Perception, 1978, volume 7, pages 161-166

Spatial-frequency masking with briefly pulsed patterns

Gordon E Legge
Department of Psychology, University of Minnesota, Minneapolis, Minnesota 55455, USA
Michael A Cohen
Laboratory of Psychophysics, Harvard University, Cambridge, Massachusetts 02138, USA
Charles F Stromeyer III¶
Division of Applied Sciences, Harvard University, Cambridge, Massachusetts 02138, USA
Received 20 June 1977, in revised form 19 October 1977

Abstract. Spatial-frequency masking was studied with *briefly pulsed* (25 ms) vertical gratings. The mask was a noise grating, and the test pattern was a sinusoidal grating. A low-frequency band of noise masked a low- but not high-spatial-frequency test grating when the patterns were presented simultaneously. A high-frequency band of noise did not mask a low-frequency test grating when the patterns were presented simultaneously or when the mask was presented after the test pattern (backward masking). Masking was, however, observed when the mask or test pattern was of sufficiently high contrast so that the *stimuli* had nonlinear distortion and thus produced DC shifts of the field luminance.

1 Introduction

Channels that are selectively sensitive to different bands of spatial frequencies have been shown by masking. Stromeyer and Julesz (1972) observed that a vertical, sine-wave test grating was masked only by vertical noise gratings similar in spatial frequency. The masking had a full-bandwidth at half-amplitude of about 1·25 octaves (except at very low spatial frequencies). Test gratings 2 or more octaves away from the mask frequency were negligibly affected by the mask. The mask was presented continuously, and the test grating was presented continuously or for relatively long intervals.

With briefly *pulsed* patterns, Breitmeyer (1975) observed considerable masking between mask and test gratings separated by very large spatial-frequency intervals. The mask was a 2-octave wide band of noise of 15% contrast. The mask and test gratings each appeared for 25 ms, either synchronously or with various stimulus onset asynchronies (SOA). A high-frequency band of noise centered on 15 cycles deg^{-1} raised the threshold of a low-frequency grating of 0·94 cycles deg^{-1} (4 octaves below the center frequency of the noise) by approximately 400% when the mask and test gratings were presented simultaneously. A low-frequency band of noise centered on 0·94 cycles deg^{-1} raised the threshold of a high-frequency grating of 15 cycles deg^{-1} (4 octaves above the center frequency of the noise) by about 60% when the mask and test gratings were presented simultaneously. The masking, however, was *greater* when the mask was presented 60 to 360 ms *after* the test grating. The masking varied from about 70% to 120% over this range, with peak effects occurring at SOAs of 120 and 150 ms for the two observers. The SOA value is thus *not* critical, for substantial masking occurs over a broad range. Breitmeyer suggested that this *backward* masking might reflect inhibition of sustained mechanisms, that detect the high-frequency pattern, by transient mechanisms, that respond *rapidly* to the low-frequency mask.

¶ Author to whom requests for reprints should be sent.

Thus it would appear that briefly pulsed patterns mask each other even when their spatial frequencies are very different. To further understand the difference of masking obtained with continuously presented and briefly pulsed patterns, we sought to replicate the experiments of Breitmeyer.

2 Method

2.1 *Stimuli*

Conditions were similar to those used by Breitmeyer. In both his experiment and the present experiment the patterns were displayed on a CRT with a white P4 phosphor whose luminance decays to e^{-1} in substantially less than 1 ms, and the fields were 5 deg in diameter, of approximately 17 cd m^{-2}, with a dark surround. The CRT used in the present experiment was a Tektronix 602. The display was viewed from a distance of 100 cm by the observer's favoured eye, which was well-refracted with spectacle lenses. There was a fixation point in the center of the field.

