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# PATTERN DISCRIMINATION WITH FLICKERING STIMULI

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**Abstract**—The spatial contrast at which Observers are able to discriminate between horizontal and vertical gratings in a 2AFC task shows the same dependence on spatial and temporal frequency as does 2AFC detection. We conclude that mechanisms carrying information about spatial contrast have their sensitivity to low spatial frequency sinusoidal gratings improved by flicker and that such mechanisms are likely to mediate the detection of low spatial-frequency gratings both at low and at high temporal frequencies.

## INTRODUCTION

In detection experiments using free fixation of stationary gratings, the function relating contrast sensitivity to spatial frequency has a characteristic shape; sensitivity reaches a maximum at some intermediate spatial frequency, usually between one and five cycles per degree (c/deg) and declines for both higher and lower spatial frequencies. The high spatial frequency decline is a reflection of the limited resolution of both optics and neural processing (Campbell and Green, 1965) but the low frequency loss in sensitivity results from lateral interactions at, or subsequent to, the sensory receptors. These interactions may be in the form of centre-surround antagonism in receptive fields (Schade, 1956) or they may simply reflect the differential effects of small eye movements during fixation (Arend, 1976).

The characteristic shape was first noted by Schade (1956) and his observations have often been confirmed in experiments using a variety of different displays and procedures; although the exact spatial frequency at which the peak sensitivity occurs may change under different conditions, the shape of the contrast-sensitivity function measured with stationary gratings is always the same, provided certain precautions are taken (Estevez and Cavonius, 1976).

If the contrast-sensitivity function is measured with flickering gratings the loss in sensitivity at low spatial frequencies disappears (Robson, 1966; Kelly, 1969). This result has been interpreted as indicating that the lateral interactions which produce the loss in sensitivity are reduced in effectiveness at high temporal frequencies (Robson, 1966; Budrikis, 1972).

More recently it has been suggested that the high sensitivity to flickering low-spatial-frequency gratings is mediated by a separate visual mechanism which signals temporal changes without carrying any information about spatial pattern (Keesey, 1972; King-Smith and Kulikowski, 1975), and that the "pattern" signalling mechanism has approximately the same spatial properties at all temporal frequencies. This suggestion arises from the finding that subjects can distinguish two sensations elicited by flickering stimuli: a sensation of flicker, and a sensation of pattern (Van Nes *et al.*, 1967; Keesey, 1972; King-Smith and Kulikowski, 1975). The sensation of flicker occurs at low spatial contrast when low spatial and high temporal frequencies are used (Van Nes *et al.*, 1967) and may not be associated with any sensation of pattern or even of movement in a particular direction when observations are made using moving gratings (Van Nes *et al.*, 1967; King-Smith and Kulikowski, 1975). Such a finding is consistent with the notion that the sensation of flicker (and hence the detection of flickering low spatial-frequency gratings) originates in a mechanism that signals only temporal changes.

When flickering gratings of higher contrasts are used, Observers are able, of course, to distinguish spatial details. Further, if Observers are asked to set contrast thresholds for seeing spatial pattern the resulting contrast sensitivity function shows a loss in sensitivity at low spatial frequencies, even with flickering gratings (Van Nes *et al.*, 1967). This finding has been interpreted as suggesting that the spatial characteristics of mechanisms signalling spatial pattern are relatively unaffected by variations in temporal frequency.

We have repeated some of these observations (experiments 1 and 2) and extended them by using an orientation-discrimination task (experiment 3) which allows us to investigate pattern-sensitive mechanisms under stimulus conditions where the dominant sensation is one of flicker.

## METHODS

### *Experimental procedures*

*2AFC detection.* Experiment 1 was a self-paced two-alternative temporal forced-choice (2AFC) detec-

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tion experiment. On each trial (initiated by the Observer) two intervals, each 1 sec long, and separated by 100 msec, were indicated by tones.

During one of the intervals a grating was presented and the Observer's task was to signal the interval in which the grating had been presented by pressing a switch. The spatial frequency of the grating was chosen at random from the set of eight used for all the experiments.

The contrast of each of the eight gratings used in each experiment was independently adjusted during the experiment by a staircase algorithm (Whetherill and Levitt, 1965) so that it moved towards the level at which the probability of a correct response was about 0.8. The step size (initially 0.3 log units) was halved each time the staircase reversed its direction until it reached 0.0375 log units. A further three reversals then terminated the staircase for that spatial frequency. The geometric mean of the contrast values at these last four reversals was taken as threshold. The eight spatial frequencies ranged from 0.2 to 2.24 c/deg in 1/2 octave steps. All gratings in any one session had the same temporal frequency and a session lasted until all eight staircases had terminated (about 30 min).

