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LOCAL AND DISTAL FACTORS IN VISUAL GRATING INDUCTION

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Abstract—When a uniform test field is surrounded by luminance or chromatic gratings, a grating is induced in the test field. The perceived spatial frequency and orientation of the induced grating can be different from the frequency and orientation of the inducing gratings. Local edge effects are the factors primarily responsible for visual grating induction. Distal parts of the inducing stimulus affect only the amplitude of the induced modulation.

Grating induction Color induction Simultaneous contrast

INTRODUCTION

McCourt (1982) and Foley and McCourt (1985) showed that when a narrow uniform strip is inserted within a sinusoidal grating, an induced grating is perceived in the strip (Fig. 1a). They measured the properties of the induced percept by using real modulation in the test strip to cancel the induced modulation. On the basis of these measurements, they claimed that the induced grating has the same orientation and spatial frequency as the sinusoidal inducing grating, and that these properties can be explained by a class of neurons with narrow centers and elongated receptive fields that are oriented parallel to the axis of orientation of the inducing grating. In the present study, these assertions were opposed by the hypothesis that grating induction is just a particular case of classical simultaneous induction. In classical induction, the appearance of a test field with a closed boundary is altered when it is flanked or surrounded by inducing fields (Chevruel, 1848). Studies of induction generally use inducing fields that are uniform in appearance and the test field is also perceived as uniform. The mechanisms responsible for classical induction are not known. However, a large number of studies summarized in Yund and Armington (1975) have established that elements of the surround proximal to the test influence the induced percept more than distal elements. If grating induction is a special case of classical, then the spatial modulation adjacent to the edge of the test may be more important than the global properties of the inducing gratings.

A series of novel stimuli were created to examine the role that proximal and distal elements of the inducing stimulus play in grating induction. In the following sections, visual displays will be used to show: (i) the orientation of the induced grating can be different from the orientation of the inducing grating; (ii) the spatial frequency of the induced grating can be different from the spatial frequency of the inducing grating; (iii) distal elements of the inducing stimulus affect only the amplitude of the induced modulation; and (iv) locally induced patches of contrast may combine to generate the percept of induced gratings. It is only possible to present black-and-white photographs in this paper, therefore, only luminance stimuli will be discussed. However, complete sets of isoluminant stimuli were made as well, using the minimally distinct border technique. The amplitude of induced modulation was less for chromatic stimuli than for luminance stimuli, otherwise the effects were qualitatively similar. Four conventions will be followed in the description of the stimuli. First, the angle of orientation or elevation of a grating will refer to the angle between the principal axis of orientation and the horizontal. Second, the spatial frequency will refer to the frequency along the axis perpendicular to the principal axis of orientation. Third, when the relative phase of two spatially separated gratings of identical frequency and orientation is discussed, it will be relative to a line parallel to the axis of orientation. Fourth, parts of the inducing surround adjacent to the test field will be termed proximal, parts at some distance from the test field will be termed distal.

ORIENTATION OF INDUCED GRATINGS

To show that the perceived orientation of the induced grating is independent of the orientation of the inducing grating, two sets of displays, Figs 1(a–d) and 2(a–d) are presented. In each of these sets, inducing gratings of only one orientation and spatial frequency are used, but the perceived orientations of the induced gratings vary as the phase of the vertical grating below the test area is varied relative to the phase of the vertical grating above the test area. In Fig. 1(a) the vertical grating above is in phase with the grating below the test area. The central test patch is physically homogeneous, but it appears to consist of a vertical grating in counter-phase to the inducing gratings and of a lesser amplitude than the inducing gratings. In Fig. 1(b), the vertical grating below the test patch has been shifted an eighth of a cycle to the left relative to the grating on top. Now the induced percept is that of a tilted grating. The tilt of the induced grating is more pronounced when the inducing gratings are a quarter of a cycle out of phase as in Fig. 1(c). In each of these cases the orientation of the induced grating depends not on the orientation of the inducing gratings, but on the relative phase*. When the two inducing gratings are in counter-phase (Fig. 1d), the test patch is perceived as locally induced light and dark patches on the edges of the test field and not as a faint grating. It is possible that these locally induced patches are combined to give the appearance of a grating in some conditions (1a–c), but not in others (1d). Similar percepts are demonstrated for inducing gratings of a lower spatial frequency in Fig. 2(a–d). The induced percept is that of a vertical grating in Fig. 2(a) and of tilted gratings in Fig. 2(b) and (c). When the two inducing gratings are in counter-phase as in Fig. 2(d), the test field is perceived as light and dark patches. A noteworthy aspect of the induced gratings is that the perceived orientation seems to follow a minimizing principle. In Figs 1 and 2, a shift of the bottom grating in one direction by some fraction of a cycle, is equivalent to a shift in the opposite direction by one minus that fraction of a cycle. The orientation of the induced grating always corresponds to the smaller of the two phase-shifts, which in these displays corresponds to the smaller deviation from the vertical. The percept is consistent with a process by which locally induced light and dark patches are perceptually combined with the nearest like patches.