Low-frequency and high-frequency masking noise was used. The noise was obtained by passing white noise (produced by a General Radio random noise generator, number 1390A) through an Allison Laboratory Model 2B band-pass filter. Figure 1 shows the relative attenuation produced by the filters for the two bands of masking noise. The low-frequency noise was approximately centered on 1·0 cycle deg^{-1} and covered about 2 octaves. The high-frequency noise extended from about 7·5 to 18 cycles deg^{-1}, with somewhat more energy at the lower end of the band. The output impedance of the filter was adjusted to obtain maximal flatness of the band. Breitmeyer used a flat band of noise from 7·5 to 30 cycles deg^{-1}. The noise we have chosen should more effectively mask a low-frequency test pattern because the noise and test grating are closer in spatial frequency, and the noise is more visible since the contrast sensitivity function descends rapidly at high spatial frequencies.

The noise contrast was adjusted with a true root-mean-square voltmeter (Ballantine Laboratories, Model 320), which was calibrated with a calibrated square-wave voltage. The noise contrast is given by σ_L/L_0, where σ_L is the standard deviation of the Gaussian luminance variation at any given point on the screen produced by the noise, and L_0 is the mean luminance. The term σ_L is directly proportional to the root-mean-square voltage of the noise (Stromeyer and Julesz 1972). The contrast of the test grating is $(L_{\max}-L_{\min})/(L_{\max}+L_{\min})$ where $L_{\max}$ and $L_{\min}$ are the maximum and minimum luminances in the pattern.

The x axis sweep rate was 12·5 ms. At a more rapid rate, the noise appeared to have lower contrast and would presumably produce less masking. All stimuli were

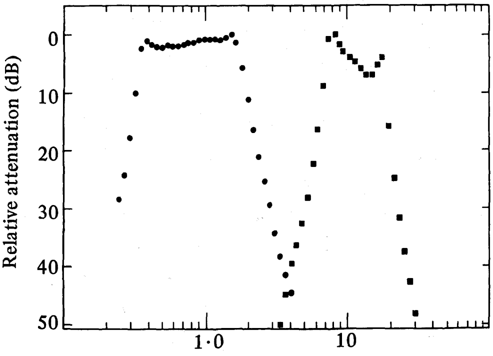

Figure 1. Relative attenuation of the masking noise. The low-frequency mask (circles) is approximately 2 octaves wide, 0·5–2·0 cycles deg^{-1}; the high-frequency mask (square) is approximately 7·5–18 cycles deg^{-1}.

presented for 25 ms, or two sweeps. The onsets of the sweep and stimulus were not synchronized. Thus the noise pattern might turn suddenly on or off in the center of the field, generating some additional spatial frequencies outside the noise band, which might increase masking. The noise pattern consisted of two, or part of three, spatially uncorrelated, successive frames, while the test grating had the same phase in each frame.

The timing of the patterns was ascertained with an oscilloscope and digital frequency meter.

2.2 *Procedure*

The visibility of test gratings was measured with and without the masks, in separate runs. The runs were done in counterbalanced pairs. A run consisted of 100 trials, in which the test pattern was presented at four contrast values (including blanks) with equal probability according to a random schedule. The observer rated the visibility of each test pattern on a whole-number scale of 1 to 5 (Egan et al 1959) and was told after each trial what contrast value had been used. ROC curves were fitted to the ratings by a maximum likelihood estimation to determine the detectability, d' (Green and Swets 1966), of the test patterns (Stromeyer and Klein 1974; Stromeyer et al 1977). Each curve in the Results is typically based on two to three runs.

3 Results

3.1 *Low-frequency mask*

The low-spatial-frequency mask was maintained at 15·0% contrast. Figure 2 shows that the mask very effectively masked a grating of 1·0 cycle deg^{-1} that fell in the center of the noise band. The mask and test patterns were presented simultaneously. Closed and open circles show d' values obtained with and without the mask, respectively. The masking is more than tenfold, viz the curves are separated laterally by more than tenfold on the contrast axis. Figure 3 shows that when the experiment was repeated with a test grating of 12 cycles deg^{-1} (~2·5 octaves above the noise band) there was essentially no masking. The mask and test patterns were presented simultaneously. Figure 4 shows results with a mask that *follows* the 12 cycles deg^{-1} test grating with a SOA of 158 ms. There was essentially no backward masking. Observers reported that when the test grating was clearly seen, it appeared definitely to precede the mask. Breitmeyer's results suggest that an SOA of ~158 ms should be optimal to obtain backward masking. However, he observed that substantial masking occurs for SOAs of 60–360 ms. Thus the SOA value is not critical over a large range (see Introduction).

