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LETTERS TO THE EDITORS

SPATIOTEMPORAL VARIATIONS IN THE SQUARE/SINE RATIO: EVIDENCE OF INDEPENDENT CHANNELS AT LOW SPATIAL FREQUENCIES

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INTRODUCTION

Much psychophysical evidence has indicated that the human visual system contains a number of independent mechanisms, each selectively sensitive to a narrow band of spatial frequencies [see Braddick *et al.*, (1979) for a complete review]. The existence of such a "multiple channel" visual system was first suggested by Campbell and Robson (1968) who based their inference on the relative detectability of square-wave and sine-wave gratings (the "square/sine ratio") with the same fundamental frequency. For medium to high spatial frequencies, square-wave gratings were more detectable by $4/\pi$ (1.27). This is what would be expected if gratings were detected only when the fundamental component reached threshold. At low spatial frequencies, however, the square/sine detection ratio rose above 1.27. One possible explanation for this deviation was that the harmonic components of the square-wave summated linearly within a single broad-band channel. Campbell and Robson rejected this idea because such a model badly overestimated sensitivity. They concluded that the harmonic components of the square-wave were not simply added together by a single channel but might be detected separately by independent channels. An alternate explanation for the rise in the square/sine ratio was that observers were more sensitive to the harmonics than to the fundamental of a square wave. This explanation is plausible because of the fact that sensitivity falls off rapidly below about 2 c/deg for steadily presented sine-wave gratings. Even though the harmonics are smaller in amplitude, they could be detected first if the visual system were much less sensitive to the fundamental frequency than to the spatial frequency of one or more of the harmonics.

The decision by Campbell and Robson to accept the multiple channel model at low spatial frequencies was based primarily on negative evidence, i.e. failure of simple linear summation within a single channel to predict sensitivity. However, other nonlinear models of summation might yet account for their data. We have attempted to confirm their conclusions with more direct evidence. This was accomplished by varying the exposure duration of low frequency square- and sine-wave gratings. At long durations, detection of square-wave gratings by mechanisms responding to the higher harmonic components is favored because of the severe loss in sensitivity in spatial frequencies below about 2 c/deg. At short durations, however, the low frequency fall-off in sensitivity can be reduced or eliminated (Nachmias, 1967). Under these conditions, gratings should be more likely detected by the largest (i.e. fundamental) component, and the square/sine ratio should again be 1.27.

METHOD

Observers monocularly viewed sine- and square-wave gratings presented on a Tektronix 602 display with a mean luminance of 4 cd/m^2. One observer (TC) was a severe myope and viewed the display at his far point (conjugate focus on the retina) which was 12 cm. A second, emmetropic observer (JM) was optically corrected for the same viewing distance. The short viewing distance was employed to produce a $48° \times 30°$ field in order that enough stripes would be presented to ensure a narrow band stimulus. Gratings were pulsed on the display every 3 sec with no change in mean luminance. Observers turned a featureless knob to adjust grating contrast to threshold. Each session was initiated with 5 min of dark adaptation followed by 3 min of viewing the unmodulated CRT screen. In one session, observers detected square-wave and sine-wave gratings with a fundamental spatial frequency of 0.1, 0.3 or 0.9 c/deg presented for 25 or 1000 msec. In another session, stimuli were gratings of 0.1 c/deg presented over a range of durations. Stimuli were switched on and off gradually with a triangular temporal envelope or abruptly with a rectangular envelope. In each condition, observers made contrast threshold determinations in pairs so that one sine-wave and square-wave setting were made in succession. This minimized variations in the square/sine ratio due to drift in response bias. Data shown are the mean of eight threshold determinations for each condition.

RESULTS AND DISCUSSION

Data for the two observers are shown in Fig. 1. Thresholds for detection of square-wave gratings were always lower than for sine-wave gratings of the same fundamental frequency and duration. For the

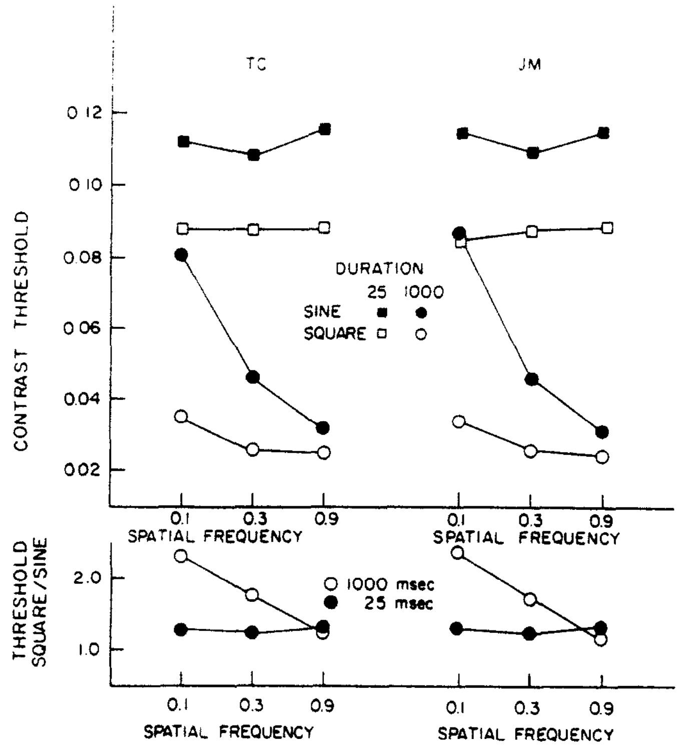

Fig. 1. Contrast threshold as a function of test spatial frequency. Circles represent data for 1000 msec exposures and squares, data for 25 msec durations. Filled symbols show sine-wave thresholds and open symbols, square-wave thresholds. Lower panel shows ratio of square- and sine-wave grating thresholds as a function of spatial frequency. Largest standard error was 7% for 1000 msec durations, and 4% for 25 msec durations.

