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Errors in Direction-of-Motion Discrimination with Dichoptically Viewed Stimuli

A. M. DERRINGTON,* I. FINE,† G. B. HENNING†

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At durations shorter than about 150 msec, a complex grating comprising a static 1-c/deg grating and a moving 3-c/deg grating is perceived as moving in the direction opposite that of the physical direction of motion. Here the phenomenon is further examined by measuring the perceived direction of motion of the fused images of a 1-c/deg grating presented to one eye and a moving 3-c/deg grating presented to the other. The strength of the illusion is almost unaffected by dichoptic presentation. This observation is consistent with the hypothesis that perceived motion is a consequence of the way the visual system integrates signals arising from different detectors tuned to the two component gratings.

Motion Direction discrimination Binocular interaction

INTRODUCTION

A motion illusion arises with stimuli of short duration when a static grating of about 1 c/deg is added to a moving grating of about 3 c/deg. At short durations, the pattern appears to move in the opposite direction from that in which the 3 c/deg grating moves (Derrington & Henning, 1987; Henning & Derrington, 1988). A question arises whether the illusion results from the operation of the compound stimulus on a single mechanism (Derrington & Henning, 1987), or whether information from separate mechanisms, each sensitive to one of the components of the stimulus, is somehow combined to produce the error (Henning & Derrington, 1988).

Derrington and Henning (1987) tested and excluded the possibility that the reversed motion arose from spatial or temporal aliasing, but they showed that under some circumstances the response of individual motion-detectors to a compound stimulus could be reversed in a way that might account for the illusion. However the reversal in the output of the motion-detector was predicted to be strongly dependent on the relative phase of the two components in the complex pattern, whereas the perceptual reversals showed no such dependence on spatial phase (Henning & Derrington, 1988). While these findings do not exclude the possibility that the effect can be explained in terms of the operation of a single detector, they provide no support for such an explanation.

The aim of this paper is to test one of the predictions that arises from the second type of hypothesis, that the reversed motion is a consequence of the interaction between separate mechanisms tuned to the components of the stimulus. If these early motion mechanisms are essentially monocular (Georgeson & Shackleton, 1989), then if the reversed motion still occurs when the two components that interact to produce it are presented to different eyes this would imply that the interaction occurs between mechanisms rather than within a single mechanism.

METHOD

General methods

The stimuli were presented on the screen of a Barco CDCT/6551 colour display with a mean luminance of approx. 42 cd/m^2. The display was driven through 8-bit DACs from a Cambridge Research system VSG2/1 to produce a uniform grey field [For details see Derrington and Suero (1991).] Two circular visual fields, each subtending 4° of visual angle at the viewing distance of 1.17 cm, were presented separately, one to each eye. A matt black vertical septum extended between the observer and the screen to ensure that each circular area was visible to only one eye and solid black triangles (subtending 0.4° a side) were centred in the circles to aid fusion. Each circle appeared in the centre of a monocularly viewed rectangle that subtended 7° horizontally by 11° vertically in a dark surround. The rectangles, including the circles, had the mean luminance of the display; neither the mean luminance nor the CIE co-ordinates of the display were altered by the addition of the signals.

The observers (wearing their own spectacles), fused the two fields using 6 D prisms in each eye. (Two of the observers were authors, IF and GBH; the third, PAG, an experienced observer.)

Gratings of different spatial frequencies were presented within the dichoptically viewed circles on

*Department of Physiological Sciences, The Medical School, Framlington Place, Newcastle upon Tyne NE2 4HH, England.
†Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford OX1 3UD, England.

alternate frames of a 120 Hz non-interlaced display so that vertically orientated gratings (of 1 or 3 c/deg) could be presented either separately to each eye or superimposed in one eye. Each grating was thus refreshed at a frequency of 60 Hz. The peak Michelson contrast of each grating, when present, was 12%, giving a peak time-average contrast of 6%.

The gratings were presented within temporal envelopes that were Gaussian functions of time and two different durations were used: a shorter duration stimulus for which the Gaussian envelope had a standard deviation of 18 msec (giving an effective duration of approx. 36 msec) and, in the first experiment only, a longer duration, 140 msec standard deviation (280 msec duration). Stimuli of either duration were temporally truncated within 1 sec observation intervals marked for the observers by a tone. The speed and direction of movement of each grating could be separately and independently adjusted and the starting spatial phase of each component varied randomly from observation interval to observation interval.

