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LETTER TO THE EDITORS

THE INDUCED EFFECT: A REPLY TO THE ARGUMENTS OF MAYHEW AND FRISBY

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In a recent issue of *Vision Research*, Mayhew and Frisby (1982) raise a number of questions concerning our recently-presented theory of the induced size effect (Arditi *et al.*, 1981). The basis of our theory is a simple one: that the apparent depth in the induced effect is a consequence of the horizontal disparity produced in the images of obliquely-oriented contours by the geometry of vertical magnification. Mayhew and Frisby correctly point out some errors in the original exposition of our theory, but erroneously state that their objections are "insuperable".

(1) We first consider the case of a complex texture, which both motivated our original description of the effects of vertical magnification in terms of spatial harmonic components, and at which Mayhew and Frisby's arguments are primarily directed. We should stress that we are not advancing the following as a new theory, but are merely suggesting how the original theory can still effectively explain the induced effect obtained with complex random textures. We assume that stereoscopic mechanisms may operate on harmonically filtered images of a complex texture, and also on "local" elements of the filtered images such as individual "bars" in that image. For descriptive purposes, such "bars" may be considered as lines.

As Mayhew and Frisby recognize, each individual line of an oblique grating vertically magnified in one half-image, produces disparities consistent with tilt about both a vertical and a horizontal axis. Consider first only the tilt about a vertical axis. Recall that its direction and magnitude are *independent* of the orientation of the line and are consistent with the magnitude and direction of the traditionally-defined induced effect (Arditi *et al.*, 1981). This proof stands despite the fact that a *single* grating composed of such lines will not be tilted left-right. Now consider the tilt about a horizontal axis. It is easy to show that, in contrast, the direction and magnitude of this tilt depend critically on the orientation of the line. This orientation dependence holds for gratings (or harmonic components) as well.

It is obvious that, when presented with a complex texture containing harmonic components at many orientations, the visual system must cope with a great deal of conflicting disparity information. All of the harmonic components *qua* gratings signal a different amount of tilt about a horizontal axis depending on their orientation, while all of the "local" (i.e. individual lines or bars) disparity information is consistent with a single direction and magnitude of tilt, that predicted in our theory and in the empirically observed induced effect. This is schematically illustrated in Fig. 1. Now we are left with a puzzle: How does the visual system resolve such conflicts of disparity information arising from the same object? We cannot yet answer this question, but it seems likely, especially given the fact that the induced effect does occur with complex random textures, that the large amount of consistent local disparity dominates and determines the tilt seen in the induced effect.

(2) Concerning the generalization of our line-by-line analysis to gratings, Mayhew and Frisby are correct in pointing out that vertical magnification of one half-

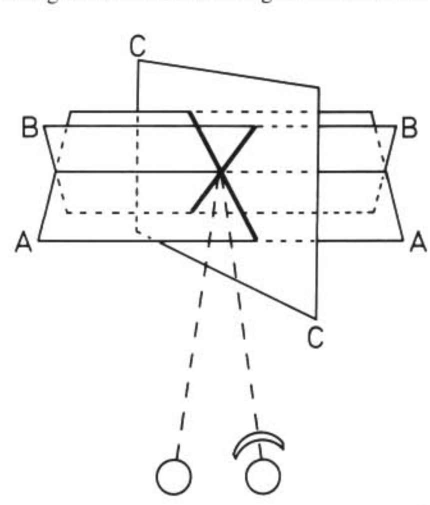

Fig. 1. Conflicting disparity information of harmonic components of a scene when one half-field is vertically magnified. The leftward tilting (on the page) line defines a family of planes including the one labelled "A" which has only top-to-bottom tilt. The rightward tilting line defines another family, including the oppositely tilted plane "B". Planes "A" and "B" are examples of the different tilts about a horizontal axis predicted by gratings (harmonic components) of different orientation. Examination of the central lines from such gratings reveals that the *only* plane containing *both* lines is neither of these, but rather the left-to-right tilted plane "C". The family of planes parallel to "C" will in fact contain *all* oblique lines, *whatever their orientation or position in the field of view*. Thus, while the components of a complex pattern will by themselves suggest a variety of tilts depending on their orientation (as will a single oblique grating), all *local* disparity gradients will suggest tilt consistent with both the direction and magnitude of the observed induced effect.

