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The Effect of Interactions Between One-Dimensional Component Gratings on Two-Dimensional Motion Perception

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Ferrera and Wilson [(1990) *Vision Research*, *30*, 273–287] reported veridical perception of the direction of motion of Type I plaids, whose component gratings span the resultant direction, but marked misperception of the direction of motion of Type II plaids, whose component gratings both lie on one side of the resultant direction. Because they failed to find any effect of component direction (angular) separation on this misperception, Ferrera and Wilson concluded that the misperception was not due to perceptual repulsion of component directions. We report that component direction repulsion does occur, that plaid direction misperception is tuned to component separation, with larger repulsions for smaller angles. It is concluded that there is no fundamental difference in direction coding for Type I and Type II plaids, and that Ferrera and Wilson failed to find a direction separation effect because the range of separations they used was insufficiently broad to detect the slope of the angular function.

Plaid Motion Intersection of constraints Distribution shift Direction perception

INTRODUCTION

A drifting one-dimensional pattern, such as a sine-wave grating, always appears to move orthogonally to its bars when it is viewed through a circular aperture which conceals the ends of those bars. Thus, a vertical grating drifting in any of the directions shown by the motion vectors in Fig. 1(a), and with speeds represented by those vector lengths would, through such an aperture, appear to drift in the direction OV and with the speed represented by the length OV. That is, given any vector in velocity space (such as OV) a line orthogonal to it (such as AB) represents the terminating locus of all other vectors drawn from O to AB which have the component vector OV. Thus, any gratings parallel to AB with any of the motion vectors shown in Fig. 1(a) will, through an aperture, have a perceived motion vector based upon the physical motion vector OV. This ambiguity is known as the *aperture problem* (Wallach, 1935) and the line AB is termed a *line of constraint* (Fennema & Thompson, 1979; Adelson & Movshon, 1982; Movshon, Adelson, Gizzi & Newsome, 1985).

This ambiguity does not occur with two-dimensional patterns composed of two superimposed drifting gratings at different orientations. This is so because if each of the component gratings has a line of constraint, the two constraint lines must also differ in orientation and will therefore intersect in velocity space, defining a unique velocity vector from point O to the intersection point. In Fig. 1(b), for example, the two component vectors C_1 and C_2 have orthogonal constraint lines which intersect at R. Consequently, two superimposed gratings with motion vectors C_1 and C_2 would have the unique resolved motion vector of OR.

In a series of papers exploring the perceived properties of such two-dimensional stimuli, termed *plaids*, Ferrera and Wilson (1987, 1990, 1991) have drawn a distinction between three plaid sub-categories. Plaids with components such as C_1 and C_2 in Fig. 1(b) are termed *Type I symmetrical plaids*, Type I to indicate that the component vectors lie either side of the resultant, OR, and symmetrical because the two component vectors are mirror reflections of each other. Plaids with components such as C_1 and C_3 are termed *Type I asymmetrical plaids*; and plaids with components on the same side of OR, such as C_2 and C_3, are termed *Type II plaids*. In the Fig. 1(b) examples, it can be noted that all three plaid types have been selected to produce the identical resultant vector OR.

A clear distinction needs to be drawn between the *physical* resultant vector and the *perceived* direction of plaid motion: Ferrera and Wilson (1990) have reported that whereas the perception of motion direction of all Type I plaids is essentially veridical, the direction of motion of Type II plaids is usually non-veridical with errors of between 5 and 10° in the direction of the component vectors. One possible explanation of this illusory effect is a distribution shift model exactly

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analogous to that usually offered to explain the tilt illusion and aftereffect (e.g. Blakemore, Carpenter & Georgeson, 1970; Carpenter & Blakemore, 1973; Wenderoth, O'Connor & Johnson, 1986; Wenderoth & Johnstone, 1988). Thus, it can be postulated that there are cortical neurones selectively tuned to *directions* (rather than orientations) which lie between the directions of the two component gratings of the plaid [e.g. between C_2 and C_3 in Fig. 1(a)] and these cells, which would normally be stimulated by either component stimulus alone, are actively inhibited when both components are presented simultaneously. As a consequence, the distributions of activity coding the directions C_2 and C_3 are skewed apart. In Fig. 2, the grey vectors reproduce C_2, C_3 and OR from Fig. 1(b). It can be seen that *perceived* angular expansion between the true component directions (black thin vectors) would produce *perceptual* constraint lines (dashed lines) which intersect closer to the component grating directions than do the actual constraint lines in Fig. 1(b).