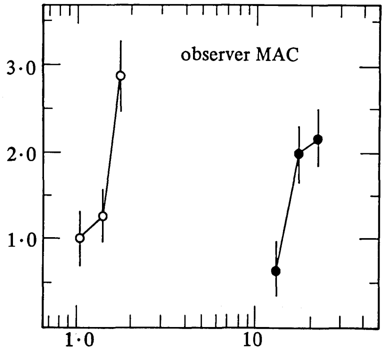

Figure 2. The d' values and ±1·0 S.E. for 1·0 cycle deg^{-1} test grating presented with (closed circles) and without (open circles) low-frequency mask of 15·0% contrast. Test and mask patterns were exposed simultaneously for 25 ms.

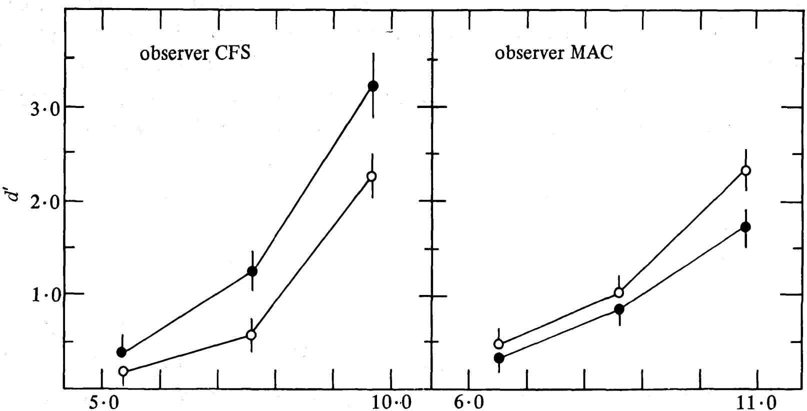

Figure 3. The d' values and ±1·0 S.E. for 12 cycles deg^{-1} test grating presented with (closed circles) and without (open circles) low-frequency mask of 15·0% contrast. Test and mask patterns were exposed simultaneously for 25 ms.

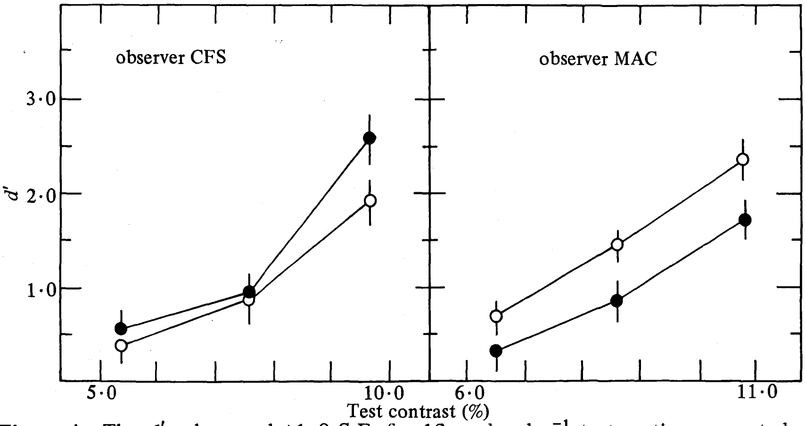

Figure 4. The d' values and ±1·0 S.E. for 12 cycles deg^{-1} test grating presented with (closed circles) and without (open circles) low-frequency mask of 15·0% contrast. Test and mask patterns were exposed for 25 ms, and the mask followed the test pattern with an SOA of 158 ms (backward masking).

