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A NEUROLOGICAL BASIS FOR VISUAL DISCOMFORT

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SUMMARY

Certain patterns of stripes are judged to be unpleasant to look at. They induce illusions of colour, shape and motion that are sometimes perceived predominantly to one side of fixation. People who suffer frequent headaches tend to report more illusions, and if the pain consistently occurs on the same side of the head the illusions tend to be lateralized. The parameters of the patterns that induce illusions (including their shape, spatial frequency, duty cycle, contrast and cortical representation) closely resemble those that elicit epileptiform electroencephalographic abnormalities in patients with photosensitive epilepsy. The viewing conditions under which such abnormalities are likely to appear are also those under which more illusions are seen.

INTRODUCTION

Certain patients with epilepsy are photosensitive and suffer seizures induced by flickering lights and patterns of striped lines. When they are exposed to visual stimuli of this kind, epileptiform EEG activity (i.e., a photoconvulsive response) may be induced. The spatial and temporal characteristics of stimuli that induce epileptiform activity are surprisingly specific and have been reviewed elsewhere (Wilkins *et al.*, 1980; Meldrum and Wilkins, 1984). It can be inferred from the topography of the EEG activity and the nature of the stimuli that induce it that the paroxysmal discharge is triggered when normal physiological excitation in the visual cortex exceeds a critical level (Meldrum and Wilkins, 1984).

When people *without* epilepsy are asked to look at patterns of striped lines (such as that reproduced in fig. 1) they may report visual illusions of colour, shape and motion. These illusions have received extensive study over the last 100 years, but for the most part their origin remains obscure. It has been postulated that small eye movements are responsible for some of the illusions of motion, and some of the effects observed in patterns of concentric annuli have been attributed to fluctuations in the power of the lens of the eye (Campbell and Robson, 1958; Wade 1977). The techniques that have been used to differentiate between these peripheral ocular

factors are often insufficient to exclude more central mechanisms. For example, after-images have been used to eliminate the contributions from eye movements, and an artificial pupil used to reduce the effects of fluctuations in accommodation, but both techniques involve a reduction in retinal stimulation. Although peripheral factors may play an important role in the generation of some of the illusions (Campbell and Robson, 1958), anomalous effects remain under conditions of stabilized vision and when fluctuations in accommodation can be discounted (Wade 1977). It has been argued (Georgeson, 1976, 1980; Welpe, 1976) that some of the illusions of shape derive not from peripheral factors but from inhibitory interactions

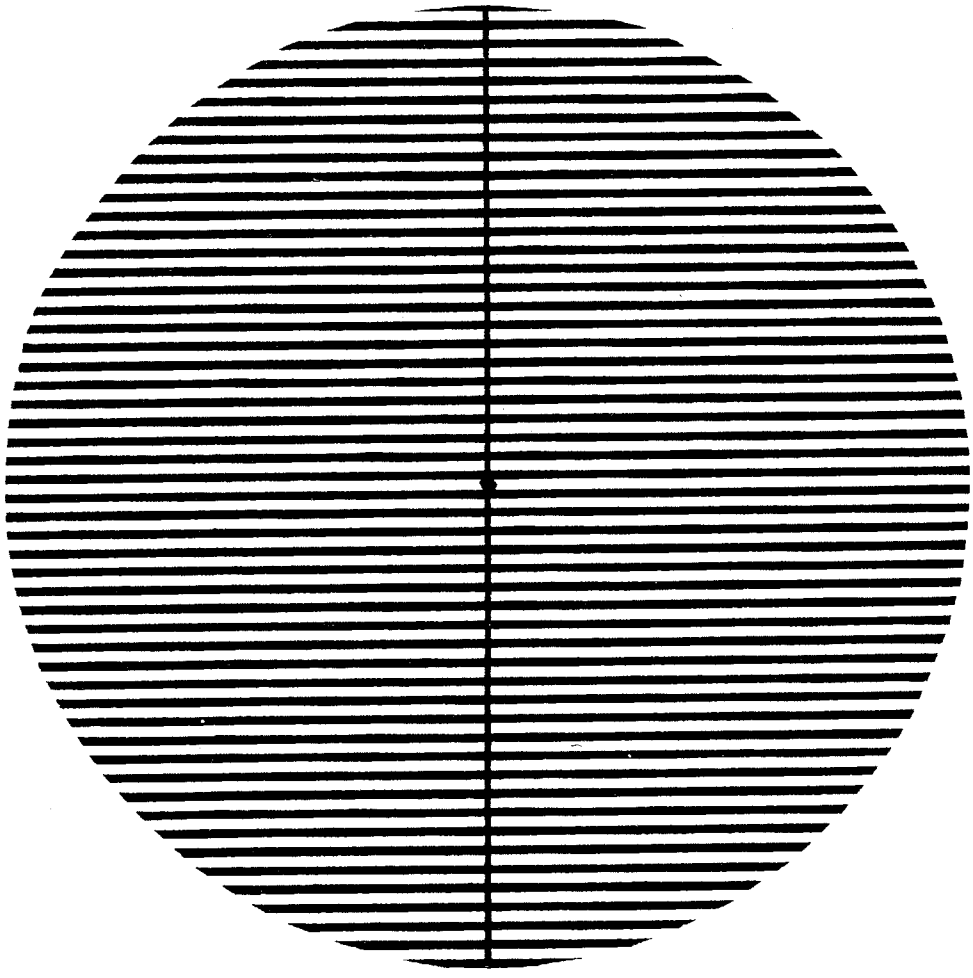


FIG. 1. A grating with square-wave luminance profile and a Michelson contrast of about 0.7. At a viewing distance of 43 cm this grating has a spatial frequency of 3 cycles/deg.

at the level of the striate cortex. It is possible that similar mechanisms also underly the illusions of colour and motion, particularly since the latter illusions are often integrated with those of shape in a unitary percept.

The wide variety of visual illusions seen in striped patterns have provided the impetus for the op art movement (Wade, 1978, 1982), and the paintings that have attracted most attention are those which generate spatial distortion associated with a subjective impression of movement. These effects can be unpleasant. Critics have described op paintings as 'assaulting the retina' (Oster, 1965). When Bridget Riley held an exhibition of her paintings the attendants complained of headaches and applied for dark glasses (*Daily Telegraph*, 1971). Complaints of this kind are not restricted to works of art. When escalators with a striped metal tread were introduced in the London underground there was criticism of the 'dazzling glare' that they produced (Collins, 1969). We know of no studies that have attempted to document the spatial properties of patterns that induce these unpleasant effects. One purpose of the present paper is to show that the spatial properties are quite specific and are related to the induction of visual illusions, headache and seizures.

The paper is divided into two sections. In the first section it is shown that the unpleasantness of patterns depends on their spatial frequency. The patterns that are maximally unpleasant are those that induce the most illusions. The number and location of the illusions that people report are associated with the incidence and nature of the headaches they suffer. In the second section it is shown that the visual stimuli that induce illusions and the conditions in which they do so are precisely those that in photosensitive patients induce epileptiform electroencephalographic abnormalities.

SECTION 1

'Pleasantness' of Patterns

In the first experiment subjects were asked simply to judge the 'pleasantness' of gratings with different spatial frequencies. Far from finding such a task incongruous, subjects took it seriously and gave very consistent judgements.

Experiment 1

The preference for striped patterns was measured using ratings of individual patterns, and paired comparison of pairs of patterns. Prints of vertical stripes (square-wave gratings with spatial frequencies of 0.5, 1.0, 2.0, 4.0, 8.0, 16.0 and 32.0 cycles/cm) were illuminated by a 100 Hz fluorescent source and presented at a viewing distance of about 50 cm for about 10 s each. The patterns were circular in outline, radius 100 mm, and they had a Michelson contrast of 0.7 and a mean luminance of about 100 cd/m^2. Twenty-nine female volunteers on the subject panel of the Applied Psychology Unit aged 19 to 68 years were tested as a group. Subjects with epilepsy were instructed not to participate. The subjects gave a preference for each of the 21 pairwise combinations of the seven gratings. Fifteen subjects received the pairs in random orders, and a further 8 received the pairs with a spatial frequency of less than 4 cycles/cm first (selected at random) and a further 6 received the pairs with frequencies above 4 cycles/cm first. In both the latter groups the pairs with mixed (high and low) spatial frequencies were given last. The pairs of gratings were presented one above the other, on the pages of a booklet. Each of

the patterns was then presented individually in (different) random orders. Subjects were required (1) to rate the pattern for pleasantness on a five-point scale ranging from 'very pleasant' to 'very unpleasant' and (2) to list any visual or nonvisual effects that the pattern produced.