Although this seems a plausible explanation of the effect which Ferrera and Wilson (1990) obtained with Type II plaids, Ferrera and Wilson rejected the explanation. They measured the illusory effect with three Type II plaids having angles of 22, 37 and 47° between the component vectors and obtained errors in perceived resultant direction which "decreased slightly with increasing angle" but the decrease was not significant. As they noted, the lateral inhibition or distribution shift model predicts substantial decrease because the proportion of neurones inhibited would decrease as the angle between the vectors increased. That is, the illusion should have an angular function similar to the tilt illusion, with largest repulsion effects at smallest angles; and the smaller the angle expansion (Fig. 2) the less the resultant vector will depart from the true resultant vector.

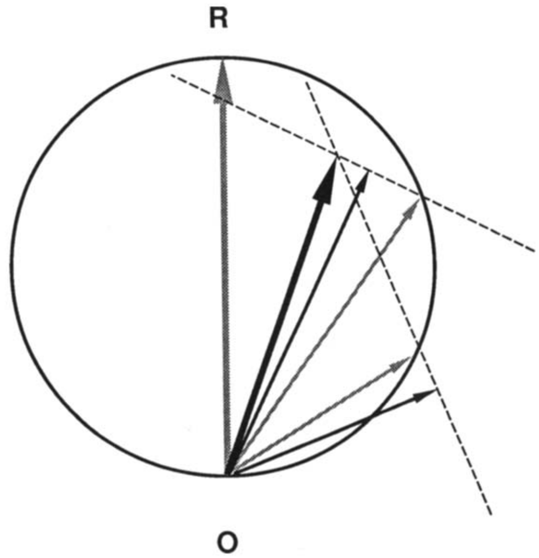

FIGURE 2. Grey vectors reproduce C_2, C_3 and OR from Fig. 1(b). Perceptual expansion of component directions (thin black vectors) would produce constraint lines (dashed) which intersect in the direction of the components relative to OR producing errors in perceived plaid direction (thick black vector).

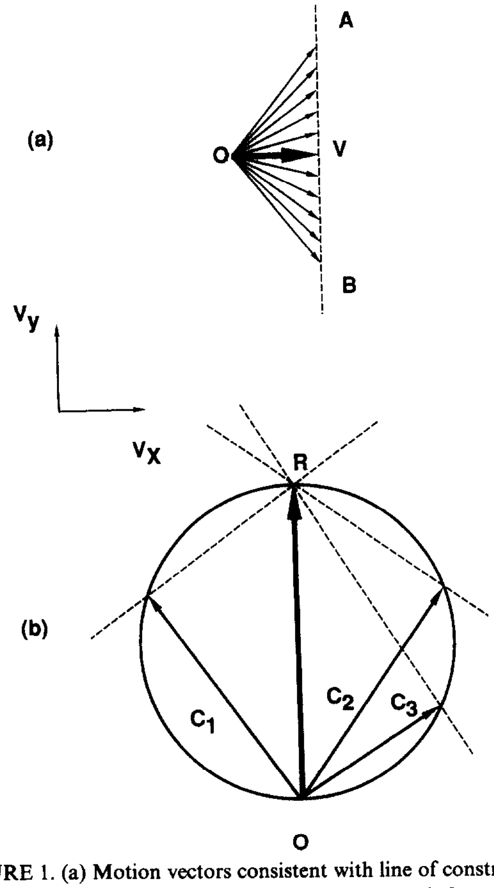

FIGURE 1. (a) Motion vectors consistent with line of constraint, AB. See text. (b) Component motion vectors, C_1, C_2 and C_3, any pair of which have IOC lines which intersect at R.

This evidence against the lateral inhibition model is not very strong: the tilt illusion is much larger between orientations separated by 10–15° than between larger orientations and, more important, inspection of typical angular functions indicates that the rate of change in magnitude is *markedly* reduced if one excludes the measures at small angular separations (e.g. Carpenter & Blakemore, 1973; O'Toole & Wenderoth, 1977). Consequently, Ferrera and Wilson may have obtained only a small and non-significant decrease in the Type II plaid effect with increases in component grating direction separations because the smallest separation they used was as large as 22°.

The aim of the present experiments was to test this proposition. First, we conducted a pilot study to determine whether we could obtain any preliminary evidence for component interactions. Having done so, and because our methods were very different from those used by Ferrera and Wilson, the subsequent experiment was designed to try to repeat their finding that Type I plaid resultant directions are *not* markedly misperceived, at the same time validating our own methodology.