*Yes-no detection.* Experiment 2 differed from Experiment 1 in that only one observation interval was used on each trial and it always contained a grating. The Observer's task was to indicate whether or not he had seen the grating. A different staircase procedure adjusted the contrast towards that at which the probability of reporting having seen the grating was 0.5.

*2AFC orientation discrimination.* Experiment 3 was identical to Experiment 1 except that both observation intervals contained gratings that differed only in that one was horizontal and the other was vertical. The Observer's task was to indicate in which order the orientations had been presented. The staircase algorithm adjusted the contrast towards that at which the probability of a correct discrimination was about 0.8.

### *Stimuli*

Horizontal or vertical sinusoidal gratings of spatial frequencies ranging from 0.2 to 2.24 c/deg were displayed on the face of an oscilloscope (Hewlett-Packard HP 1332A), in a square 9 × 9 cm field, uniformly illuminated to 45 cd.m$^{-2}$. Observers viewed the display from 34.5 cm, at which distance it subtended a visual angle of 15 deg. Forehead and chin rests were used to maintain the proper viewing distance.

The method of displaying gratings was standard (Schade, 1956) except that during the flyback after each frame of the display the raster and timebase signals were interchanged between the X and Y axes of the display oscilloscope. Frames of the display were thus alternately horizontal and vertical. Signals for brightness modulation were generated on alternate frames of the display so that, by choosing which set of frames to use, either horizontal or vertical gratings could be displayed. This technique gives no secondary cues to orientation.

In each observation interval, marked for the Observer by a tone, a grating was displayed for 1 sec. The contrast of the grating, which could be either static or flickering with sinusoidal counterphase modulation at 10 Hz, was shaped by a Gaussian temporal envelope (sigma = 0.12 sec) to avoid temporal transients. Figure 1 shows the contrast as a function of time for static and 10 Hz flickering gratings respectively.

Grating contrast was adjusted by a programmeable attenuator controlled by a computer (PDP 11-34), which also triggered each frame of the display, switched the display frame orientations and generated spatial and temporal modulation signals.

### *Observers*

The Observers in Experiments 1 and 3 were the authors; those in Experiment 2 were undergraduates, familiar with the experimental task, but unfamiliar with its theoretical background. The Observers had well corrected vision; no instructions about fixation were given, and all Observers except GBH used binocular vision.

*Psychometric functions* relating percentage correct responses to contrast were measured in preliminary experiments in both detection and discrimination paradigms with low and high spatial and temporal frequencies. They were all approximately parallel on logarithmic contrast coordinates so that we felt justified in using a single point on the psychometric function in subsequent comparisons of different stimuli.