Results. The mean preference for each grating derived from the pairwise comparisons is shown in fig. 2A. It can be seen that gratings with more extreme spatial frequencies were preferred to those with frequencies between 2 and 8 cycles/deg. Using the method of circular triads (David, 1963, p. 25) the preferences are all significantly different from chance ($P < 0.01$). A comparison of the three curves provides an indication of the range effects (Poulton, 1979) introduced by the

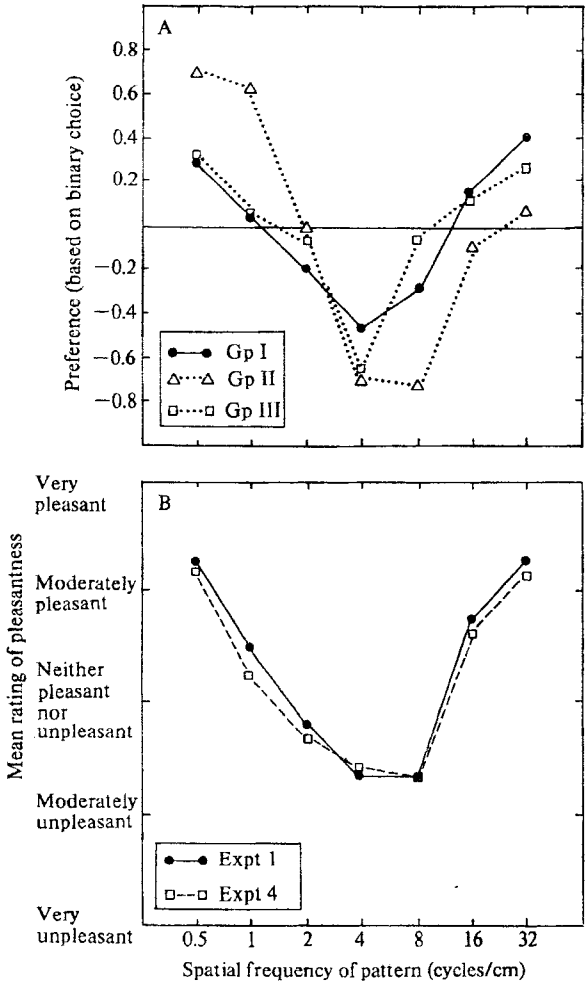


FIG. 2. Preference for square-wave gratings as a function of spatial frequency (Experiment 1). A, data from comparisons of pairwise combinations of gratings. Group I received the pairs in random orders, Group II received the low spatial frequencies first and Group III the high frequencies first. B, data from ratings (Experiments 1 and 4).

order of presentation. These range effects were not sufficient to affect the overall shape of the preference function. The individual ratings illustrated in fig. 2B also showed a significant effect of spatial frequency ($\chi^2 = 59.26$, d.f. $= 6$, $P < 0.001$, Meddis, 1980), with a significant quadratic component ($Z = 7.29$, $P < 0.001$, Meddis, 1980).

When invited to describe the effects that each pattern produced, the subjects listed both visual and nonvisual effects. In descending order of frequency the visual effects may be paraphrased as follows: colours (red, green, yellow, blue), diamond-shaped lattice, shimmer, blurring, dazzle, glare, bending of the lines, fading, 'blobs' and flickering. To our surprise, 11 of the 29 volunteers also listed adverse effects such as 'eyeache', tiredness, headache or 'dizziness'. The number of such complaints is shown as a function of spatial frequency in fig. 3. The number of complaints is high given that the pattern presentations were short and relatively few in number.

Relationship between Visual Illusions and Incidence of Headache

The next experiment was conducted in an attempt to determine whether headache might be the late result of prolonged observation of potentially epileptogenic patterns.

Experiment 2

The subjects were undergraduate physiology students at the University of Cambridge (28 men and 38 women aged 19 to 38 years) who were paid £1 for participating. For ethical reasons they were informed that there was a possibility that they might suffer a headache and persons with epilepsy or migraine were excluded. Two groups of volunteers were required to fixate the centre of a pattern of horizontal stripes for a succession of eight 10 s presentations. After each they noted the illusions they saw using the following checklist: 'blurring', 'shimmering', 'flickering', 'bending of the lines', 'shadowy shapes', 'red', 'yellow', 'green', 'blue'. The gratings were similar to those used in Experiment 1 but had a

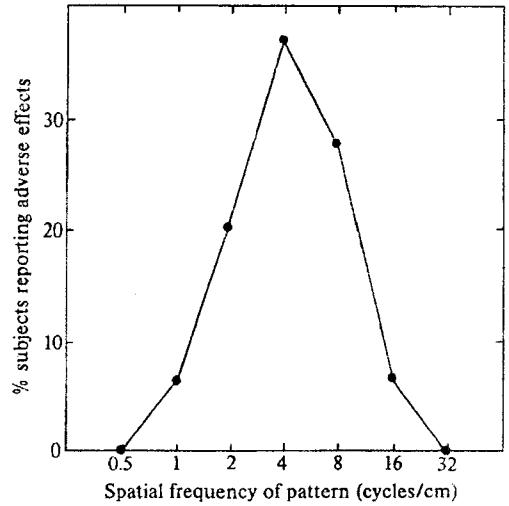


FIG. 3. Complaints of adverse nonvisual effects following the observation of gratings, expressed as a function of spatial frequency (Experiment 1).

TABLE 1. MEAN NO. OF ILLUSIONS REPORTED IN EXPERIMENT 2

4 cycle/cm group	*No. of subjects*	*Mean no. of illusions*	*SD*	*t*	*P*
First day					
Headache	12	35.0	11.3	3.18	< 0.005
No headache	23	24.6	7.3		
Third day					
Headache	6	25.5	9.0	< 1	
No headache	29	28.7	10.3		
0.5 cycle/cm group					
First day					
Headache	11	14.3	7.2	< 1	
No headache	16	14.6	8.0		
Third day					
Headache	5	16.6	8.0	< 1	
No headache	22	14.0	7.5		

spatial frequency of 4, or 0.5 cycles/cm, depending on the subject group. The mean luminance was about 20 cd/m^2. The volunteers were asked to keep a diary of their headaches for the subsequent seven days. A week later they were told that in order to control for the effects of suggestibility they had been randomly allocated to 'experimental' or 'control' groups, and they were asked to guess in which group they had been placed. They were then asked to guess the purpose of the study.

Results. There was no significant difference between the groups with respect to the proportion of students (about 50 per cent) who correctly perceived the general purpose of the study, or with respect to the proportion (also about 50 per cent) who thought they had been allocated to the experimental condition. However, the large number of students who correctly perceived the general purpose of the study makes interpretation of the results difficult. Table 1 summarizes the main findings. Subjects in both groups reported fewer headaches on the third day than on the first, probably because of decreasing interest in the study but possibly because of an induction of headaches on the first day as a result of pattern viewing. Subjects in the 4 cycles/cm group who suffered a headache on the first day tended to have checked more illusions. As can be seen from Table 1, this relationship is statistically highly significant ($t = 3.18$, $P < 0.005$). The number of illusions seen was not significantly related to the age or sex of the subjects.

The above results were inconclusive as regards the induction of headaches by patterns but they suggested a possible relationship between headache susceptibility and the illusions seen in a pattern of horizontal stripes with a spatial frequency of 4 cycles/cm. Experiments 3 to 5 were designed to determine whether this finding was replicable.

Subjects were asked to estimate the incidence of their headaches over the last twelve months by responding to questions similar to the following. 'Think of headaches that you have had over the last month and whether they have been getting more frequent or less frequent. Use this information to help you estimate how many headaches you have had in the last twelve months.' Pilot studies had shown subjects' replies to this question to be reliable and relatively unbiassed. In the first pilot study sixth-form students (aged 17 to 19 years) were asked to estimate the annual incidence of their headaches, the number of headaches suffered in the previous seven days and the date of their last headache. The latter estimate was used to derive the time elapsed since the last headache. The Spearman rank correlations obtained between the three alternative measures of headache incidence were all greater than 0.5 and statistically significant. In the second pilot study a group of 55 women on the Applied Psychology Unit panel (aged 23 to 64 years) were asked to keep a headache diary for a month. The correlation between the incidence of headaches recorded in the diaries and the subjects' previous estimate of the annual incidence of their headaches is shown in fig. 4. It can be seen there is no consistent bias towards overestimation or underestimation of headache incidence. The scatter may be attributed to the short sampling period of one month, and to the inaccuracy of subjects' memory for their headaches. The rank correlation ($r_s = 0.66$) is nevertheless sufficiently high to lend credence to subjects' estimates.

Relationship between Susceptibility to Headaches and to Visual Illusions

Estimates of the annual incidence of headaches were used in the next three experiments in an attempt to determine whether there existed a relationship between headache susceptibility and illusions. For ethical reasons subjects with migraine and epilepsy were excluded.

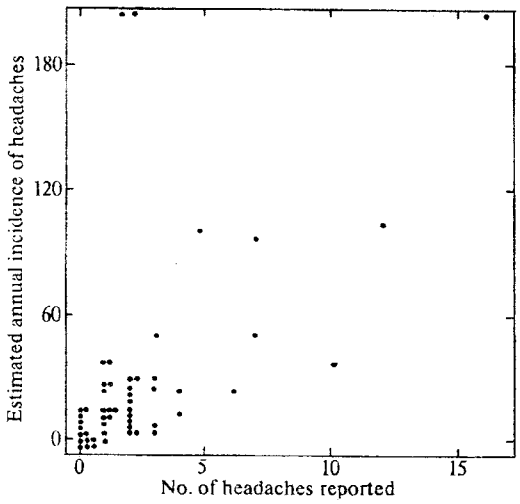


FIG. 4. Scatterplot showing the correlation between subjects' estimates of the annual incidence of their headaches and the number of headaches occurring in the subsequent month (pilot experiment).