PILOT STUDY

When the component gratings of a plaid are similar in spatial frequency, speed and contrast, it is virtually impossible to see the component motions (Movshon *et al.*, 1985). For example, if the similar components are two sine-wave gratings oriented 45 and 315° (measured clockwise from left horizontal) and drifting to the right, the observer sees a single, coherent *pattern* drifting horizontally to the right. The pattern can be described as consisting of alternating dark and light "blobs" which are formed where light bars cross orthogonal light bars and where dark bars cross orthogonal dark bars. Note that whereas orthogonal component gratings produce circular blobs, as the component gratings approach each other in orientation, the blobs become more elongated because the bars of the two gratings overlap for larger parts of their lengths. As a result, when the components are very close in orientation, as in most Type II plaids, the blobs actually resemble gratings which are oriented half way between the component orientations and which appear to drift orthogonally to that orientation.

In this pilot study, we wished to measure the perceived direction of motion of one plaid component grating first when presented alone (pretest) and then in the presence of the other component (test), the prediction being that the judged test direction would be shifted away from the inducing component's direction relative to the pretest judgement. In order to conduct such an experiment, coherent plaids could not be used because the individual component directions cannot then be resolved. Accordingly, the Michelson contrast, defined as $(L_{max} - L_{min})/(L_{max} + L_{min})$, was made different for test and inducing gratings. The aim was to promote non-coherent motion, often described as "transparent" or "sliding" motion, in which the two gratings are seen drifting separately and independently over each other, orthogonally to their own orientations. Because informal observations suggested that square-wave gratings cohered less than sine-wave gratings, we used the former. Finally, it seemed possible to us that the misperception of Type II plaid direction could be related to the perceived motion of the elongated "blobs", described above. To remove this source of possible confounding, 85% duty cycle square-wave gratings were used, which produced very small, diamond shaped but barely elongated blobs. Three different inducing velocities were used, in case any obtained effect was velocity tuned.

Method

Apparatus and stimuli

Test and inducing gratings were generated by a Macintosh IIci computer and output separately on two AppleColor 33 cm RGB High Resolution monitors. The two plaid components were then visually superimposed by a the half-silvered mirror of a tachistoscope. Maximum and minimum luminances of the high contrast inducing grating were 95.95 and 1.05 cd/m^2, respectively. For the low contrast test grating, the corresponding values were 21.95 and 18.2 cd/m^2. Thus, the contrasts of the two gratings were 0.98 and 0.09. The test grating always had a velocity of 1.44°/sec at the viewing distance of 57 cm. The three inducing velocities employed were 0, 1.44 and 2.88°/sec. The test grating always was oriented 45° and drifted in the direction 315°. The inducing grating was presented with four different drift directions: 292.5, 270, 225 and 180°, so that the angle between its direction and that of the test grating was 22.5, 45, 90 or 135°.

Procedure

A pointer was attached rigidly to a protractor which could rotate freely over an etched vertical mark. Only the pointer, located at arm's length, was visible to the subject, who simply set the pointer in the direction of perceived plaid component motion. The experimenter read the direction and wrote it down. Each subject was tested under all twelve conditions and made four judgements under each from a pointer starting position which was randomly $\pm 10°$ from the true test direction. The instruction was to make the adjustment in any manner, so long as the final setting was as accurate as possible.

Subjects

There were four subjects, all with emmetropic or corrected vision, volunteers from an Introductory Psychology course who participated in return for nominal course credit.

Results and Discussion

The results of the pilot study are shown in Fig. 3 and were sufficiently clear cut to warrant further formal experiments. Misperceptions of the test component direction appeared to occur at component separations of 22.5 and 45° but not at the larger separations. The largest illusion (15.2°) occurred with the stationary inducing grating, suggesting that the effect is not speed tuned. Indeed, the three curves in Fig. 3 for the three different inducing speeds are very similar.

A repeated measures analysis of variance with planned trend comparisons showed that there was significant

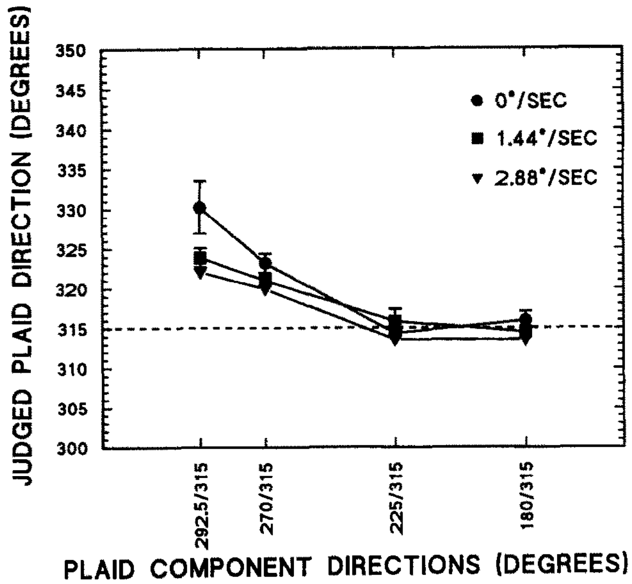

FIGURE 3. Judged plaid component direction as a function of inducing component direction, for inducing velocities of 0 (circles), 1.44 (squares) and 2.88°/sec (triangles).

linear trend across velocities [$F(1,3) = 11.86$, $P < 0.05$] but this appears largely due to the 0°/sec point at 22.5° separation. Both linear and quadratic trends were significant across component separation ($F(1,3) = 306.35$ and 10.45, $P < 0.0005$ and <0.05, respectively), consistent with the exponential-type shape of the function. Other trend tests were not significant.