All the experiments described were self-paced, temporal, two-alternative, forced-choice (2-AFC) tasks requiring discrimination of the direction of motion. Each trial, initiated by the observer, contained two observation intervals each nominally 1 sec in duration. The direction of motion for the first interval was chosen at random; in the second observation interval, the direction of motion was reversed. In all experiments a number of different conditions were randomly interleaved with the constraint that no stimulus was presented for the nth time until all stimuli had been presented $(n - 1)$ times. The observers were required to press a key in order to choose the interval in which leftward motion occurred and no feedback was given.

Experiment 1

Method. This experiment simply demonstrated that the illusory motion occurred at short durations when the low- and high-frequency components were presented to separate eyes. Six stimuli were randomly interleaved in each block of 2-AFC trials. The six stimuli were: (i) a monocularly presented 3-c/deg sinusoidal grating moving at 4 deg/sec, (ii) a monocularly presented 1-c/deg sinusoidal grating also moving at 4 deg/sec, (iii) the sum of the two moving gratings presented monocularly, (iv) the binocularly fused sum of the two gratings where the 1-c/deg grating was presented to one eye and the 3-c/deg grating to the other, (v) the sum of a static 1-c/deg grating and the moving 3-c/deg grating presented monocularly, and (vi) the binocularly fused sum of the two gratings where the static 1-c/deg grating was presented to one eye and the 3-c/deg grating to the other.

The chief interest lies in comparisons between those conditions in which both gratings were presented to the same eye and those in which each component was presented to a different eye.

Results and discussion. The percentage correct direction-of-motion discrimination in the six different conditions are shown separately for the three observers in Table 1. Each datapoint is based on at least 75 observations from each observer.

With stimuli of 280 msec duration (italicized type) none of the observers had any difficulty determining the direction of motion in any of the conditions; all achieved virtually 100% correct responses whether the stimuli were single gratings, monocularly superimposed compound gratings, or dichoptically superimposed compound gratings.

On the other hand, with stimuli of 36 msec duration (bold type) the apparent direction of motion was reversed when a static 1-c/deg grating was added to a moving 3-c/deg grating. The reversal occurred whether the two gratings were added monocularly or dichoptically. In no condition at either signal duration were the observers able to say whether the complex gratings had been presented monocularly or dichoptically.

The addition of a 1-c/deg grating moving at the same speed and in the same direction as the 3-c/deg grating had little effect on performance in either the monocular or dichoptic conditions. This was suprising because in other stimulus conditions with physically superimposed gratings (Henning & Derrington, 1988; Derrington & Goddard, 1992) this manipulation would have produced approx. 50% correct judgements, i.e. would have exactly cancelled the illusory motion; this point will be taken up later. Thus the results of Expt 1, although demonstrating that the illusory motion occurred when the two components were presented to different eyes, do not establish the relative strength of the illusion in the monocular and dichoptic conditions. Experiment 2 was designed to provide estimates of the relative strength.

Experiment 2

Method. In this experiment the velocity of the 3-c/deg grating was again kept constant at 4 deg/sec while the velocity of the 1-c/deg grating was varied to determine the psychometric function relating the probability that the stimulus appeared to move in the same direction that the 3-c/deg component moved, to the speed of movement of the 1-c/deg component. From this function (specifically from the speed that produces a probability of 0.5) we can estimate the velocity of the illusory

TABLE 1. Percentage "correct" judgements of three observers in the different presentation conditions in Expt 1

		PAG	IF	GBH
Simple	1 c/deg	**100**	**91**	**100**
monocular		*100*	*100*	*100*
L or R eye	3 c/deg	**100**	**99**	**100**
		100	*98*	*100*
Compound	1 c/deg	**8**	**20**	**0**
monocular	Static	*100*	*100*	*100*
1 and 3 c/deg	1 c/deg	**78**	**98**	**76**
L or R eye	Moving	*100*	*100*	*100*
Compound	1 c/deg	**26**	**14**	**10**
dichoptic	Static	*98*	*100*	*100*
1 c/deg L eye	1 c/deg	**94**	**78**	**100**
3 c/deg R eye	Moving	*100*	*100*	*100*

Durations: bold, 36 msec; italicized, 280 msec.

reversed motion (Henning & Derrington, 1988) for both monocular and dichoptic presentations. The same 2-AFC direction-of-motion discrimination task was used with eight different speeds (in two groups of four) for the 1-c/deg grating. The shorter stimulus duration was used throughout and the 1-c/deg grating always moved in the same direction as the 3-c/deg grating moved. Each point was based on 50 observations and no feedback was given.