Experiment 3

A group of female nursing and physiotherapy students aged 18 to 23 years from Addenbrookes Hospital, Cambridge was tested. The students were asked to estimate how many headaches they had had in the last twelve months. They then observed a printed pattern of horizontal stripes for 30 s at a distance of about 40 cm before checking the illusions they saw on the following list: 'fading of the pattern', 'bending of the lines', 'blurring', 'shimmering', 'flickering', 'colour', 'shadowy lines that are not really there', 'other (please specify)...'. Twenty-eight of the students, selected at random, observed a print of a horizontal square-wave grating with a spatial frequency of 4 cycles/cm. The remaining 26 students observed a grating with a spatial frequency of 0.5 cycles/cm. The gratings were similar to those used in Experiment 1. They were illuminated by overhead 100 Hz fluorescent lights and had a mean luminance of about 200 cd/m^2.

Results. The Spearman rank correlation between the estimate of the annual incidence of headaches and the number of illusions checked was 0.44 ($P < 0.05$) for the students who observed the 4 cycles/cm pattern and 0.03 for the students who observed the 0.5 cycles/cm pattern. The scatterplot for the 4 cycles/cm condition is shown in fig. 5.

These results confirm the spatial frequency selectivity of the relationship between illusions and headaches seen in Experiment 2. Experiment 4 was designed to test the extent of this selectivity.

Experiment 4

Eighteen men and 19 women aged 18 to 76 years from the Applied Psychology Unit's panel acted as subjects. They were instructed first to position a printed pattern of horizontal stripes at a distance of about 50 cm, and to look at a point at the centre of the grating for 5 s. They were then asked to look at a white sheet of paper for a further 5 s, and to check off the effects that they experienced. The checklist included not only the visual effects described in Experiment 1 but also 'illusory stripes', 'twinkling dots streaming up and down', 'eyeache', 'headache', 'nausea' and 'dizziness'. A total of 6 square-wave gratings similar to those used in Experiment 1 with spatial frequencies of 0.5, 1.0, 2.0, 4.0, 8.0 and 16.0 cycles/cm were presented in a random order. A further set was then presented in a different random order and the subjects were asked to rate the pleasantness of each pattern on a scale similar to that used in Experiment 1. The conditions of illumination were similar to those used in the previous experiments.

The subjects also completed a questionnaire that asked not only about the annual incidence of headaches but about their severity and locus. Questions about precipitating, exacerbating and alleviating factors, associated symptoms and variability were also included. In addition subjects were asked whether they had 'seen a doctor about their headaches'. At the end of the questionnaire subjects were asked to estimate how frequently they suffered the following symptoms: 'irritation or soreness of the eyes, dryness of the eyes, redness of the eyes, temporary blurring of vision (despite glasses if worn), spots or shapes in front of their eyes, faint colours surrounding objects, pain in response to light, narrowing of vision (one or both sides), any other visual problems' (Mackay, 1980).

Results. Table 2 presents the 2×2 contingency tables relating the illusions seen during observation of the pattern to subjects' estimates of the annual incidence of their headaches (illusions seen after observation of the pattern were not included). The relationship is largest for the grating with the spatial frequency of 4 cycles/cm ($r_s = 0.49$, $P < 0.05$) and this is not simply because more illusions were seen. Fig. 5 shows the scatterplot of the 4 cycles/cm condition. There were no significant effects of age or sex.

TABLE 2. CONTINGENCY TABLES SHOWING SEPARATELY FOR EACH SPATIAL FREQUENCY THE RELATIONSHIP BETWEEN SUBJECTS' HEADACHE SUSCEPTIBILITY AND THE NO. OF ILLUSIONS THEY REPORTED IN EXPERIMENT 4

Spatial frequency (cycles/cm)	*Headache susceptibility*	*Illusions reported*		χ^2	*P*
		0	*≥ 1*		
0.5	Low	14	4		
	High	14	5	0.08	0.77
1.0	Low	9	9		
	High	8	11	0.23	0.63
2.0	Low	4	14		
	High	2	17	0.93	0.33
4.0	Low	14	4		
	High	4	15	11.90	0.00
8.0	Low	5	13		
	High	1	18	3.44	0.06
16.0	Low	9	9		
	High	4	15	3.39	0.06

An analysis of the questionnaire revealed that subjects with frequent headaches tended to suffer relatively severe pain ($r_s = 0.68$, $P < 0.01$). They tended to complain of more frequent irritation or soreness of the eyes, temporary blurring of vision, pain in response to light ($P < 0.03$, sign tests). Only three had ever consulted a doctor about their headaches and only one had done so within the last twelve months.

The mean ratings of pleasantness were closely similar to those obtained previously and they appear in fig. 2B.

In the remaining replication only the 4 cycles/cm grating was used.

Experiment 5

A group of 33 male undergraduates in theoretical physics at the University of Cambridge, aged 19 to 23 years, were asked each of the following questions in turn: 'Do you see colour or colours?', 'Do the lines appear to bend?', 'Do the lines seems to blur?', 'Does the pattern flicker?', 'Do the lines wobble or shimmer?', 'Do parts of the pattern disappear and reappear?' After each question the students were asked to look at the fixation point in the centre of the horizontal grating for a total of 5 s and then to turn the pattern over and answer 'yes' or 'no' to the question. The subjects were then asked to estimate the annual incidence of their headaches. The 4 cycles/cm pattern and conditions of illumination were similar to those previously used.

Results. The Spearman rank correlation between the number of visual effects reported and the estimates of the annual incidence of headache was 0.49 ($P < 0.05$).

Discussion

Experiments 3–5 show a positive correlation between peoples' estimate of the annual incidence of their headaches and the number of illusions they report having

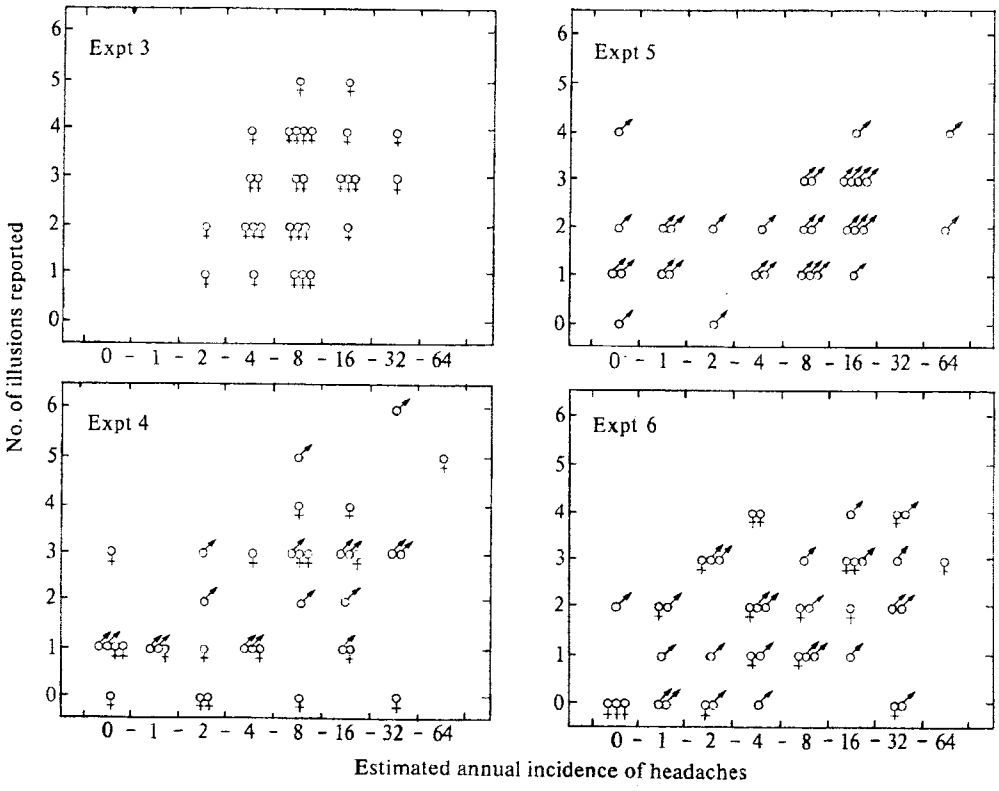


FIG. 5. Scatterplot showing the correlation between subjects' estimates of the annual incidence of their headaches and the number of illusions they saw in a grating with a spatial frequency of 4 cycles/cm (Experiments 3, 4 and 5).

seen in a pattern of stripes with a spatial frequency of 4 cycles/cm. Fig. 5 shows the relevant scatterplots for data obtained in Experiments 3, 4 and 5.

Two experiments (3 and 4) are consistent in demonstrating that the association between illusions and headaches obtains mainly for gratings with a spatial frequency of 4 cycles/cm and not for those with a lower frequency. The selective nature of the association would argue against the correlation being attributable entirely to subjects' suggestibility (some subjects being more prepared than others to admit to borderline headaches and borderline illusions). In two experiments subjects were asked not only about the incidence of their headaches but about other events (absentminded errors, in Experiment 4; episodes of back pain in another unpublished experiment). Any general contribution of suggestibility should produce a correlation between the reported incidence of these events and the number of illusions. In both cases the relevant rank correlation was negligible ($r_s = 0.07$; $r_s = 0.06$, respectively).

