Temporal Properties of Binocular Mechanisms in the Human Visual System

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Summary. A dichoptic stimulation paradigm was used to determine the degree to which the two monocular images must match in terms of the temporal properties to yield facilitation in binocular grating detection. Several converging lines of evidence point to the existence of two separate neural mechanisms in binocular detection. One of these mechanisms is selective for temporal frequency and limited in its capacity to integrate information from the two eyes over time. The other mechanism is much less selective for temporal frequency and integrates over a longer period of time. At threshold these two separate mechanisms behave independently and exhibit similar degrees of binocular summation.

Key words: Binocular mechanisms – Human visual system – Temporal frequency

On a variety of visual detection tasks human observers are more sensitive when using two eyes as compared to one (Blake and Fox, 1973), an outcome known as binocular summation. Because this enhancement in binocular sensitivity exceeds that predicted on the basis of probability summation alone, it is generally believed that the superiority of binocular viewing stems from genuine neural summation between the two eyes. For this reason binocular summation provides a psychophysical index for measuring the operating characteristics of the binocular visual nervous system.

Several years ago Blake and Levinson (1977) employed a dichoptic stimulation paradigm to measure the spatial selectivity of the neural mechanisms underlying binocular contrast summation. It was found that binocular contrast thresholds for grating detection were lower than monocular thresholds only if the two eyes received patterns which were similar or identical in spatial frequency and orientation. In the present paper we have extended this dichoptic paradigm to the time domain. Our results show that at threshold the extent of neural interaction between the two eyes, as gauged by the magnitude of binocular summation, depends as well upon the temporal properties of the two monocular components.

Methods

Apparatus

Grating patterns of sinusoidal waveform were generated electronically (Enroth-Cugell and Robson, 1966) on the two matched oscilloscope screens with P31 phosphors. A raster was generated on each screen by applying a high-frequency (100 kHz) triangle wave to the vertical amplifier while maintaining a 100 Hz frame rate. The beam current of each cathode-ray tube could be modulated by sine-wave signals from separate function generators, each time locked to the timebase of the associated oscilloscope. By multiplying these signals with a low frequency sinusoid from another pair of function generators, the contrast of either grating could be modulated over time to produce either of two different types of flicker. One type, denoted by us as 'on-off' flicker, involved periodical replacement of the grating with a blank field of the same average luminance. The other type of flicker, which we shall call 'counterphase' flicker, involved continuously interchanging the light and dark bars, such that the grating alternated in phase sinusoidally. The temporal frequency (Hz) for both on-off and counterphase flicker refers to the number of times per second that the grating went through a complete cycle of contrast modulation; for the counterphase mode this meant that the spatial phase of the grating shifted by 180 deg twice each complete cycle. With this arrangement, spatial frequency, temporal frequency and contrast of either grating could be varied independently without changing the average luminance, which for both displays was 7 cd/m². The two screens subtended a rectangular area 7° x 5° visual angle.

With the head firmly positioned on a dental impression board, the observer viewed the two displays dichoptically through a mirror stereoscope, with a viewing distance of 114 cm. In all experiments, the gratings were vertically oriented. By turning a precision potentiometer, the observer could vary the contrast of
the gratings; this contrast was read as a voltage on a digital voltmeter. The experimenter could vary the contrast of either grating in 1-dB steps (0.05 log-units) using calibrated attenuators. Contrast and voltage were linearly related within the range of values used in these experiments.

Procedure

For most of the experiments the method of adjustment technique was used to measure contrast thresholds. To begin there was an initial 2-min period of adaptation to the uncontoured raster display. Following this period of light adaptation the observer adjusted the contrast of a test grating until the display was just noticeably different from the uncontoured screen. To facilitate this judgement the test grating and uncontoured display were repetitively interchanged every 3 s. The test gratings were introduced and withdrawn gradually over 250 ms using a shaped rise/fall circuit; this served to eliminate abrupt transients at the onset and offset of the grating. The observer was allowed as many 3 s. intervals as necessary to achieve the desired contrast setting, and then he triggered a digital print-out of the contrast. Six such threshold settings were made for each stimulus condition and the arithmetic mean was taken as the estimate of threshold.

Observers

The participants in these experiments were the two authors and a third person who is experienced in psychophysics but was naive about the purpose of this study. All three observers have normal or corrected-to-normal visual acuity and all have excellent stereopsis. All were well practiced in making threshold judgements and the variability of their contrast settings was typically quite small, with standard errors on the order of 0.015 log-units.

Results

Binocular Summation with Stationary, Flickering, and Counterphase Gratings

Initially, we measured monocular and binocular contrast thresholds for two forms of temporal modulation, counterphase and on/off flicker, and for steady gratings which appeared stationary. From previous work (e.g., Kulikowski and Tolhurst, 1973) it is known that thresholds for these various types of gratings can differ, depending on spatial frequency, by as much as 0.3 log-units. We wondered whether those various types of gratings might also differ in terms of the amount of binocular summation that they yield. A recent study by Rose (1978), which compared pattern and movement thresholds under monocular and binocular viewing, suggested that these amounts should differ.

In this experiment monocular (left-eye and right-eye) and binocular contrast thresholds were measured over a four octave range of spatial frequencies. For the counterphase and on/off flicker conditions, a 3.5 Hz modulation rate was used. For the monocular threshold measurements, the non-tested eye remained open and viewed the uncontoured raster. It is important to note that for all conditions the observer's task was simply to set the display contrast to the value where the test grating was barely discernible from the uncontoured display, with no regard to the phenomenal appearance (e.g., flicker vs. pattern) of the test grating.

For none of the three observers tested was there any consistent difference between the two monocular thresholds. Consequently, for each stimulus condition we averaged the two monocular thresholds and divided this value by the binocular threshold to derive a ratio index of the amount of binocular summation. Figure 1 shows the typical results, with the circles plotting the summation ratios for stationary gratings, the squares the outcome with counterphase flicker and the triangles the result with on/off flicker. There was no tendency for this summation ratio to differ for the various types of gratings. For two of three observers there was a trend for the summation ratio to decrease with spatial frequency, but analysis of variance shows that this effect fails to reach the level of statistical significance. The data from all three observers are summarized in Fig. 2; each histogram shows the average binocular summation ratio, with standard errors, for the three types of gratings.

The equivalence of the summation ratios for stationary and counterphase gratings was somewhat unexpected, in view of the previous work of Rose (1978). His findings had led us to anticipate that the improvement in binocular viewing would be larger for counterphase gratings than it would for stationary patterns, but there was no evidence for this in our results. Why was this the case? We know that when