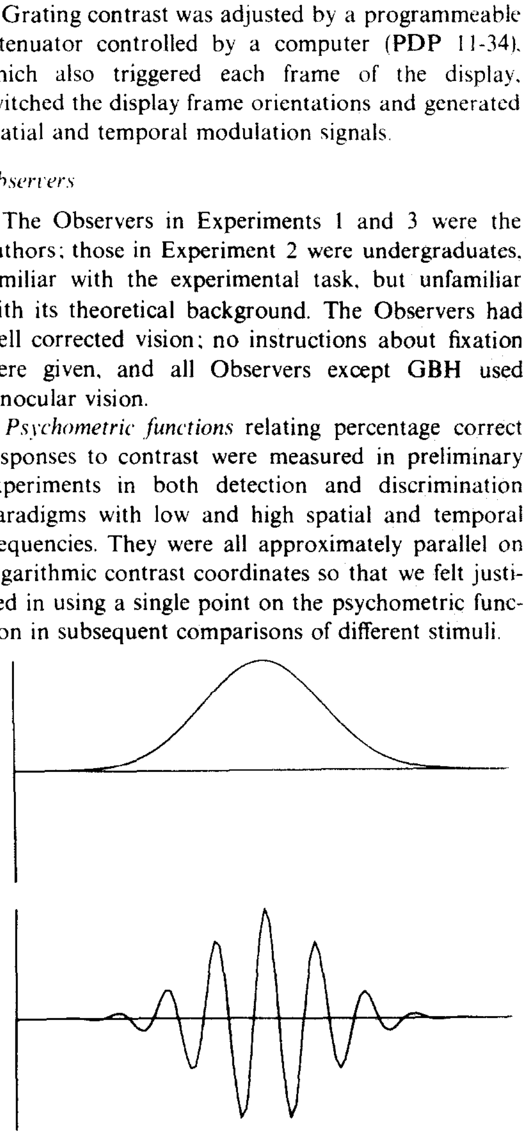


Fig. 1. The upper curve shows the temporal envelope of signal contrast for the non-flickering (static or zero Hz) condition as a function of time. The envelope is Gaussian with sigma equal to 0.12 sec. The lower curve shows the temporal envelope of signal contrast for the 10 Hz counterphase flicker condition as a function of time. The envelope is the product of a 10 Hz sinusoid and a Gaussian function with sigma equal to 0.12 sec. The sinusoid is in cosine phase at the peak of the Gaussian function. The horizontal axis of the figure has an extent of 1 sec, the vertical axis is linear with an indeterminate scale.

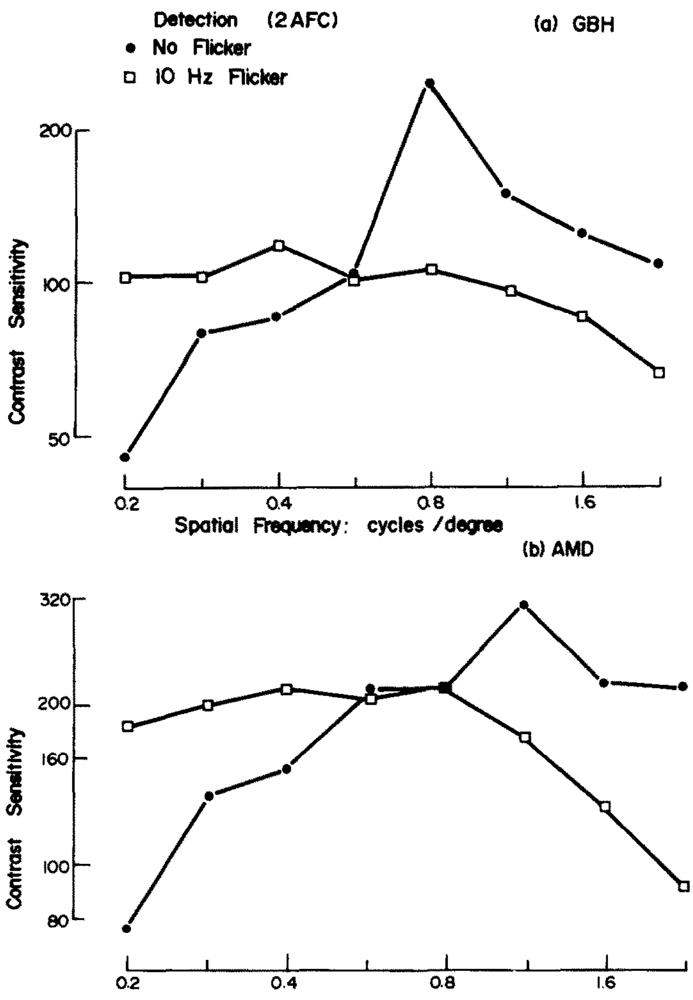
## RESULTS

Figures 2a and 2b show contrast-sensitivity functions (reciprocal of threshold, plotted as a function of spatial frequency) for the detection of static and 10 Hz flickering gratings in a 2 alternative forced choice task (experiment 1). Detection of static gratings (filled circles) shows a decline in sensitivity by a factor of about two for every halving of spatial frequency below about 1 cycle per degree. Detection of flickering gratings (empty squares), on the other hand, shows little or no change in sensitivity over this range of spatial frequencies. Both curves show the beginnings of a decline at high spatial frequency. The observers' results are very similar except for a small difference in absolute sensitivity which is probably partly attributable to a difference in sensitivity between monocular and binocular vision (Campbell and Green, 1965a).