In the above experiments subjects were not asked whether they had a headache

before they looked at the patterns. This was because in two pilot studies in which subjects were given an opportunity to report headaches at the time of testing only about 1 subject in 20 did so.

If the relationship between illusions and headaches was due to neurological factors rather than those of a more general nature it is possible that there might exist a relationship between the locus of head pain and the locus of illusions within the pattern. Such a relationship emerged in the experiments now to be described.

Relationship between Asymmetry of Illusions and Lateralization of Head Pain

Two studies were conducted: one with normal volunteers and the other with outpatients from a neurological clinic whose principal complaint was one of headache.

Experiment 6

Fifty panel volunteers (women aged 29 to 52 years) observed at a distance of about 40 cm a print of horizontal stripes (square-wave grating, spatial frequency 4 cycles/cm) in which the left and right halves were separated by a vertical black line 2 mm wide. They checked 'mainly on the left side', 'equally on both sides', or 'mainly on the right side' against the following list: 'colour', 'fading of the pattern', 'blurring', 'bending of the lines', 'shimmering', 'flickering', 'dots streaming up and down', 'shadowy lines that were not really there'. The volunteers later completed an extensive questionnaire concerning their headaches. This included questions about the usual localization of the pain: first, a checklist of items such as 'all over the head', 'left side only', 'right side only', etc., and second, four diagrams of the head (full face, back, left and right profiles) on which to shade the areas usually affected.

Results. Thirty-two of the 50 subjects reported both headaches and illusions, and in 6 the headaches were of an inconsistent lateralization. For the remaining 26 subjects the headaches were either bilateral or consistently on the same side. The

TABLE 3. ASSOCIATION BETWEEN REPORTS OF LATERALLY ASYMMETRIC ILLUSIONS AND REPORTS OF UNILATERAL HEADACHE IN EXPERIMENTS 6 AND 7

	Illusions in visual hemifields	
	Equal	*Unequal*
A. Panel volunteers		
Bilateral headaches	13	1
Unilateral headaches (consistent side)	6	6*
	$\chi^2 = 6.03, P < 0.05$	
B. Neurological patients		
Bilateral headaches	13	3
Unilateral headaches (consistent side)	8	14**
	$\chi^2 = 7.55, P < 0.01$	

* 5 maximal in ipsilateral field. ** 7 maximal in ipsilateral field.

significant association between the occurrence of asymmetric illusions and the occurrence of unilateral headaches is shown in Table 3A. Five out of the 6 subjects with both asymmetric illusions and consistent unilateral head pain reported illusions maximal on the *same* side as the head pain.

Experiment 7

In order to increase the sample of subjects with unilateral headache, neurological outpatients were tested. The patients all had a primary complaint of headache. Nine men and 37 women, aged 12 to 63 years from the Northern and Western General Hospitals, Edinburgh, were tested individually. They completed an extensive questionnaire about their headaches with items similar to those used in the previous study and in Experiment 4. Table 4 shows the number of patients with clinical diagnoses of headache as 'migraine', 'migraine and tension', 'tension' and 'depression'. The table also lists the number of patients in each of these categories complaining of clusters of symptoms found to be of importance in a factor analytic study of headache symptoms (Ziegler and Hassanein, 1982). Once they had completed the questionnaire the patients were shown a succession of 5 patterns of horizontal stripes, circular in outline and of increasing diameter, followed by 2 unilateral gratings, 1 in the left visual field and 1 in the right. The gratings had a spatial frequency of 4 cycles/cm and Michelson contrast of 0.7. The first five had radii of 7, 13, 25, 50 and 100 mm. Each bore a central fixation point. The unilateral gratings were formed by bisecting the largest pattern about a vertical midline. A fixation point was positioned 5 mm away from the middle of the straight edge of each half. All the patterns were mounted on grey card with a reflectance similar to that of the mean of the black and white stripes. The patterns were presented for 10 s each at a distance of 40 cm, after which the patients were asked to describe the illusions they saw using the following checklist: 'fading of the pattern', 'bending of the lines', 'blurring', 'shimmer', 'flickering', 'colours', 'shadowy lines', 'other'. When all the patterns had been presented they were asked to say whether one of the unilateral patterns had produced more illusions than the other.

Results. Table 3B shows the relationship between the inequality of the illusions seen in the two visual hemifields and the lateralization of headache as assessed by the questionnaire. Patients with a headache of inconsistent lateralization have been omitted. Note that once again persons who had bilateral headaches were unlikely to see asymmetric illusions. Seven of the 14 patients saw illusions mainly in the visual field ipsilateral to the pain. In other words, for this series, as for the last, there was little relationship between the side of illusions and the side of headache; the

TABLE 4. DIAGNOSES AND SYMPTOMS OF PATIENTS PARTICIPATING IN EXPERIMENT 7

	Diagnosis				
Headaches usually associated with	*'Migraine'* ($n = 24$)	*'Migraine and tension'* ($n = 5$)	*'Tension'* ($n = 7$)	*'Depression'* ($n = 2$)	*None* ($n = 8$)
Weakness or numbness	18	4	2	0	2
Loss of appetite, nausea, or vomiting	24	4	5	1	7
Visual precipitation or photophobia	18	5	5	1	3
Unilateral pain	21	4	2	1	4
Change in vision	20	3	2	1	1

relationship obtained simply in terms of presence of an asymmetry and the presence of unilateral headaches.

Patients with unilateral headaches are usually diagnosed as suffering from migraine rather than tension headache. From these considerations alone, a relationship between the presence of asymmetric illusions and a diagnosis of migraine might be anticipated. The association was significant and is shown in Table 5B. There was also a tendency for patients with a diagnosis of migraine to report seeing a greater number of different illusions (*see* Table 5A). The threshold radius at which illusions were first reported did not differ between the groups. Analysis of the individual illusions did not suggest that some were more discriminative than others.

TABLE 5. RELATIONSHIP BETWEEN ILLUSIONS AND DIAGNOSIS OF HEADACHE IN EXPERIMENT 7

		Headache diagnosis	
		'Migraine'	'Tension'
A. No. of different illusions	$\leqslant 2$	14	7
	> 2	10	1
		$\chi^2 = 2.26$, $P = 0.13$	
B. Symmetry of Illusions			
Symmetric		10	7
Asymmetric		14	1
		$\chi^2 = 5.06$, $P = 0.024$	

Responses to the individual questions on the questionnaire were reduced to binary scores by division about the median and submitted to a single link cluster analysis (Jardine and Sibson, 1971). The main clusters are summarized in Table 6. This shows that, with a few exceptions, the total number of illusions seen in all patterns is a variable that clusters together with symptoms of migraine. This clustering may reflect the relatively large proportion of patients with a diagnosis of migraine.

Latent class analysis was used in a subsequent statistical investigation of the data. Latent class analysis is a form of factor analysis applicable to discrete observations (Plackett, 1981, p. 105) and it hypothesizes the existence of (latent) groups of patients for which there are different rates of incidence of various symptoms. It estimates these rates and the probabilities of group membership and then infers for each patient, on the basis of his particular symptoms, the probability that he belongs to each group.

TABLE 6. SAMPLES OF ITEMS CLUSTERING MINIMALLY AND MAXIMALLY WITH TOTAL ILLUSIONS, SHOWING THE DIRECTION OF ASSOCIATION (EXPERIMENT 7)

Minimal	*Maximal*
Many alleviating factors (−)	Associated unsteadiness on feet (+)
Family history of high blood pressure (+)	Associated vomiting (+)
Pain in middle of forehead (+)	Last headache unilateral (+)
Associated ringing in ears (+)	Pain usually right-sided (+)
Meals generally appetizing (+)	Throbbing pain (+)
History of epilepsy (+)	Associated nausea (−)
Headaches start at same time of day (+)	Know it's coming (+)
History of ear complaints (−)	Associated loss of appetite (+)
Pain spreads (+)	Many exacerbating factors (+)
	Associated lightheadedness (+)
	Associated tender scalp (−)
	Associated change in vision (+)

Five symptoms were chosen arbitrarily: nausea, 'stuffed up' nose, tenderness of the scalp, changes in vision and prior warning. From these symptoms an assignment of the patient to two groups was derived. The groups were differentiated in the proportions 66 and 34 per cent and members of the larger group had a higher incidence of each of the five symptoms. This derived grouping had a significant association with (1) the clinician's diagnostic categories, when dichotomized as 'migraine' and 'other' and (2) with the occurrence of an above-median number of visual illusions.

In the subsequent replication using volunteers on the subject panel, few of whom had severe headaches, the cluster and latent groups analyses failed to reveal similar findings.

A second small-scale replication involved 27 patients from a neurological clinic and from general practice in Harlow, all of whom had a primary complaint of headache, diagnosed as migraine in all but 4 cases. In this study the questionnaire included, in addition to those items used in Experiment 7, items concerning the 9 ocular and visual symptoms listed in the description of Experiment 4. The number of patients who took part in the study was too small for the results of a cluster analysis to be reliable, but when the ocular and visual symptoms were subjected to an *a priori* analysis, 'temporary blurring of vision' was significantly associated with the total number of illusions reported (maximum $\chi^2 = 8.06$, d.f. $= 1$, $P < 0.02$).