1000 msec duration, typical loss of sensitivity with reduced spatial frequency was demonstrated by both observers. As reported by Campbell and Robson, the square/sine ratio is greater than 1.27 at very low spatial frequencies but drops to this value at a spatial frequency of about 0.9 c/deg. The 25 msec duration, however, produced equal sensitivity to all three test spatial frequencies. Observers reported that the 25 msec square-wave grating appeared sinusoidal at threshold while the 1 sec square-wave appeared to have sharp edges. This presumably occurred because the long duration grating was detected on the basis of the harmonics while the shorter duration square-wave was detected by a channel sensitive to the fundamental.

The multiple channel model predicts that the square/sine ratio should now be 1.27 since detection will be mediated by a channel sensitive to the largest component, which is the fundamental. The single channel model, on the other hand, predicts summation between the first and third harmonics which should produce a square/sine ratio greater than $4/\pi$. Based on the data, the simplest form of the single channel model predicts a ratio of about 2 for 0.1 c/deg gratings. This, however, ignores possible complications arising from retinal inhomogeneity. Further, it is possible that the different latencies of different spatial frequencies could produce asynchronous processing of the square-wave harmonics. It is unlikely that this was an important factor in the present experiment because latencies for spatial frequencies below 1 c/deg exhibit little variations (Breitmeyer, 1975). Data show that the square/sine ratio for short durations was 1.27, as suggested by the multiple channel model proposed by Campbell and Robson.

The effect of duration on the square/sine ratio was further investigated in a second session. Previous research (Breitmeyer and Julesz, 1975) has demonstrated that channels at lower spatial frequencies are more sensitive to temporal transients than those at higher spatial frequencies. Therefore, gradual temporal onsets and offsets should increase the square/sine ratio since this mode of presentation will reduce the detectability of the lower frequency fundamental relative to the higher frequency harmonics. Figure 2 shows the square/sine ratios obtained when test gratings were presented for different durations in a rectangular-wave or gradual triangular envelope. At short durations, the square/sine ratio was $4/\pi$ for both modes of presentation. The ratio increased with longer durations, but the effect is greater with the gradual triangular-wave presentation.

In sum, our data strongly confirm the conclusions made by Campbell and Robson. The deviation of the

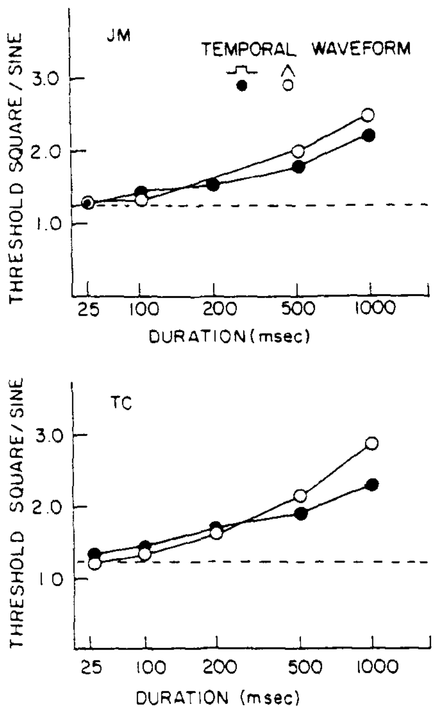

Fig. 2. Square sine contrast threshold ratio as a function of duration. Solid circles represent data for gratings switched on and off with abrupt rectangular-wave temporal envelope. Open circles represent thresholds obtained with gradual triangular-wave temporal on and offset.

square sine ratio from $4/\pi$ at very low spatial frequencies is due to the greater detectability of the harmonic components rather than to the existence of broad band channels which summate wide ranges of spatial frequencies. The results reported above are also in agreement with the data of Furchner, Thomas and Campbell (1977) which likewise support the notion of multiple channels at very low spatial frequencies.

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REFERENCES

Braddick O., Campbell F. W. and Atkinson J. (1978) Channels in vision: Basic aspects. In *Handbook of Sensory Physiology: Vol. VIII, Perception* (edited by Held R., Leibowitz H. and Teuber H. L.). Springer, New York.

Breitmeyer B. (1975) Simple reaction time as a measure of the temporal response properties of transient and sustained channels. *Vision Res.* **15**, 1411–1412.

Breitmeyer B., and Julesz B. (1975) The role of on and off transients in determining the psychophysical spatial frequency response. *Vision Res.* **15**, 411–415.

Campbell F. W., and Robson J. G. (1968) Application of Fourier analysis to the visibility of gratings. *J. Physiol.* **197**, 551–566.

Furchner S. C., Thomas J. P. and Campbell F. W. (1977) Detection and discrimination of simple and complex patterns at low spatial frequencies. *Vision Res.* **17**, 827–836.

Nachmias J. (1967) Effect of exposure duration on the visual contrast sensitivity with square wave gratings. *J. opt. Soc. Am.* **57**, 421–427.