Since these data suggest that Type II plaid components do interact in the direction (or orientation) domain, Expt 1 was designed to determine whether an angular function similar to that in Fig. 3 occurs with coherent Type II plaids when the direction of the whole plaid, not a single component, is judged. That is, we decided to re-investigate the claim of Ferrera and Wilson (1990) that *no* such angular function exists.

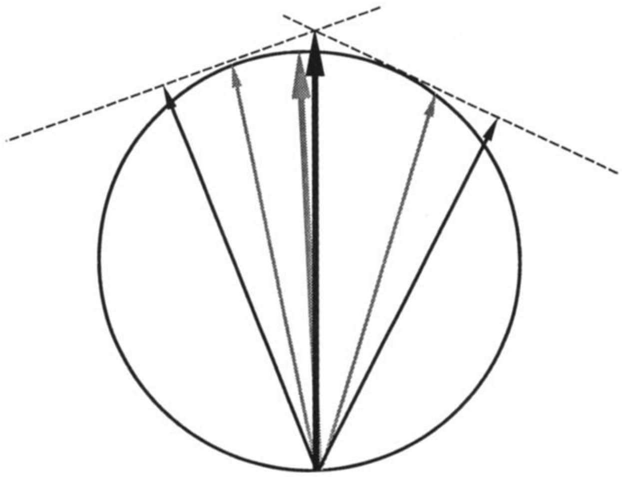

FIGURE 4. For Type I plaids, true component directions (thin grey vectors) may be considerably repelled perceptually (thin black vectors) without substantially affecting perceived plaid direction (thick black vector).

EXPERIMENT 1

In this experiment, we used both asymmetrical Type I as well as Type II plaids, with component angular separations of 10, 20, 30 and 40°. To test whether judgements of direction were influenced by the elongated "blobs", particularly at small angular separations, not only sine-wave but also 85% duty cycle square-wave grating components were used.

In the event that perceived angular expansion between component directions did occur, we expected that the Type II plaid directions would be markedly misperceived at smaller angular separations such as 10° and perhaps 20°, as illustrated in Fig. 2. However, as Fig. 4 shows, similar perceived expansion in the case of Type I asymmetrical plaids would have little effect on perceived plaid direction so that a small effect, if any, was expected in those cases.

Method

Apparatus

Stimulus displays were generated by a Macintosh IIci computer and displayed on a single 33 cm AppleColor High Resolution RGB monitor. Drifting plaid stimuli were created by allocating alternate pixels on each raster scan line to one or the other component gratings by assigning one 127 grey level colour lookup table (CLUT) to the even pixels and a second, independent CLUT to the odd pixels. Alternate horizontal scan lines of pixels were shifted one pixel out-of-phase so that the two gratings were effectively assigned to pixels arranged in the pattern of either the light or the dark squares of a checkerboard. Other methods of spatially interleaving the two gratings were available (e.g. no phase shifting so that one grating occupied all odd pixels). However, these alternatives were less satisfactory because the intersections of light and dark bars were then represented by light and dark continuous lines of pixels rather than by alternating light and dark single pixels. That is, the spatial interleaving was least obvious using the checkerboard array.

Methods of direction measurement were as in the pilot study except that this time the pointer was set to match the direction of motion of the entire plaid.

Stimuli

All gratings had a spatial frequency of 0.46 c/deg and all gratings and plaids had maximum and minimum luminances of 104.6 and 0.7 cd/m^2 so that contrast was 0.98.* All plaids truly drifted straight down (270°) and the complete set of component directions and velocities used to achieve this is shown in Table 1.†

Procedure

Subjects were presented with each drifting plaid for 10 sec and were required to adjust the pointer to the direction of pattern movement within the 10 sec, after which the screen became dark. Approximately five practice trials were required to ensure that this task could be done within the 10 sec. All 19 subjects made just one judgement under each of the eight conditions in Table 1 both for sine-wave plaids and for 85% duty cycle square-wave plaids. In addition, each subject judged the direction of a symmetrical sine-wave plaid, with components drifting 225 and 315°, which served as a control judgement.