Discussion

Experiments 3–7 are consistent in demonstrating a relationship between the headaches people suffer and the number and lateralization of the illusions they report when they look at certain striped patterns. The association between unilateral head pain and asymmetry of illusions is difficult to interpret in terms of peripheral ocular factors such as astigmatism, phoria or reduced acuity. The fact that the

association was obtained despite an absence of any relationship between the direction of asymmetry and the side of pain is consistent with the weakness of the relationship between the side of visual aura and the side of head pain in patients with migraine headache (Peatfield *et al.*, 1981).

The statistical relationships reported above appeared only when relatively large groups of people were tested and it was not practicable for all the participants to receive an ophthalmological examination. However, in studies reported elsewhere, 17 volunteers who complained of 'eye-strain or headache' from reading were given an extensive ophthalmological investigation in addition to a test of illusion susceptibility. The ophthalmological findings were not associated with the illusions reported. The illusions, but not the ophthalmological findings, predicted the efficacy of a reading aid that covered the lines of text above and below those being read (Wilkins and Nimmo-Smith, 1984).

In the experiments reported above no attempt has been made to separate the illusions of colour, shape and motion. This is because there was no suggestion of a separate contribution to the relationship with headache. The relationship obtained only when the illusions were considered together. Such an approach is justifiable if it can be demonstrated that the illusions have a common neurological basis. As mentioned before, the evidence concerning the origins of the illusions is controversial, although central mechanisms have been postulated. The hypothesis of central mechanisms receives further support in the following experiments which demonstrate that various stimuli provoke illusions to the extent that they also evoke epileptiform EEG abnormalities in patients with photosensitive epilepsy. In these experiments, as in those above, analyses of the individual illusions was unproductive. It was the number but not the nature of the illusions that was related to the properties of the pattern.

SECTION 2

In studies of photosensitive patients (Wilkins *et al.*, 1980) it has been shown that the probability of epileptiform activity in response to a pattern depends on the following pattern parameters.

1. The shape of the pattern. If the component checks of a checker-board pattern are elongated in one direction the probability of paroxysmal activity increases with the logarithm of the length/width ratio (*see* fig. 6A).

2. The spatial frequency of the pattern. The spatial frequency optimal for the induction of paroxysmal activity depends somewhat on the angular subtense of the pattern, but for gratings subtending 20 deg is about 3 cycles/deg (*see* fig. 7A).

3. The duty cycle of the pattern. Duty cycle describes the relative width and separation of the component bars of a repetitive pattern in terms of the pulse/cycle fraction. The probability of paroxysmal activity is maximal when the width and spacing are in the ratio of approximately 1 : 1, that is, when the duty cycle has a value of about 50 per cent (*see* fig. 8A).

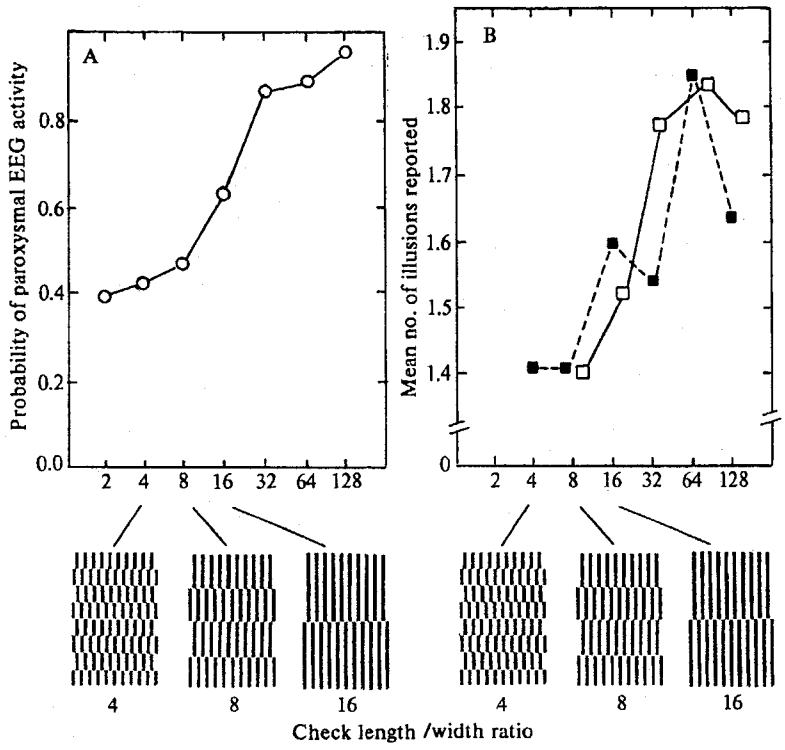


FIG. 6. A, probability of paroxysmal EEG activity as a function of check length/width ratio (*after* Wilkins *et al.*, 1979; one photosensitive patient, mean of 3 sessions). B, mean number of illusions reported by subjects without epilepsy, expressed as a function of check length/width ratio (Experiment 8). □——□ = 100 mm radius. ■- - - - ■ = 80 mm radius.

4. The contrast of the pattern. The probability of paroxysmal activity increases with the Michelson contrast precipitously in the range 5–30 per cent, but thereafter shows little increase with further increases in contrast (*see* fig. 9A).

5. The size of the pattern. The size of the pattern can be varied in a number of ways (*see* introduction to Experiments 11 and 12). The probability of paroxysmal activity increases with size, and patients differ in the threshold size below which no paroxysmal activity appears.

6. The position of the pattern in the visual field. In general, patterns presented in the lateral hemifields (stimuli A and B, Table 9) are more epileptogenic than patterns of equivalent size presented in the upper and lower fields (stimuli C and D, Table 9). Some patients demonstrate marked differences in photoconvulsive threshold between the two lateral hemifields.

7. Monocular *versus* binocular presentation. The probability of paroxysmal activity is greatly reduced when presentation is monocular.

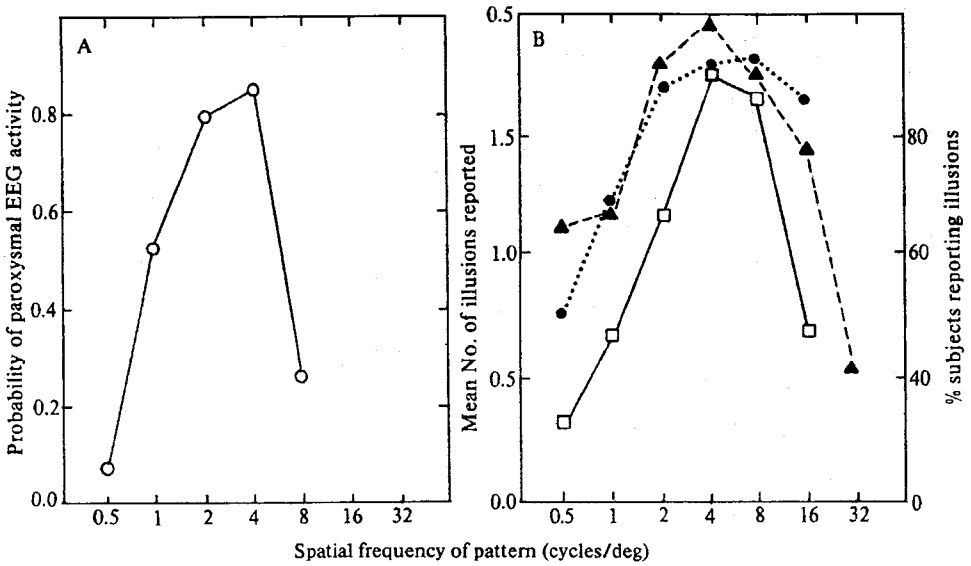


FIG. 7. A, probability of paroxysmal EEG activity as a function of the spatial frequency of a square-wave grating (*after* Wilkins *et al.*, 1979; mean of 8 photosensitive patients). B, mean number of illusions reported (□——□) by subjects without epilepsy (Experiment 4), and the percentage of subjects reporting illusions, expressed as functions of spatial frequency (Experiment 1 (▲ - - - - ▲) and 4 (● · · · · ●)).