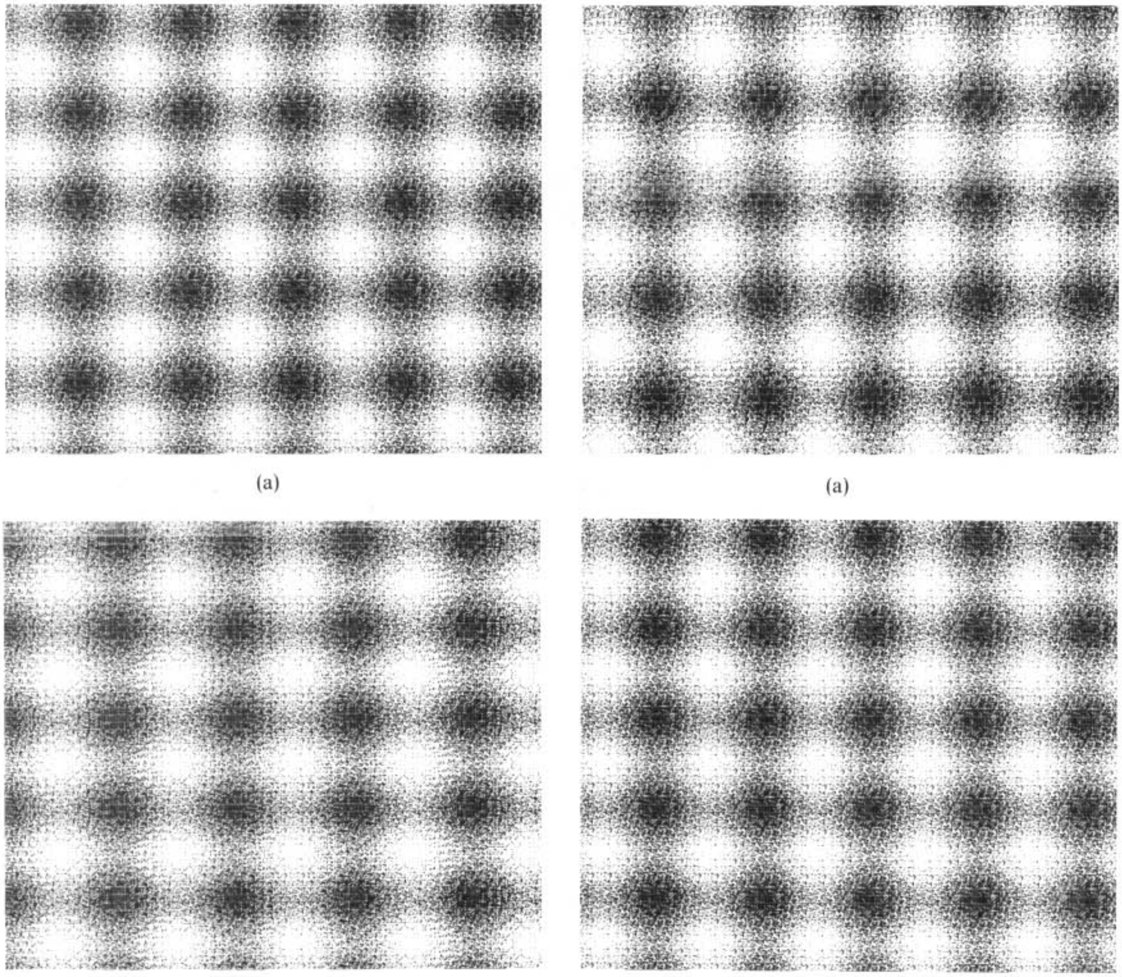

Fig. 2. Checkerboard stereograms each composed of the sum of a vertical and a horizontal sine wave grating expanded 10% (a) vertically in the right half-image and (b) horizontally in the left half-image. Tilt is apparent only in (b).

image of an oblique grating predicts tilt about a vertical, but not a horizontal axis. We concede the fact that indeed, a stereogram composed of a single oblique grating vertically expanded in one half-image does produce a percept of tilt from top to bottom. We have observed, however, that this holds true with meridional lenses as well as with stereograms, and thus actually *supports* our theory, in that it shows that horizontal disparity determines the apparent depth obtained with such lenses.

It also emphasizes the fact that the induced effect itself is very difficult to define. Mayhew and Frisby obviously have strong preconceived ideas about what does and what does not constitute an exemplary case. We, on the other hand, are inclined to accept all stereoscopic phenomena produced by vertical magnification of one half-field as examples of the induced effect. Our purpose in our original theory was to explain such phenomena without invoking special mechanisms or processes, and the observation that single oblique gratings produces an induced effect with top-to-bottom tilt fits nicely into our way of thinking. In attempting to use this as an argument against our theory, Mayhew and Frisby have confused a defining property with an empirical observation. To us, it seems more prudent to redefine the induced effect than to arbitrarily omit a new observation about it. Indeed, it seems unlikely that Ogle would have dismissed this observation as casually as Mayhew and Frisby have, had he been aware of it.