Results

Figures 5 and 6 present the judged plaid directions as a function of component separation for Type I and Type II plaids, respectively. The dashed horizontal line at 270° on the ordinate indicates the true plaid direction.

Considering Type I plaids first (Fig. 5) it is clear that there was no misperception at all in the symmetrical 90° control condition, where the mean judged direction was

*Plaid luminances were not double grating luminances because the two gratings of the plaid occupied spatially discrete pixels.

†The Type I plaid with 10° component separation is the limiting case of a Type I plaid in that one of the component directions is the *same* as the resultant direction.

TABLE 1. Parameters for Type I and Type II plaids used in Expt 1

Component separation	Type I plaid components: Directions (°)	Type I plaid components: Speeds (°/sec)	Type II plaid components: Directions (°)	Type II plaid components: Speeds (°/sec)
10°	270, 280	3.55, 3.47	290, 300	3.32, 3.06
20°	265, 285	3.55, 3.39	285, 305	3.39, 2.94
30°	260, 290	3.47, 3.31	280, 310	3.47, 2.74
40°	255, 295	3.39, 3.24	275, 315	3.55, 2.51

270.08°, with a standard error < 1°. Inspection of Fig. 5 shows that there were small errors of 3.74 and 4.74° for sine- and square-wave plaids, respectively, in the 10° separation condition and errors appeared to decrease as component separation increased. Statistical analysis confirmed this suggestion: repeated measures analysis of variance with planned trend comparisons indicated that from 10 to 40° component separation, the mean errors in perceived direction decreased in linear fashion, with $F(1,18) = 10.16$ and $P < 0.01$. Quadratic trend was not significant, with $F(1,18) = 0.59$ and $P > 0.05$. There was no significant difference between sine- and square-wave plaids, $F(1,18) = 0.06$ and $P > 0.05$.

Figure 6 shows that plaid directions were markedly misperceived in the case of Type II plaids and the data certainly suggest a tilt-illusion type angular function, with obtained errors in judged direction decreasing with plaid component separation. The mean obtained errors for 10–40° separations were respectively, 17.15, 7.71, 5.50 and 1.97° in the case of sine-wave plaids; and 14.42, 9.58, 3.11 and 4.16° in the case of square-wave plaids. In this case, repeated measures analysis showed that there was no effect of plaid type once again, $F(1,18) = 0.22$ and $P > 0.5$, but there was both linear trend [$F(1,18) = 34.17$, $P < 0.0005$] and quadratic trend [$F(1,18) = 12.21$, $P < 0.005$] across component separations.

DISCUSSION

The results of Expt 1 were entirely consistent with the predictions that errors would occur in judged plaid direction both for Type I and Type II plaids, but that much larger errors would occur with Type II plaids (Figs 2 and 4). The significant decrease in errors with increases in component directional differences was consistent with the hypothesis that these components stimulate neural channels selective for those directions of motion which, as a result of mutual inhibition, are coded as directions which are further apart.

The question immediately arises as to why Ferrera and Wilson (1990) failed to find evidence for changes in errors in the perceived direction of Type II plaids when they increased the directional difference between the component gratings. We suggested earlier that Ferrera and Wilson may have failed to obtain such an effect because the smallest angle between component directions which they used was 22°. Consistent with this suggestion is the fact that the functions in Figs 5 and 6 are relatively flat from 20 to 40°; and reanalysis of the data after omitting the 10° effects indicated that the effect of separation was then indeed not significant, with $F(1,18) = 2.28$ and $P > 0.1$.

Finally, we considered the possibility that the misperception of the Type II plaid direction was due to the apparent drift direction of the elongated blobs which, as was noted earlier, is the mean direction of the components. However, as Fig. 6 indicates, this cannot be the explanation for three reasons. First, the mean component direction (dotted line) was well removed from the actual perceived directions. Second, the mean component direction was constant whereas the perceived direction varied significantly with component

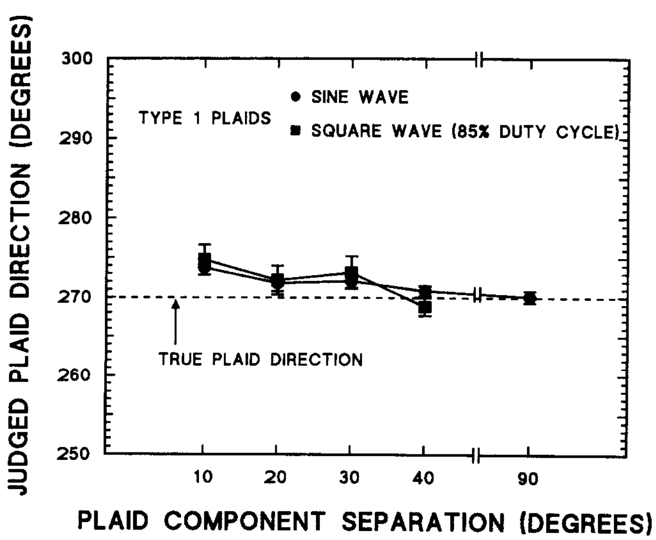

FIGURE 5. Judged Type I plaid direction for sine-wave (circles) and 85% duty cycle square-wave (squares) plaids, Expt 1.