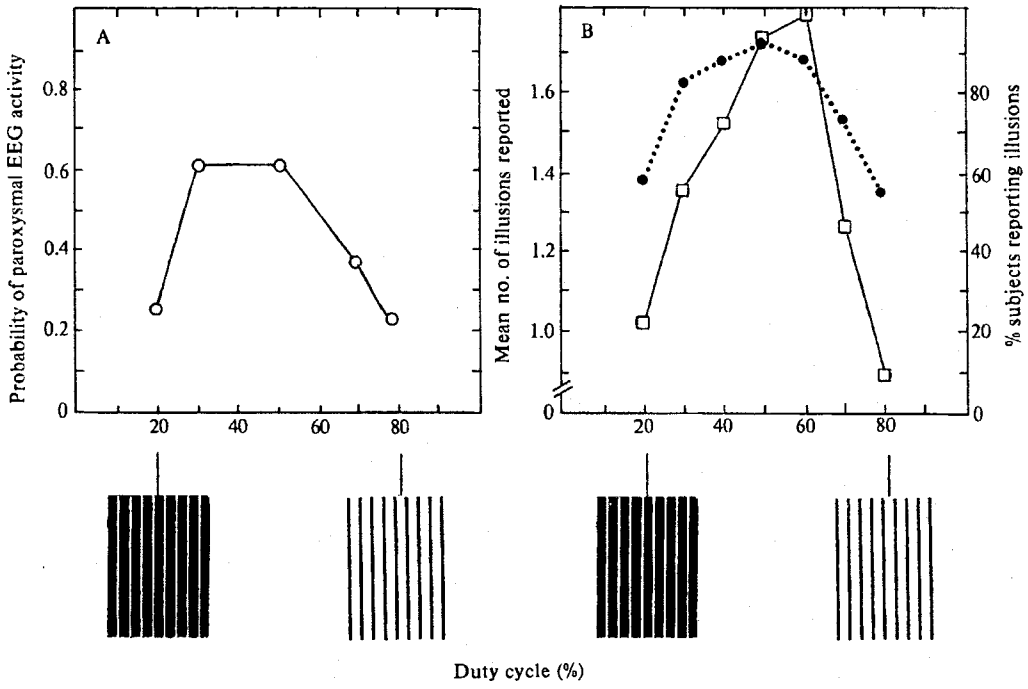


FIG. 8. A, probability of paroxysmal EEG activity as a function of the duty cycle of a square-wave grating (unpublished data; mean of 4 photosensitive patients). B, mean number of illusions reported (□——□) by subjects without epilepsy, and the percentage of subjects reporting illusions (● · · · · ●), expressed as a function of duty cycle (Experiment 9).

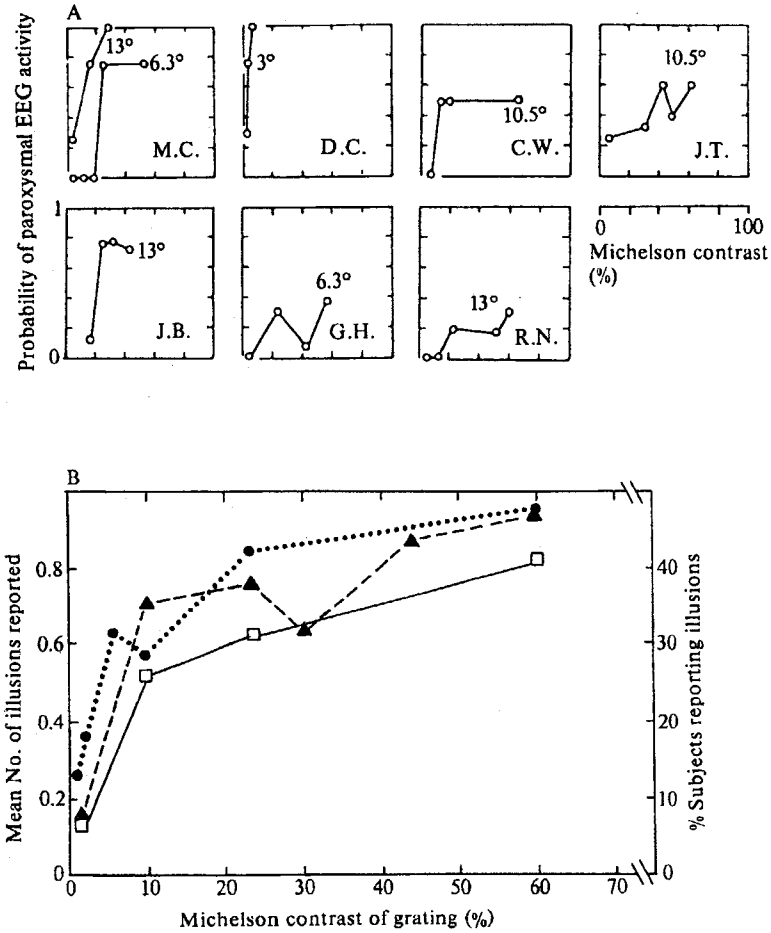


FIG. 9. A, probability of paroxysmal EEG activity as a function of the Michelson contrast of a square-wave grating (*after* Wilkins *et al.*, 1980). The data for each patient are shown in a separate panel, together with the radius of the grating in degrees of visual angle. B, mean number of illusions reported (□——□) by subjects without epilepsy, and the percentage of subjects reporting illusions (lin ▲- - - -▲; log ● · · · · ●), expressed as a function of contrast (Experiment 10).

Effects of the Spatial Frequency of a Pattern

The data from Experiment 4 (summarized in Table 2) have already shown how the number of illusions varies as a function of spatial frequency. These data have been plotted, together with those from Experiment 1, in fig. 7B. Despite the different procedures involved in Experiments 1 and 4, notably as regards in range of spatial frequencies under comparison and the absence of a formal checklist in Experiment 1, the percentage of subjects reporting illusions is a very similar function of spatial frequency. The mean number of illusions seen is calculated from the data of Experiment 4 and has a function very similar to that for the probability

of paroxysmal activity (fig. 7A). In both functions the maximum is between 1 and 8 cycles/deg.

In the following experiments subjects without epilepsy were asked to report the illusions they saw in patterns that varied with respect to the remainder of the 7 parameters listed above.

General Procedure

The volunteers who took part in these experiments (members of the Applied Psychology Unit subject panel, 6 men and 105 women, aged 25 to 76 years) were tested in 6 groups. Each volunteer was presented with a booklet containing prints of patterns and was instructed to look at each print in turn for 10 s at a distance of about 40 cm, and then to check the illusions seen on the following list: 'red', 'green', 'blue', 'yellow', 'blurring', 'bending of stripes', 'shimmering', 'flickering', 'fading', 'shadowy shapes', 'other (please specify)'. The patterns were illuminated by overhead 20 kHz fluorescent tubes and the prints had a Michelson contrast of 0.7 and a mean luminance of about 100 cd/m^2.

Two groups (38 subjects in all) took part in Experiment 9. The 4 remaining groups each received a set of prints consisting of the patterns used in Experiments 8, 11, 12 and 13. The order of presentation was random and counterbalanced in the first group, random but constant in the second group, and random for the third and fourth groups. Since the data from the four groups were closely comparable they have been combined.

Data Analysis

The number of illusions reported was transformed before analysis in order to remove the effects of the large numbers of zero scores, according to the formula $\sqrt{(x+3/8)}$ suggested by Johnson and Leone (1964).

Experiment 8. Effects of Check Length

The patterns used are shown schematically in fig. 6. The component checks were 2.5 mm wide and the patterns were circular in outline with a radius of 100 mm (first and second groups) or 80 mm (third and fourth groups). The length/width ratio was determined by successive division of the pattern, beginning with a division through the centre. Thus the series 100 mm in radius had ratios of 160, 80, 40, 20 and 10, whereas the series 80 mm in radius had ratios of 128, 64, 32, 16, 8 and 4.

Results. The mean number of illusions is plotted as a function of length/width ratio in fig. 6B. It can be seen that there is a trend such that patterns with longer stripes elicit more illusions. The trend, as revealed by a linear regression analysis based on the transformed data, was significant for the data from the first and second groups ($t = 2.83$, d.f. $= 144$, $P < 0.01$) but not for the data from the third and fourth groups ($t = 1.57$, d.f. $= 165$, $P < 0.2$). The percentage of subjects reporting illusions varied from 82 to 91 per cent and showed no consistent trend as a function of check length/width.

When the illusions were analysed separately there was a tendency for fewer reports of 'red', 'green' and 'shadowy shapes' for the smaller length/width ratios, but this was not significant ($\chi^2 = 29.6$, d.f. $= 36$, $P = 0.76$).

Experiment 9. Effects of Duty Cycle

Seven gratings with a spatial frequency of 4 cycles/cm and a duty cycle of 21, 29, 42, 51, 62, 71 and 79 per cent were presented in different random orders. When they had checked the illusions seen, subjects were asked to reorder the gratings according to their personal preference for each.

Results. The mean number of illusions reported and the percentage of subjects reporting illusions are shown as a function of duty cycle in fig. 8B. For both functions the quadratic component was statistically highly significant ($t = 5.30$, d. f. $= 222$, $P < 0.001$; $Z = 4.01$, d.f. $= 6$, $P < 0.001$, Meddis, 1980).

When the individual illusions were analysed separately there was no indication that the proportion of illusions of the various types differed between patterns ($\chi^2 = 34.0$, d.f $= 54$, $P = 0.98$).

Subjects' mean rank of preference for the gratings was 4.5, 5.2, 5.2, 4.7, 3.9, 2.5 and 1.9 in order of increasing duty cycle, indicating a preference for gratings with extreme values. Both the linear and quadratic components of the trend were significant ($\chi^2 = 56.9$, d.f. $= 1$, $P < 0.001$ and $\chi^2 = 17.8$, d.f. $= 1$, $P < 0.001$, respectively).