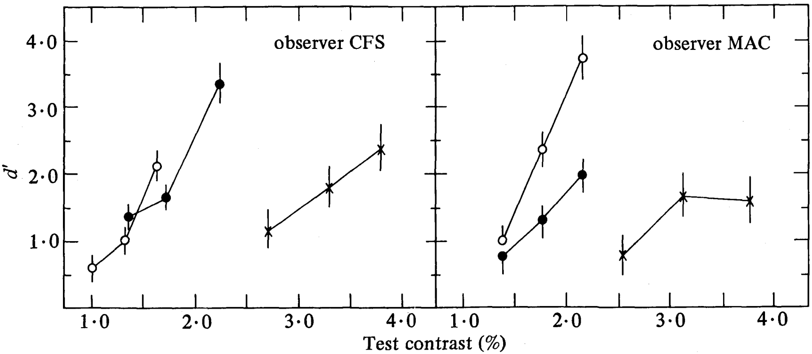

Figure 5. The d' values and the ±1·0 S.E. for 1·0 cycle deg^{-1} test grating presented without a mask (open circles) and with high-frequency mask of 13·0% (open circles) and 21·7% contrast (crosses). Test and mask patterns were exposed simultaneously for 25 ms.

3.2 *High-frequency mask*

Figure 5 shows results obtained with the high-frequency mask of 7·5 to 18 cycles deg^{-1} and a test grating of 1·0 cycle deg^{-1}. The patterns were presented simultaneously. There was little masking when the mask contrast was 13·0% (closed circles). For observer MAC, the masking was approximately 30%; (i.e. curves separated laterally by 30%); for observer CFS, the masking was less. When the mask contrast was set above ~13% there was visible nonlinear distortion in the stimulus display, manifested as a sudden *brightening* of the field when the mask turned on (see Discussion). The crosses in figure 5 show that there was appreciable masking when the mask contrast was 21·7%, at which level there was very apparent distortion.

4 Discussion

The present experiments showed that a pulsed, low-spatial-frequency mask did not appreciably affect a pulsed, high-spatial-frequency test grating and conversely. The masking effects were *at most* 30%, provided the mask contrast was kept below 13% to prevent nonlinear distortion of the stimuli (figures 3–5). Care was taken so that the stimuli did not have nonlinear distortion. Such distortion would occur with high-contrast patterns because the functional relation between the *z* axis voltage and phosphor luminance was slightly positively accelerated. The effects of such distortion will be considered.

The 1·0 cycle deg^{-1} test grating, presented *alone* for 25 ms, appeared as a *sudden, formless disturbance*—it did not appear as a pattern of stripes, although the contrast was sufficiently low so that the stimulus had insignificant nonlinear distortion. The high-spatial-frequency noise of 21·7% contrast produced a sudden brightening of the field when the noise was exposed briefly. The brightening was due to nonlinear distortion of the stimulus and was seen when the observers were not properly refracted, so that high spatial frequencies were invisible. This noise produced masking (figure 5). The masking essentially disappeared when the noise contrast was reduced to 13·0% (figure 5). At this level the noise did not produce an apparent brightening of the field.

A sudden shift in the DC level of the field might mask a low-spatial-frequency pattern that is presented synchronously with the DC shift. Stromeyer et al (in preparation) observed that a low-spatial-frequency grating that sinusoidally reversed contrast at a rapid rate could be strongly masked by a DC fluctuation of the field luminance that occurred in phase with the grating reversal. Shickman (1970) observed similar masking for a large, 2 deg, spot briefly flashed on a spatially uniform field that fluctuated sinusoidally in time. For rapid fluctuations of the field, masking was maximal at the *instant* that the field was changing most rapidly (viz, when the derivative of field luminance was maximal).

Masking of a low-frequency target by high-spatial-frequency noise, however, might be expected for other reasons. Henning et al (1975) observed that a high-spatial-frequency grating that varied sinusoidally in contrast across the grating (viz, a sinusoidally amplitude modulated grating) masked a low-spatial-frequency test grating whose spatial frequency matched the contrast variation of the mask pattern. The mask consists of *only* high spatial frequencies, and yet it may strongly mask a low-spatial-frequency test grating. A high-spatial-frequency noise grating, such as used in the present experiment, varies spatially in contrast and might thus also be expected to produce masking of a low-frequency test pattern. Such masking effects were very weak in the present experiments.