Results. Figure 1(a–c) shows the results of this experiment. In each figure the percentage of "correct" judgements is shown as a function of the speed of the 1-c/deg component. (A "correct" judgement is one for which the observer judges the stimuli to be moving as they are.) The psychometric functions of all three observers are approximately parallel so that we may take the speed of the 1-c/deg grating that corresponds to the 50% "correct" level to characterize the data; at this speed, the observers are equally likely to report stimuli that actually move leftward as moving leftward or rightward and we call this speed the cancellation speed. When the stimuli are superimposed monocularly, the three observers' cancellation speeds, estimated by interpolation on the best-fitting cumulative Gaussian, were 2.0, 2.7 and 2.2 deg/sec, respectively. They require slightly slower speeds when the stimuli are presented dichoptically: 1.7, 1.9 and 1.6 deg/sec. These differences are very small, but

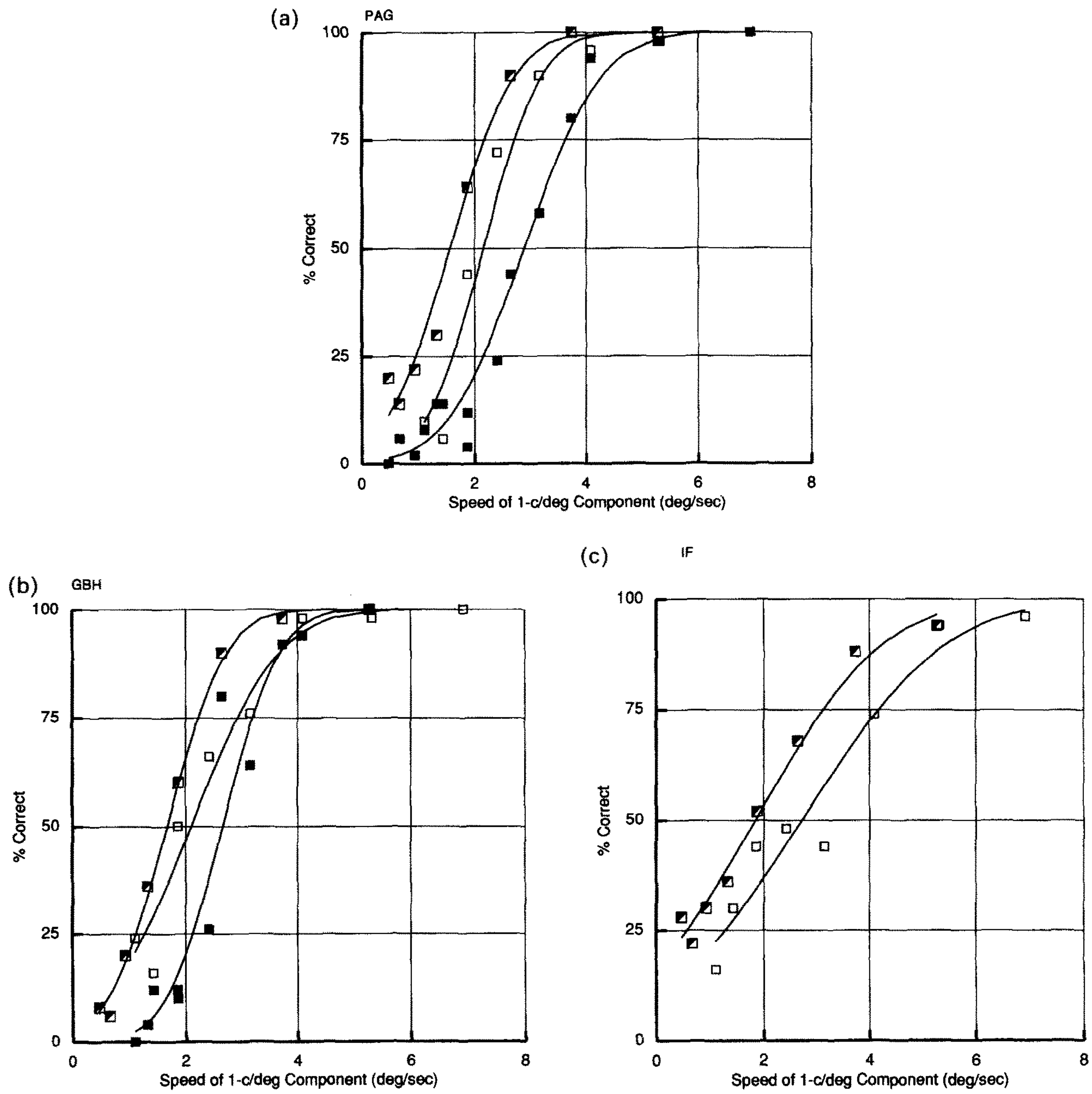

FIGURE 1. Each panel shows, for one observer, the probability of correctly reporting the direction-of-motion of a complex stimulus, made by adding a 3-c/deg grating moving at 4 deg/sec to a 1-c/deg grating moving in the same direction, as a function of the speed of the 1-c/deg grating. Half solid symbols show results obtained when the two components were presented dichoptically. Open symbols show results obtained when the two components were presented to the left eye, and a blank, uniform field of the same mean luminance was presented to the right eye. Solid symbols in (a) and (b) show results when the same stimulus display was viewed binocularly. The stimulus duration was 36 msec, the contrast of each component was 0.12, and each data point is based on 50 2-AFC trials.

TABLE 2. Cancellation velocity

	PAG	IF	GBH
Monocular	2.16 ± 0.075	2.73 ± 0.15	2.10 ± 0.098
Dichoptic	1.56 ± 0.07	1.87 ± 0.13	1.67 ± 0.073
Binocular	2.89 ± 0.076		2.66 ± 0.066

Velocity of 1-c/deg grating (± SD of estimate) required to cancel the illusory motion induced by a 3-c/deg grating moving at 4 deg/sec under different presentation conditions. Duration 36 msec.

they are statistically significant: the standard deviations of the thresholds, estimated by a bootstrap procedure (Foster & Bischof, 1991), are between one-quarter and one-sixth the size of the differences. The results are tabulated in Table 2.

GENERAL DISCUSSION

There are two points to deal with here. First, how do these results compare with previous results using similar presentation conditions, and second, can we exclude the possibility that the illusory reversed motion arises in a single elementary motion-detecting mechamism.The speed of the reversed motion observed in this study was slightly lower than that observed previously, but we think it likely that this is simply a consequence of the differences in the parameters of the stimulus. Figure 1 shows that the illusory reversed motion is cancelled when the low spatial frequency grating moves at approximately half the speed of the higher spatial frequency grating. This is a somewhat smaller effect than has been observed before—Henning and Derrington (1988) found that approximately the same speed of motion was necessary