Experiment 10. Effects of Pattern Contrast

Forty-one women on the Applied Psychology Unit panel (aged 18 to 68 years) were tested individually. They were asked to state their preference for 2 patterns that differed only in contrast. The patterns were black and white square-wave gratings, circular in outline and 20 deg in diameter, which had a spatial frequency of 3.3 cycles/deg and a mean luminance of 20 cd/m^2. They were viewed through apertures in a box containing an oblique semisilvered mirror that superimposed optically the images of two fields, one containing a print of the grating and the other a grey unpatterned surface with the same mean reflectance. Linear polarizers were positioned over each field and orientated so that the plane of polarization was horizontal for one field and vertical for the other. Two viewing apertures, one immediately above the other, were covered by polarizers and the subjects gaze was directed first through one aperture and then the other. The orientation of the polarizers controlled the relative attenuation of the two fields so that the apparent contrast of the pattern differed for the two apertures, although its mean luminance was identical. The subject was instructed to compare the pattern seen through the two apertures and to give a preference for one of the two contrasts. She was also asked to report any illusions she saw and to indentify the aperture through which they were seen. The checklist was identical to that given in the General Procedure. Eight levels of contrast were compared: 1, 2, 6, 11, 23, 33, 44 and 60 per cent. These were divided into two sets of six: 1, 11, 22, 33, 44 and 60, and 1, 3, 6, 11, 22 and 60. Four levels of contrast were common to each set, but in one set the spacing was approximately linear and in the other approximately logarithmic. The pairwise combinations of the stimuli in each set were compared in two consecutive series of 15 trials. Half the subjects received the logarithmic set first and the linear set second, and half received the sets in reverse order.

Results. For the group as a whole there was no consistent preference for one grating contrast over another. Nevertheless if subjects reported seeing illusions in one of a pair of gratings then they almost invariably preferred the other ($P < 0.001$, sign test). Fig. 9B shows the percentage of subjects reporting illusions, and the mean number of illusions reported, as a function of grating contrast. There was no significant effect of the order of presentation of the linear and logarithmic sets and so the data have been collapsed across this variable. It will be noted that the percentage of subjects reporting illusions is a similar curvilinear function of contrast, regardless of whether the data were obtained from the sets of stimuli that were linearly or logarithmically spaced. The mean number of illusions reported has been derived from both sets. When the illusions were analysed separately there was

a tendency for relatively few reports of 'shimmering' at low contrasts, but the proportion of illusions of each type did not differ significantly as a function of contrast ($\chi^2 = 25.8$, d.f. $= 18$, $P = 0.1$).

From the shape of the functions shown in fig. 9B it is obvious that there is a sharp increase in the number of illusions seen when the pattern contrast is less than 30 per cent, although at contrasts above 30 per cent the illusions increase relatively little with contrast. In this respect at least the function is similar to that for the probability of paroxysmal activity in photosensitive patients shown in the panels in fig. 9A. The mean probability across patients is approximately linear when plotted as a function of log contrast, as is the function for the mean number of illusions.

Effects of Pattern Size

In photosensitive patients the probability of paroxysmal activity in response to patterns of stripes is critically dependent on the size of the pattern. Each patient has a different threshold size below which no paroxysmal activity occurs and above which the probability of paroxysmal activity increases with pattern size.

When gratings of concentric circles are cut as for the slices of a cake and opposed diametrically (Table 7) pattern size may be increased by increasing the angular size of the sectors. This has the advantage that all retinal eccentricities are affected by the change in size. If the probability of paroxysmal activity is plotted as a function of total pattern area the curves for different patients then appear to have roughly the

TABLE 7. MEAN NO. OF ILLUSIONS REPORTED IN EXPERIMENT II

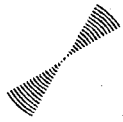
	Stimulus	*Mean no. of illusions reported*	*t*	*P*
A		0.56		
			1.09	< 0.15
B		0.68		
			0.18	n.s
C		0.68		
			2.39	< 0.01
D		1.03		

TABLE 8. PARAMETERS OF PATTERNS AND MEAN NO. OF ILLUSIONS REPORTED IN EXPERIMENT 12

	Stimulus	Radii (mm) Inner	Outer	Area (cm^2)	Q* (%)	Mean no. of illusions reported	t	P
A		—	18	9	14	0.87		
							1.86	n.s.
B		65	100	181	14	1.00		
							2.49	< 0.05
C		—	40	45	28	1.18		
							0.41	n.s.
D		39	100	269	28	1.20		
							2.69	< 0.01
E		—	100	314	55	1.39		

* Percentage of visual cortex devoted to the analysis of the region of visual space occupied by the pattern, Drasdo (1977).

same slope but different x-intercepts. For most patients, the curves for patterns with four sectors (Table 7, stimuli C and D) overlap with the curves for patterns with two (Table 7, stimuli A and B): the two types of pattern are equally epileptogenic when they have the same total area (Wilkins *et al.*, 1980).

A different finding emerges when the gratings are straight lines, circular in outline, and pattern size is increased by increasing the pattern radius (Table 8, stimuli A, C, E). The functions relating the probability of paroxysmal activity to the area of the pattern have different x-intercepts, as before, but the slopes of the functions are no longer similar. The slopes resemble one another only when the probability is plotted as a function of the logarithm of the pattern area: for each patient the radius of the pattern has to be doubled to increase the probability from near zero to near unity (Wilkins *et al.*, 1979). This finding doubtless reflects the fact that the larger patterns now stimulate proportionately more of the peripheral retina, which has a smaller cortical representation. Such an interpretation is in line with the effects of selective stimulation of central and peripheral retina. When the central section of the pattern is removed so as to form a striped annulus (Table 8, stimuli B and D) the epileptogenic effects of the pattern are reduced by an amount that can be predicted from published estimates of the human cortical magnification factor. The total area of the pattern is not then predictive (Wilkins *et al.*, 1980).

In the experiments that follow, size was manipulated in each of the ways described above and normal subjects were asked to list the illusions they saw.

Experiment 11. Effects of Stimulation of Different Retinal Areas

The stimuli used are shown in Table 7. Half the two-sector patterns were rotated 90 deg to those shown. The concentric rings had a spatial frequency (diagonal measurement) of 4 cycles/cm, an outer radius of 100 mm, and the angles of the sectors were 30 or 60 deg.

Results. The mean number of illusions checked is shown in Table 7. Pairwise t-comparisons, based on the transformed scores, are summarized in the same table and indicate that the mean number of illusions for a pattern with two sectors was similar to that for a pattern with four sectors half the size. In patients with photosensitive epilepsy the probability of paroxysmal EEG activity is determined by the total pattern area, regardless of the number of sectors. The same is the case with respect to the mean number of illusions seen.

There was no significant differences between the four types of pattern with respect to the proportion of illusions of each type ($\chi^2 = 28.0$, d.f. $= 27$, $P = 0.4$) or the percentage of subjects reporting illusions ($\chi^2 = 4.3$, d.f. $= 3$, $P = 0.2$).

Experiment 12. Effects of Cortical Respresentation

The three complete gratings (stimuli A, C and E, Table 8) had radii of 18, 40 and 100 mm. The annuli (stimuli B and D, Table 8) had an external radius of 100 mm and internal radii of 65 and 39 mm, respectively. The percentage of visual cortex devoted to analysing the region of visual space occupied by the pattern (Q) was estimated from Drasdo's (1977) equation:

$$Q = 100\,[1 - \exp(-0.0574\theta)]$$

where θ is the angular radius of a circular region, centrally fixated. Assuming a viewing distance of 400 mm, the value of Q for the annulus with the large internal radius (stimulus B) was identical to that of the smallest complete grating (stimulus A). The values of Q for stimuli C and D were identical and twice those for stimuli A and B. The largest complete grating (stimulus E) had a Q-value twice that for stimuli C and D and four times that of stimuli A and B.

It is unlikely that the patterns stimulate a constant proportion of the cortical cells responsible for analysing the region of visual space that each pattern occupies. The annuli had the same spatial frequency as the complete gratings (4 cycles/cm), and no account was taken of the changes in acuity with eccentricity, so the proportion of available cells actually stimulated was likely to differ considerably. Nevertheless, using similar stimuli, Wilkins *et al.* (1970) have shown that the probability of paroxysmal activity is better predicted by the value of Q than by the area of the pattern. The annuli had an area more than five times that of the discs with the equivalent Q-value, as can be seen from Table 8.

Results. The mean number of illusions reported is shown separately for each pattern in Table 8. Planned t-comparisons between pairs of stimuli yielded significant t-values for pairs with different estimates of Q (stimuli B and C, and stimuli D and E) but not for pairs with similar Q-values (stimuli A and B and stimuli C and D). The mean number of illusions increased with Q but not with pattern area, as can be seen from Table 8.

When the individual illusions were analysed separately, there was a tendency for annuli to evoke more frequent reports of shimmer and blurring, but this was not

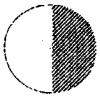
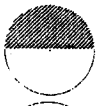
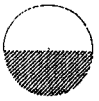
significant ($\chi^2 = 34.5$, d.f. $= 36$, $P = 0.56$). The percentage of subjects reporting illusions did not differ significantly for the pairwise comparisons shown in Table 8.

Experiment 13. Effects of Hemifield Presentation

Subjects in the first group were asked to check the illusions they saw in gratings similar to those represented schematically in Table 9; these were square-wave gratings, spatial frequency 4 cycles/cm, hemiradius 100 mm, with bars orientated at 45 deg to the vertical, half with an orientation 90 deg to that illustrated. The central fixation point was positioned 4 mm from the straight edge.

Results. The mean number of illusions reported is shown in Table 9. There were no significant differences between the patterns, $F(3, 57) = 1.12$, $P = 0.34$.