The present results show that low-spatial-frequency noise produced very little masking of a high-spatial-frequency grating (figures 3 and 4). A test grating of 12 cycles deg^{-1} was used, because at a higher spatial frequency (e.g. 15 cycles deg^{-1}) a

DC shift was observed at the test onset, for the test contrast at threshold was high and produced significant nonlinear distortion. A DC shift would provide a spurious detection cue that might be affected by the low-frequency noise.

Other studies have shown that a mask consisting of a sine-wave grating may *facilitate* the detection of a test grating even three or four times higher in spatial frequency (Stromeyer and Klein 1974; Barfield and Tolhurst 1975; Sansbury 1974; Georgeson 1975; Nachmias and Weber 1975; Legge 1976). Legge (1976) used a test grating of 12 cycles deg^{-1} exposed for 100 ms. The mask was a grating of 3 or 6 cycles deg^{-1} and 22% contrast. The mask immediately preceded and followed the test pattern for 20 ms. The mask *facilitated* detection of the test pattern in a two-alternative forced-choice paradigm. Stromeyer and Klein (1974) and Georgeson (1975) observed that, when the mask and test grating spatial frequencies were further separated (ratio of 1 : 5), the facilitation disappeared and the mask appeared to have no effect.

The present experiments suggest that a low-spatial-frequency *noise* mask does not affect a high-spatial-frequency test grating (spatial-frequency ratio greater than 1 : 5) even when the stimuli are briefly pulsed and the mask is a noise grating. However, when the stimuli have even *very slight* nonlinear distortion, spurious masking might be expected when the patterns are of very different spatial frequencies and presented in brief pulses.

Acknowledgements. This research was supported by NIH grant 1 R01 EY01808-01. We thank Dr Stanley Klein for help with analysis of the data.

References

Barfield L, Tolhurst D J, 1975 "The detection of complex gratings by the human visual system" *Journal of Physiology (London)* **248** 37-38P

Breitmeyer B G, 1975 "Predictions of U-shaped backward pattern masking from considerations of the spatio-temporal frequency response" *Perception* **4** 297-304

Egan J P, Schulman A J, Greenberg G Z, 1959 "Operating characteristics determined by binary decisions and by ratings" *Journal of the Acoustical Society of America* **31** 768-773

Georgeson M A, 1975 *Mechanisms of Visual Image Processing: Studies on Pattern Interaction and Selective Channels in Human Vision* Ph D dissertation, University of Sussex, Brighton, England

Green D M, Swets J A, 1966 *Signal Detection Theory and Psychophysics* (New York: John Wiley)

Henning G B, Hertz B G, Broadbent D E, 1975 "Some experiments bearing on the hypothesis that the visual system analyses spatial patterns in independent bands of spatial frequency" *Vision Research* **15** 887-897

Legge G E, 1976 *Contrast Detection in Human Vision: Spatial and Temporal Properties* Ph D dissertation, Harvard University, Cambridge, Mass

Nachmias J, Weber A, 1975 "Discrimination of simple and complex gratings" *Vision Research* **15** 217-223

Sansbury R V, 1974 *Some Properties of Spatial Channels Revealed by Pulsed Simultaneous Masking* Ph D dissertation, University of Pennsylvania, Philadelphia

Shickman G M, 1970 "Visual masking by low-frequency sinusoidally modulated light" *Journal of the Optical Society of America* **60** 107-117

Stromeyer C F III, Julesz B, 1972 "Spatial-frequency masking in vision: critical bands and spread of masking" *Journal of the Optical Society of America* **62** 1221-1232

Stromeyer C F III, Klein S, 1974 "Spatial frequency channels in human vision as asymmetric (edge) mechanisms" *Vision Research* **14** 1409-1420

Stromeyer C F III, Klein S, Sternheim C E, 1977 "Is spatial adaptation caused by prolonged inhibition?" *Vision Research* **17** 603-606

Stromeyer C F III, Madsen J C, Klein S, in preparation "Masking of gratings by sinusoidally flickering uniform fields"