to cancel the reversed motion. Similarly, Derrington and Goddard (1992) found that the direction of motion of a compound grating containing components of 1 and 3 c/deg moving at 3 deg/sec in the same direction could not be discriminated, presumably because the illusory reversed motion cancelled the true motion. However in both these studies the stimuli were of shorter duration (about 28 msec in both cases) and higher temporal resolution [a 125 Hz single-field frame in Henning and Derrington (1988), and a 90 Hz two-field frame in Derrington and Goddard (1992)]. It seems reasonable to suppose that the difference in duration alone may have reduced the speed of the reversed motion, as it is known that the probability of reporting reversed motion declines as stimulus duration is increased (Derrington & Henning, 1987).

A second possible contributing factor is the contrast dilution which must be assumed to occur in our monocular and dichoptic presentation conditions. In these presentation conditions, the effective contrast of the stimulus will have been reduced by binocular integration because the other eye always viewed the illuminated display screen. Since it is known that contrast affects performance adversely under these conditions (Derrington & Goddard, 1989) we can assume that the presentation conditions cause the size of the interaction to be slightly underestimated. We tested this possibility in two of our observers by repeating Expt 2 under binocular viewing conditions. The corresponding psychometric functions are plotted using solid symbols in Fig. 1(a, b). The velocities required to null the illusory reversed motion (shown in Table 2) were substantially elevated although they were still below the values obtained using briefer displays (Henning & Derrington, 1988).

Although the cancellation speed is slightly reduced when the components are presented to different eyes, the difference is very small, except perhaps in the case of observer IF. If one takes the cancellation speed as an indication of the strength of the illusory motion, it is clear that there is very little drop in the strength of the illusory motion when the moving high-frequency grating is presented to one eye and the static low-frequency grating to the other. Thus it is quite clear that the mechanism that causes the illusory reversed motion integrates signals from the two eyes. This clearly suggests that two mechanisms are involved, since although it has been observed that dichoptic stimulation can give rise to a reliable motion signal (Anstis & Moulden, 1970; Shadlen & Carney, 1986) the motion signal is very weak or absent at short stimulus durations (Georgeson & Shackleton, 1989; Green & Blake, 1981). This strongly suggests that the motion detection mechanisms involved in computing the direction of motion of the individual gratings in our study are monocular in the sense that they are unable to perform spatio-temporal correlations between the two monocular images. The illusory reversed motion, then, can only result from the combination of information from separate motion detectors. The motion detectors which interact must presumably be selectively sensitive to different bands of spatial frequency.

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