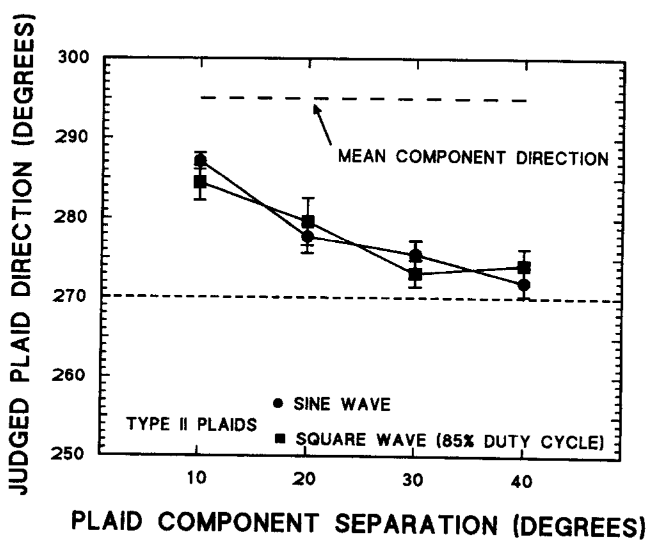

FIGURE 6. Judged Type II plaid direction for sine-wave (circles) and 85% duty cycle square-wave (squares) plaids, Expt 1.

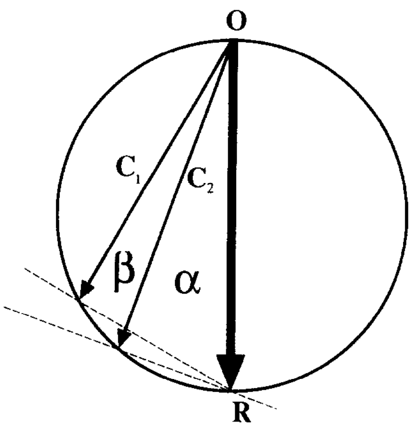

FIGURE 7. See text.

separation. Third, there was no difference between the functions for sine-wave plaids, which had elongated blobs, and for 85% duty cycle square-wave plaids, which did not.

EXPERIMENT 2

In Fig. 7, C_1 and C_2 are component vectors of a Type II plaid, the angle between the vectors is β, the resultant plaid direction is R and the angle between it and C_2 is α. It can be shown that

$$\alpha = \tan^{-1}[(\cos\beta - C_1 C_2)/\sin\beta].$$

Assume that β is actually 10° but that both C_1 and C_2 appear repelled from each other by 10° each, so that β is *coded as* 30°. In that event, substituting in the above equation with $\beta = 30°$ and $C_1/C_2 = 3.06/3.32$, the actual speeds in the 10° condition of Expt 1, α is then $-6.35°$.* Since C_2 *appears* to have the direction 280° rather than 290°, R will *appear* to have the direction $[280-(-6.35)] = 286.35°$, not unlike the obtained judged directions for sine- and square-wave plaids in Fig. 6, namely, 287.15 and 284.42°, respectively.

That is, the obtained misperception of about 16° of the direction of a Type II plaid with components separated by 10° is consistent with a 10° misperception of the direction of each of the components and not unlike the misperception obtained in the pilot study (Fig. 3). Although static tilt illusions generally are much smaller than 10°, briefly flashed effects are of that order (Wenderoth, van der Zwan & Johnstone, 1989; Harris & Calvert, 1989). In addition, Levinson and Sekuler (1976) have reported that adaptation to drifting dot fields can repulse the perceived direction of subsequently presented drifting dot fields by up to 10°, when the difference between adapting and test directions is as much as 30°; and Marshak and Sekuler (1979) reported simultaneous illusory shifts induced by one field of dots on another of up to 20°. It is conceivable that such large illusions of tilt and direction occur when stimuli are used which are adequate to stimulate transient or magnocellular channels (see Wenderoth *et al.*, 1989; Harris & Calvert, 1989).