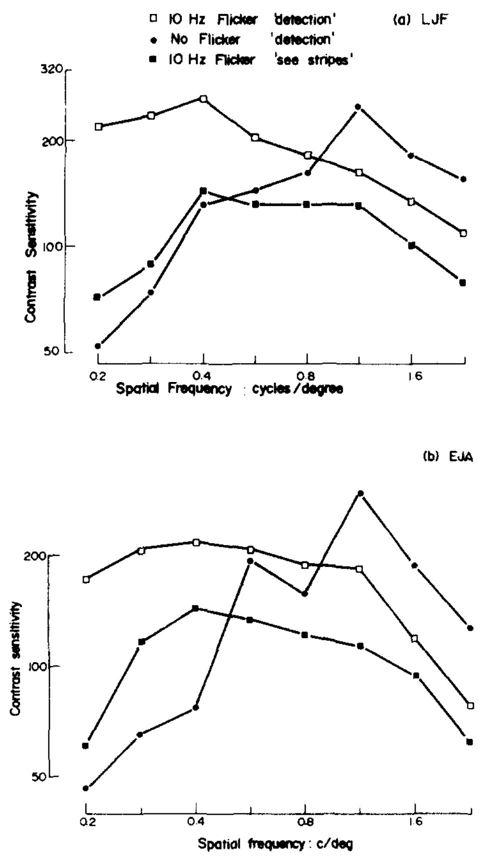
These results are similar to those of others (Robson, 1966; Kelly, 1969). In all three sets of experiments contrast sensitivity shows a decline at low spatial frequencies when static or slowly flickering gratings are used but not when high temporal frequencies are used.

Figure 2 also shows that part of the change in shape of the contrast sensitivity function occurs because flicker increases the sensitivity to low spatial frequency gratings. One possible explanation of this increase in sensitivity at high temporal frequencies is that low spatial frequency flickering gratings are detected by a second mechanism which is sensitive not to spatial pattern but to flicker.

One way of testing this hypothesis is to require Observers to detect spatial pattern and to ignore, if they can, the flicker. The difference between the results obtained in the two kinds of experiment is illustrated in Figs 3a, b which show contrast-sensitivity functions obtained in "Yes–No" experiments under three different conditions. The two curves plotted with filled circles and empty squares are similar, both in the stimulus conditions and in the results, to those in Fig. 2; they show contrast sensitivities for the detection of static and flickering (10 Hz) gratings, in which there is a loss in sensitivity at low spatial




Figures 2a and 2b show contrast sensitivity measured in a 2AFC detection task for single Observers as a function of the spatial frequency of the signal (c/deg). The solid symbols represent data from the stationary or zero Hz condition—the open symbols from the 10 Hz counter-phase flicker condition.




Figures 3a and 3b show contrast sensitivity as a function of the spatial frequency of the signal (c/deg). Sensitivity is measured in a Yes–No "detection" task for single Observers using different criteria. The filled circles represent data from the stationary or zero Hz condition—the open squares data from the 10 Hz counter-phase flicker condition. In these two conditions the Observers indicated whether they saw something happen in the observation interval. The data indicated by the filled squares are from a 10 Hz flicker condition in which the Observers indicated whether or not they saw a striped pattern in the observation interval.

frequencies for static (filled circles) but not for flickering gratings (empty squares). The filled squares, on the other hand, show data gathered using 10 Hz flickering gratings with the Observers instructed not to report having seen the grating unless they had seen stripes. With this more stringent "pattern detection" criterion a loss in sensitivity at low spatial frequencies reappears.

