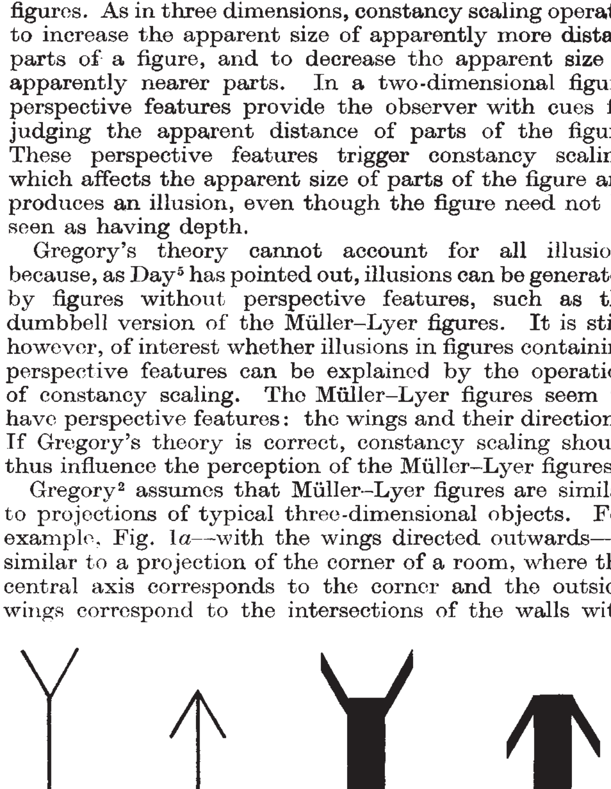

Fig. 1. *a* and *b*, Müller–Lyer figures. *c* and *d*, The same figures with enlarged width of central axis.

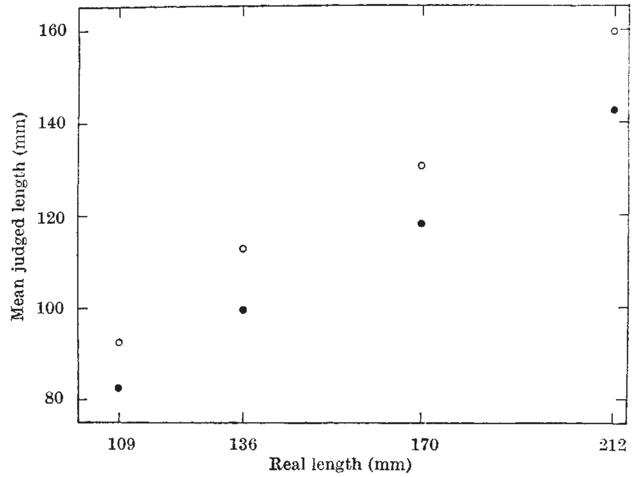

Fig. 2. Mean judged length of the central axes of Müller–Lyer figures as a function of the absolute length and the direction of the wings (●, inward; ○, outward).

If Gregory's theory is correct and internally consistent, constancy scaling not only augments the apparent length of the central axis of Fig. 1*a* but also should augment its apparent width. That is, if constancy scaling is involved, both the apparent length and the apparent width of the central axis should be affected and should be distorted in the same direction.

The present study provides a direct test of the assumption of constancy scaling by determining whether subjects' length and width judgments of Müller–Lyer figures are distorted in the same direction. Because the Müller–Lyer figures usually consist of relatively fine lines, as shown in Figs. 1*a* and 1*b*, any illusion in the perception of the width of the central axis might not be noticed on casual observation. With thicker central axes, however, as shown in Figs. 1*c* and 1*d*, any illusion in the judged widths should be readily discernible. Note that these figures provide the same perspective depth cues as do the standard Müller–Lyer figures: the wings and their directions.

In the figures used here, the inward and outward wings met the central axis at 30 and 150 degrees, respectively. Four sizes of the central axis were used: 40 × 109, 27 × 136, 64 × 170 and 43 × 212 mm. Figures were presented one at a time, vertically as in Fig. 1, at a distance of 105 cm from the subjects and about 12 cm above eye level. The figures were projected on to a green blackboard with a slide projector.

Subjects were told to judge the apparent length and width of the central axis of each figure. The response sheet contained a horizontal and a vertical line which met and ended at a point near the upper left corner of the sheet. The subject responded by making a mark on each line to indicate the length and width of the central axis. The figure remained present while the subject made his response. No more than two subjects were tested at a time. Fourteen subjects judged each of the eight figures six times in randomized blocks of trials. Responses were measured to the nearest millimetre.

The results of the experiment contradict Gregory's theory. Fig. 2 shows that the Müller–Lyer illusion occurred;