(3) Another point is made in their paragraph 3, where Mayhew and Frisby show that vertical magnification of one half-image produces an orientation disparity of the correct sign to produce the induced effect, but *also* produces a spatial frequency disparity of *opposite* sign, which would tend to oppose the direction of tilt observed in the induced effect. This observation, which escaped our notice in our original exposition, is not inconsistent with the substance of our theory. First of all, this conflicting depth cue probably provides considerably weaker depth information than the orientation disparity in the stimulus.

This is because the amount of tilt predicted by such disparities depends on the orientation of the spatial frequency components (for constant vertical magnification, the spatial frequency disparity between the gratings diminishes as the cosine of the angle from horizontal). Since the differently oriented components of a random texture each signal a different amount of left-right tilt, it is doubtful that in combination this depth information could play as significant a role in determining perceived tilt as that of the local orientation disparities, in which all components are consistent with a single tilt—that observed in the "classic" induced effect, and predicted by our original theory.

It is furthermore possible that this conflict of disparity information between local orientation and spatial frequency disparities is responsible for one of the well-documented peculiarities of the effect for which we were unable to account earlier, i.e. the "maximum" observed by Ogle (1938, 1950). Ogle observed that apparent tilt in the induced effect increases only up to a vertical magnification of about 8%; beyond this, apparent tilt ceases to grow, and often declines somewhat. This hypothesis, of course, requires more elaboration than our allotted space will permit and will be developed in a subsequent paper.

(4) In their paragraph 4, Mayhew and Frisby again confuse empirical and defining properties in their discussion of the seeming "whole-field" character of the induced effect discussed by Ogle. Ogle had observed that vertical magnification of one half-field seemed to skew the entire horizontal horopter and not merely that region which contains obvious vertical disparities. On the basis of that observation, Mayhew and Frisby put forth the curious argument that the stereoscopic tilts produced by vertical expansion of one half-image of our demonstration stereograms are not actually examples of the induced effect. Would Mayhew and Frisby also argue that when obliques happen to be present in a natural scene, the tilt which is observed using a vertically magnifying lens over one eye is *not* an example of the induced effect?

In point of fact, Ogle's (1950, p. 181) own discussion of these "whole field" experiments reveals that with only two beads on the central rod of the horopter apparatus, the induced effect may be "scarcely observable" with some subjects. Ogle also states in this regard that the effect is "markedly increased" if the beads are placed at different vertical levels on all five of the horopter rods. This observation corroborates our theory, since such placement introduces implicit obliques in the field of view. Westheimer (1978) also found a weak induced effect with very similar implicit obliques and he used a stereoscopic apparatus, not meridional lenses.

(5) Finally, in their paragraph 2, Mayhew and Frisby present a test of an important prediction of our theory: that the induced effect should not be obtained with a stimulus containing only vertical and horizontal components. They report viewing a checkerboard composed of a vertical and a horizontal grating with a magnifying lens over one eye, and seeing an induced effect. Unfortunately, the situation they describe will magnify not only the checkerboard but also its square *borders*; since these borders contain oblique spectral energy, we are not surprised that they see tilt; so do we. If, however, the precaution is taken of making the borders of each checkerboard the *same* (so that the two half-images differ *only* in the spatial frequency of the horizontally oriented component of the checkerboard), no tilt is seen, about either the vertical or the horizontal axes. In Fig. 2, we present a demonstration of this fact.*

In summary, Mayhew and Frisby's views seem to us to reflect an acceptance of a "classic" definition of the effect as popularized by Ogle. This kind of acceptance, we fear, leaves little room for new, and perhaps enlightening observations about the effect. We have discussed the fact that vertical magnification of a single oblique grating produces primarily the perception of top-to-bottom tilt, whether the magnification is produced optically or by other means. This tilt is produced by horizontal disparities of the same sort which we contend produce the "classic" induced effect. Given this *new* observation, it seems to us less confining to apply the term "induced effect" to whatever depth is seen as the result of vertical magnification of one half-image. An equally appealing alternative would be to abandon the name "induced effect" altogether, since we believe that it is simply an example, albeit not an obvious one, of mere stereopsis.

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*While we have made every effort to insure the linearity of the images in these demonstrations, we cannot be sure that they will be reproduced faithfully. We encourage the reader with suitable display hardware to examine similar patterns on their own apparatus.

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