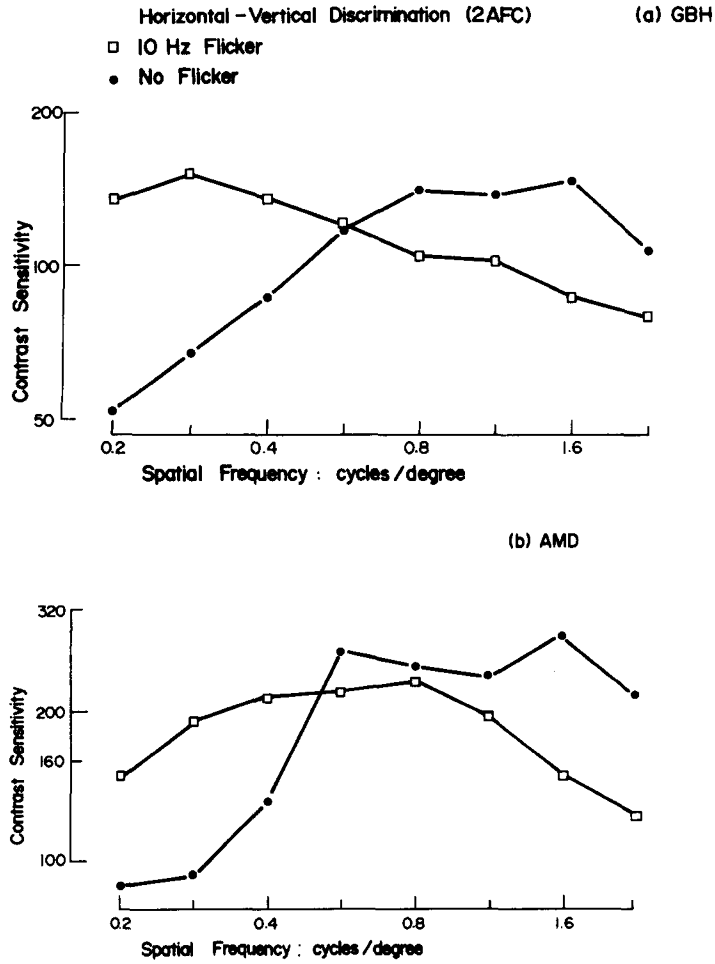
This type of result has been interpreted as showing that the mechanism which detects gratings that are at once both of low spatial frequency and flickering is not used for pattern vision, but merely signals the occurrence of movement or temporal change in the visual field. The mechanism is said to produce a sensation of flicker without any impression of pattern, or even of lateral movement within the patterned field (Van Nes *et al.*, 1967; Keesey, 1972; King-Smith and Kulikowski, 1975): that is the mechanism does not signal spatial pattern, only flicker. An alternative explanation, however, would be simply that Observers change their criteria in "Yes–No" tasks when asked to respond on the basis of some spatial aspect of the stimulus. A change in criterion may produce large changes in behaviour but such changes do not, in this case, reflect changes in the underlying mechanism but simply indicate that the Observer has changed his willingness to report having seen a signal (Nachmias, 1972). It is difficult to discriminate between the two hypotheses with "Yes–No" tasks and so we used a 2AFC grating orientation-discrimination task which cannot be performed without some sort of pattern information. This technique, introduced by Nachmias (1967) for studying the effects of exposure duration on visibility of square-wave gratings, should allow us to explore the limits of the "pattern" mechanism.

Figures 4a and 4b show contrast sensitivity functions for orientation discrimination of stationary and 10 Hz flickering gratings. The function for stationary gratings shows the familiar loss in sensitivity at low spatial frequencies. Neither Observer shows any significant loss of sensitivity at low spatial frequencies when flickering gratings are used. It is interesting to note that the absolute sensitivities of both Observers in the orientation–discrimination task are very similar to those measured in the 2AFC detection task (Fig. 2).

## DISCUSSION

It is clear from Fig. 4 that changes in temporal frequency have the same effect on orientation discrimination as they do on detection of gratings. Moreover the absolute values of contrast sensitivity measured in the two tasks are very similar. Since orientation-discrimination is a task which cannot be carried out in the absence of information about spatial pattern it seems likely that the mechanism detecting flickering gratings that have low spatial frequencies signals such information. The finding casts some doubt on the existence of a "flicker-detecting" mechanism separate from the "pattern-detecting" mechanism: since Observers are able to tell the orientation of gratings that they feel unable to see as patterns it follows that they do not know what information they have available. Indeed, until the authors had done orientation discrimination experiments, each thought that he had done Experiment 1 entirely on the basis of detection of flicker.

Although our results cast doubt on the existence of a flicker mechanism that carries no information about pattern, we are unable to address the question of the "movement sensitive" mechanisms defined by Tolhurst's (1973) adaptation experiments. Indeed if a channel is to signal the movement of a grating it must have information of some sort about spatial detail otherwise the direction of movement is indeterminate. Indeed it may be that a population of direction-selec-




Figures 4a and 4b show the reciprocal of the contrast at which two single Observers can discriminate between a vertical and an horizontal grating in a 2AFC discrimination task plotted as a function of the spatial frequency of the gratings. The filled symbols represent data from the stationary, or 0 Hz condition; the open symbols represent data from the flickering or 10 Hz condition. Both scales are logarithmic.

tive movement-analysing channels detects and therefore signals the orientation of low spatial frequency flickering gratings, as is suggested by the observations of Levinson and Sekuler (1975). The important point is that our experiments show clearly that pattern information is available in a region of stimulus space where subjective experiments suggested that it was not. In this connection it is worth noting that subjective threshold measurements using a pattern-detection criterion show an increase in sensitivity at low spatial frequencies when brief exposures are used (Arend, 1976a), presumably because the temporal properties of the stimulus are not so intrusive.

Further experiments are needed to show whether temporal factors produce any differences in pattern vision apart from changes in contrast sensitivity.

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