Figure 8(a) illustrates the hypothesised explanation of the 10° separation effect in Expt 1. The true component velocities and the true resultant are shown in grey. The solid black vectors represent the *perceived* component vectors, drawn 10° away from the true vectors. The consequent perceived resultant is the dashed vector, approx. 16° clockwise of R. Figure 8(b) represents an identical analysis, with the true component vectors still separated by 10°, but with the component directions more oblique, here 305 and 315°. Even though the perceived error in the coding of the component vectors is still 10° each the predicted perceived resultant is now much further from R, in this case about 23°.

We calculated the angles by which each *component* grating in Expt 1 would have had to be misperceived in order to produce the obtained *pattern* misperception. Repulsive shifts in each component direction of 10, 4, 2.5 and 2.5° for the component separations of 10, 20, 30 and 40° gave perceived plaid directions of 286.2,

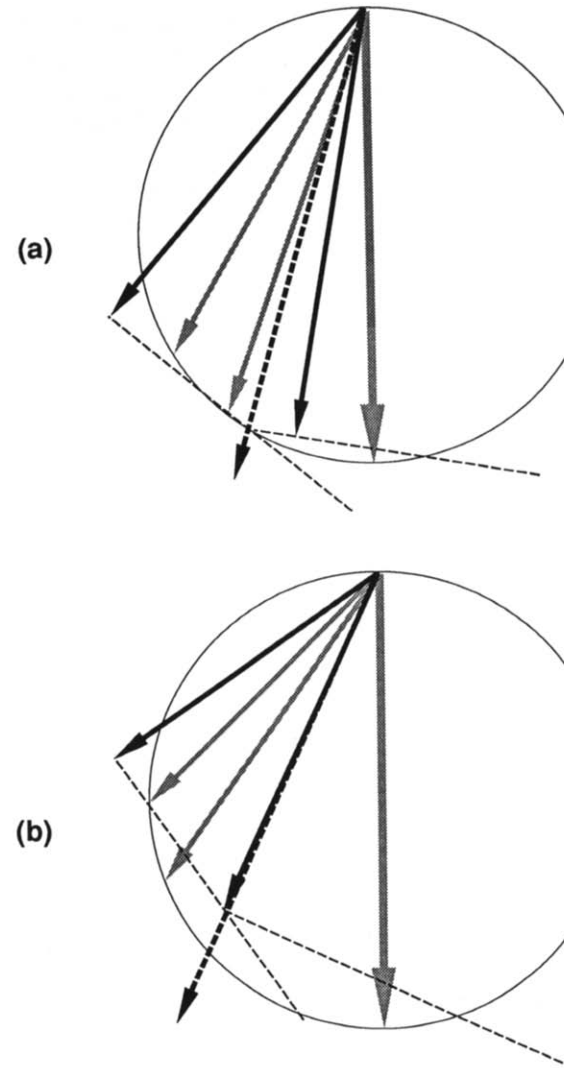

FIGURE 8. Predicted perceived plaid directions (thick dashed vectors) for Type II plaids truly moving straight down (thick grey vectors) due to hypothesised perceptual expansion (black vectors) of component drift directions (thin grey vectors). (a) Component directions 290, 300° (b) Component directions 305, 315°.

*For simplicity, it is assumed that the coding of the velocity ratio remains veridical, consistent with the null effect of velocity on plaid component misperception in the pilot study.

278.9, 274.1 and 272.2°, very similar to the obtained results in Fig. 6.

Experiment 2 was designed to test the distribution shift model directly by using Type II plaids such as that in Fig. 8(b), keeping one component direction fixed at 315° and assuming that the perceptual expansions between components separated by 10, 20, 30 and 40° will again be 10, 4, 2.5 and 2.5°, as estimated from the Expt 1 data. We could then compare calculated perceived plaid directions with obtained directions. Expt 2 was also designed to vary component separations keeping one component direction constant rather than keeping the average direction constant, as was the case in Expt 1, to test for the generality of the Expt 1 results.

Method

All details of method and procedure were as in Expt 1. Only Type II plaids were used, both sine- and 85% duty cycle square-wave plaids, as in Expt 1. One component grating always drifted in the direction 315°; the other had one of the directions 305, 295, 285 or 275°. The combinations of velocities required to produce a true resultant plaid direction of 270° can be read from Table 1. There were 18 new volunteer subjects.