TABLE 9. MEAN NO. OF ILLUSIONS REPORTED IN EXPERIMENT 13

	Stimulus	*Mean no. of illusions reported*
A		2.10
B		2.15
C		1.95
D		2.55

Experiment 14. Effects of Monocular Viewing

The subjects who took part in Experiment 10 were earlier required to look at a succession of five patterns of increasing size, similar to those used in Experiment 7, for 5 s each. The largest pattern was then viewed monocularly with first the left and then the right eye, the other eye being covered. The pattern was then viewed binocularly once again.

Results. The mean number of illusions reported and the percentage of subjects reporting illusions are shown in Table 10. Both measures show an increase with pattern size (the linear trend is significant for mean number: $t = 2.13$, $P < 0.05$ and for the proportion of subjects reporting illusions: $Z = 2.25$, $P = 0.011$, Meddis, 1980). The mean number of illusions reported is significantly smaller under monocular viewing conditions than under the equivalent binocular conditions ($t = 2.72$, $P < 0.01$) but the proportion of subjects reporting illusions does not show a difference ($Z = 1.24$, Meddis, 1980). When the illusions were analysed separately, the proportion of illusions of each type was similar under monocular and binocular viewing conditions ($\chi^2 = 19.16$, d.f. $= 27$, $P = 0.86$).

TABLE 10. MEAN NO. OF ILLUSIONS REPORTED AND PERCENTAGE OF SUBJECTS REPORTING ILLUSIONS IN EXPERIMENT 14

Pattern radius (mm)	*Viewing condition*	*Mean no. of illusions reported*	*% subjects reporting illusions*
7	Binocular	0.17	17
13	Binocular	0.78	61
25	Binocular	1.17	80
50	Binocular	1.46	90
100	Binocular	1.73	90
100	Left eye	1.34	80
100	Right eye	1.32	78
100	Binocular	1.54	83

Discussion

Experiments 8-14 have demonstrated that, with one exception, the parameters of patterns optimal for the induction of visual illusions are precisely those optimal for evoking paroxysmal EEG activity in patients with photosensitive epilepsy. This would suggest that the neural mechanisims responsible for the illusions may resemble, to some extent, those that trigger epileptic disturbances. The final experiment lends support to this view. Loss of sleep is one of the factors classically associated with a reduction of convulsive threshold. Experiment 15 demonstrates that the number of illusions reported increases after sleep deprivation.

Experiment 15. Effects of Sleep Loss

Eight female high school students aged 17 or 18 years (without epilepsy or migraine) were recruited for a study of the effects of deprivation of sleep on the EEG architecture of subsequent recovery sleep. For two initial nights the subjects slept in the EEG laboratory from about 11 p.m. to about 8 a.m. On the third night their sleep was interrupted at 4.00 a.m. and they remained awake until about 8 p.m. the same day when they were allowed to sleep for a variable period of time. The subjects then slept at home for the subsequent three nights, before returning to the laboratory for a further four nights on a regime identical to that undergone the previous week. Before and at least one half-hour after each period of laboratory sleep, and at 8 a.m. on the morning of the early awakening, subjects observed a succession of horizontal gratings similar to those used in Experiment 7 but 13, 25, 50 and 100 mm in radius. After observation of each pattern they completed a checklist identical to that described in the General Procedure. Subjects were informed only that this test was being given on behalf of a colleague.

Results. The total number of illusions per test for each of the 8 subjects is shown as a function of time in fig. 10. The perturbation at 4 a.m. is obvious. The mean number of illusions reported at 8 a.m. on the two mornings following interrupted sleep is greater than the mean at 8 a.m. on the previous mornings in 7 of the 8 subjects ($P < 0.05$, sign test).

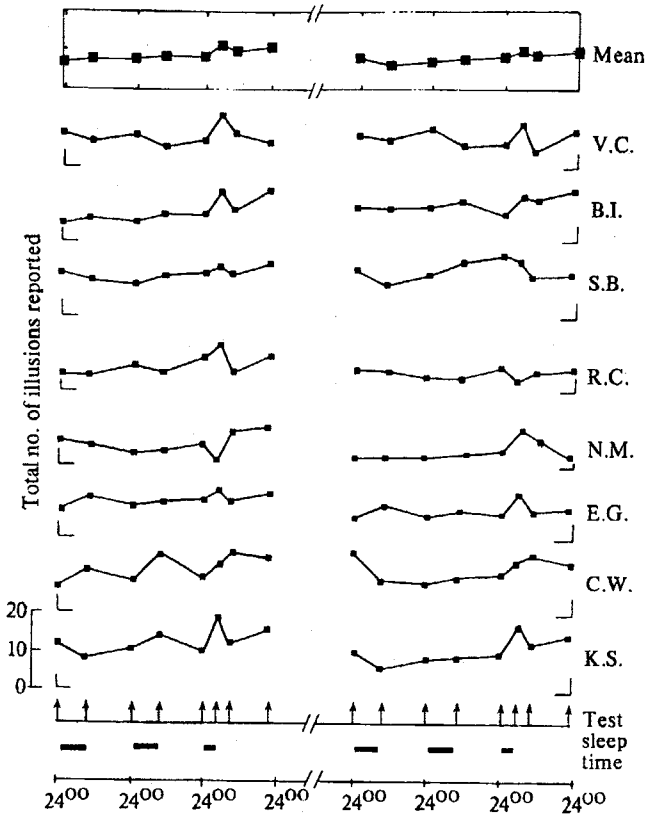


FIG. 10. Total number of illusions reported by individual subjects in Experiment 15 before and at least 30 min following sleep of about 8 h or 4 h duration.

GENERAL DISCUSSION

Certain patterns of stripes are unpleasant to look at, inducing anomalous visual effects and, less frequently, 'tired eyes' and headaches. The visual effects (illusions of colour, shape and motion) do not dissociate from one another, but all are induced by the same types of patterns. Their strength varies considerably from pattern to pattern and from person to person, but may nevertheless be measured using verbal descriptions of the various illusions produced. When normal subjects are asked to check the illusions seen on a list of such descriptions, the number but not the nature of the illusions checked is critically dependent on a range of pattern parameters. These include the shape, spatial frequency, duty cycle, contrast and angular subtense of the pattern, as well as its location in the visual field and whether it is viewed with one or both eyes. In patients with photosensitive epilepsy the probability of paroxysmal activity is dependent on the same parameters in almost

precisely the same way. This would suggest that the neural processes that underlie the illusions may share mechanisms in common with those responsible for triggering epileptic disturbances. The increase in illusions following sleep deprivation supports such an interpretation. Photosensitive epileptiform abnormalities have been attributed to a minimal diffuse failure of cortical inhibition that may be GABAergic (Meldrum and Wilkins, 1984). Sensory stimulation that induces intense cortical excitation (possibly certain patterns of stripes) may cause a breakdown of inhibitory mechanisms that either remains localized or spreads. If the discharge remains localized within the visual cortex, neurons may nevertheless be inappropriately excited so as to produce anomalous visual effects, without any electrical disturbances being measurable at the scalp. If the discharge spreads further, EEG phenomena may be produced, followed ultimately by clinical seizures.

Stimulation of the two upper or two lower visual quadrants (upper and lower hemifields, stimuli C and D, Table 9) is generally less epileptogenic than stimulation by the same pattern of one of the lateral hemifields (stimuli A and B, Table 9; *see* Wilkins *et al.*, 1981). These differences have been attributed to the independence of the cerebral hemispheres in the induction of the epileptic discharge. Patterns that occupy the upper or lower hemifields stimulate both hemispheres, but stimulate each to a lesser extent than that to which one hemisphere is stimulated by a lateral pattern. The induction of a discharge is thought to require a 'critical mass' of excitation and this mass is more likely to be achieved within one hemisphere by a lateral pattern. The absence of any differences between the illusions produced by stimulation of the lateral and the upper and the lower fields is consistent with the view that the neural processes involved are more localized than those that sustain epileptogenic disturbances.

If the illusions are indeed the result of a failure of cortical inhibition their variation from individual to individual acquires a new significance. Persons who report many illusions tend to suffer frequent headaches and if the headaches are unilateral the illusions tend to be asymmetric. These findings would tend to support the existence of a relationship between headaches and cortical inhibitory mechanisms, as already proposed on the basis of EEG responses to intermittent light by Goldensohn (1976). The upper frequency limit of the photoconvulsive response to diffuse intermittent light is generally higher in photosensitive patients who are pattern sensitive than in those who are not. There is no difference with respect to the lower frequency limit (Wilkins *et al.*, 1980). This selective association between the effects of patterns and high frequency intermittent light is of interest because in patients with migraine the amplitude of the steady state evoked potential is abnormally high for flash frequencies above 20 Hz (Golla and Winter, 1959; Jonkman and Lelieveld, 1981).

If a relationship between cortical inhibition and headaches does exist, it need not necessarily be causal, although two observations suggest that it might be: (1) a substantial proportion of patients with migraine report visual precipitants broadly similiar to those that trigger seizures (Debne, 1984) and (2) about 40 per cent of

patients with photosensitive epilepsy report 'various forms of ocular discomfort (headache, sore eyes, etc.) induced by potentially epileptogenic stimuli' (Kasteleijn-nolst Trenite *et al.*, 1982). The mechanisms whereby pattern stimulation might give rise to feelings of discomfort or pain are too various and uncertain to justify extensive speculation.

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