Results

The results of Expt 2 are shown in Fig. 9. The errors in perceived plaid direction were close to those predicted by the distribution shift model: obtained and predicted (the latter in brackets) perceived plaid directions, averaged over sine- and square-wave plaids, were: 296.3 (293.6), 278.3 (278.3), 274.8 (274.6) and 273.8 (272.2). A repeated measures analysis with planned contrasts indicated that linear trend was significant across separations [$F(1,17) = 60.48$, $P < 0.005$] as was quadratic trend [$F(1,17) = 17.60$, $P > 0.0005$]. Omission of the 10° separation data with subsequent reanalysis indicated, as

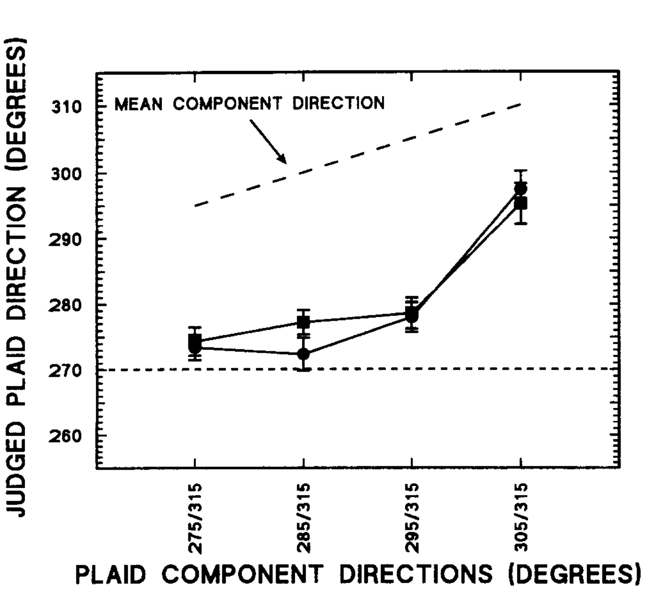

FIGURE 9. Judged plaid directions as a function of component directional separation, Expt 2.

in Expt 1, that these trends were then not significant [$F(1,17) = 3.64$ and 0.41, $P > 0.05$ in both cases].

It is clear from Fig. 9, as it was from Fig. 6, that plaid misperception is not due to the apparent drift direction of the elongated blobs: the mean component direction function is linear (dashed line) and the directions are at every point more than 10° removed from the perceived plaid direction, which does not have a linear function. It might be argued that as the angle between the component gratings decreases so the blobs become longer, fill more of the screen and hence dominate perceived direction more (accounting for the trend in misperceived direction): but as before, this cannot account for the identical function obtained with the 85% duty cycle square-wave grating which had very small blobs in all conditions.

GENERAL DISCUSSION

Ferrera and Wilson (1990) reported that both discrimination thresholds for, and illusory errors in, the perceived direction of Type II plaids were significantly greater than those for Type I plaids; and they had previously reported differences between the two types of plaid in their masking effectiveness. As a result, Ferrera and Wilson (1990) postulated that the mechanisms which code the two types of plaid motion are different, that the visual system generally does implement the intersection of constraints (IOC) construction for Type I but not for Type II plaids but that this is not a serious problem for the visual system because in most real world scenes sufficient orientations are present for the system to select Type I rather than Type II solutions.

We have demonstrated that, at least with regard to perceived plaid direction errors, it is unnecessary to postulate separate coding mechanisms for Type I and Type II plaids. In Expt 1, we demonstrated that for Type II plaids with component gratings at relative orientations of 10, 20, 30 and 40°, misperception of plaid direction is larger the smaller is the angle between the component directions. This was taken to be entirely consistent with a distribution shift model in which components with similar motion directions repel each other in the direction domain. It was demonstrated that repulsions of 20 (10° per component), 8, 5 and 5°, respectively, adequately predicted the obtained perceived direction errors and assuming similar errors in component coding in Expt 2, it was again possible to predict very large plaid direction perception errors with remarkable accuracy.

It is concluded that the intersection of constraints rule, formulated by Adelson and Movshon (1982) and Movshon *et al.* (1985) does give an adequate account of the perceived direction of both Type I and Type II plaids. It is necessary, however, to take into account the fact that direction repulsion effects even if large have little or no effect on the perceived direction of Type I plaids. In the case of Type II plaids, such repulsion effects have dramatic consequences for perceived plaid direction and the IOC rule must be formulated in terms of *perceived* or *extracted* component directions and, hence, perceived or extracted constraint lines, in order that it predicts overall pattern direction perception.

The fact that large misperception of plaid component directions occurs even when the components do not cohere, as in our pilot study, may indicate that the site of the repulsion lies in neurones sensitive to component motion rather than pattern motion, possibly those in V1 or those in MT. Wenderoth *et al.* (1988) found that motion aftereffects (MAEs) induced by plaids were larger than those induced by alternating plaid components, suggesting an extrastriate component in plaid induced effects. If component repulsion effects arise from component selective cells, and if MAE direction is determined by what we have termed "extracted" component directions, then it would be predicted that MAE directions would be the same whether induction was by simultaneously-presented or alternating plaid components.

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