SPATIAL FREQUENCY OF INDUCED GRATINGS

The method used in the previous section was extended to create stimuli that demonstrate that the perceived spatial frequency of the induced grating is independent of the spatial frequency of the inducing grating. In Fig. 3(a–d), by adjusting the orientation and phase appropriately, gratings of four different spatial frequencies are shown to induce vertical gratings of identical spatial frequency. In Fig. 3(a) two vertically oriented gratings flank a uniform test field. The test field is perceived as a vertical grating with the same spatial frequency as the inducing gratings in counter-phase to the inducing gratings. In Fig. 3(b), the inducing gratings are of higher spatial frequency than in Fig. 3(a), their elevation is 60° to the horizontal, and their phases are shifted relative to one another. The induced grating in the horizontal test patch, however, is vertical. The induced grating in Fig. 3(b) has the same number of cycles as the induced grating in Fig. 3(a). Simple visual inspection is not sufficient to estimate the harmonic components of spatial modulation, however it is evident that the fundamental frequency of modulation is equal in the two figures. In Fig. 3(c) and (d) the elevations of the inducing gratings are 45 and 30° to the horizontal respectively. The spatial frequency of the inducing gratings has been increased as the elevation has been decreased. Note that the spatial frequency of the inducing gratings in Fig. 3(d) is twice that in Fig. 3(a). In all four parts of Fig. 3, the induced gratings are of identical fundamental frequency and orientation demonstrating that the orientation and spatial frequency of the induced grating may differ markedly from the orientation and spatial frequency of the inducing stimuli. Further, it is obvious, that any of the four inducing gratings from the top portion of these four figures could be paired with any of the four inducing gratings from the bottom portion of these figures, to induce a vertical grating of the same fundamental frequency as the induced gratings in Fig. 3. Though the inducing stimuli in Fig. 3(a–d) vary

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*The term orientation has been used to be consistent with published reports. However, as an editor has pointed out, it may not be appropriate to apply the word orientation to a thin induced grating—there is a change in the induced percept, and the change is consistent with a change in orientation of an occluded grating.

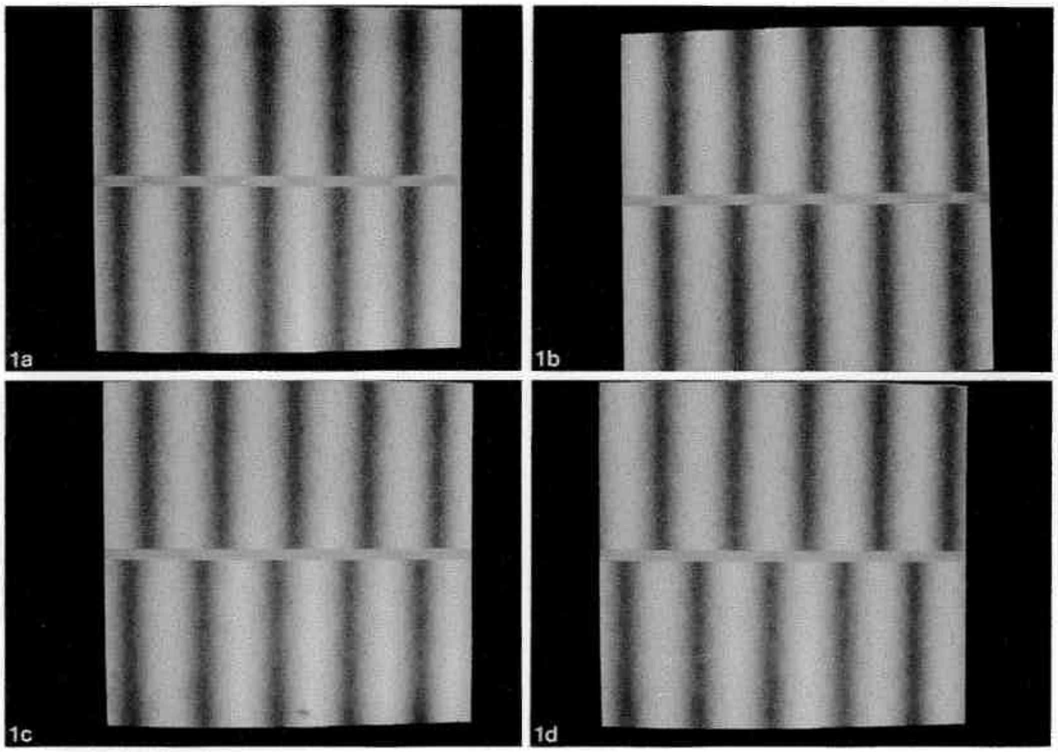

Fig. 1. Displays showing sinusoidal grating induction in the central homogeneous test field. The orientation of the induced grating depends on the phase of the inducing grating above the test field relative to the phase of the grating below the test field. The relative shifts are (a) 0.0 cycles (in-phase), (b) 0.125 cycles, (c) 0.25 cycles, (d) 0.5 cycles (counter-phase). In (d) the induced percept consists of light and dark patches. Note: mask inducing gratings to see actual homogeneity of test patch.

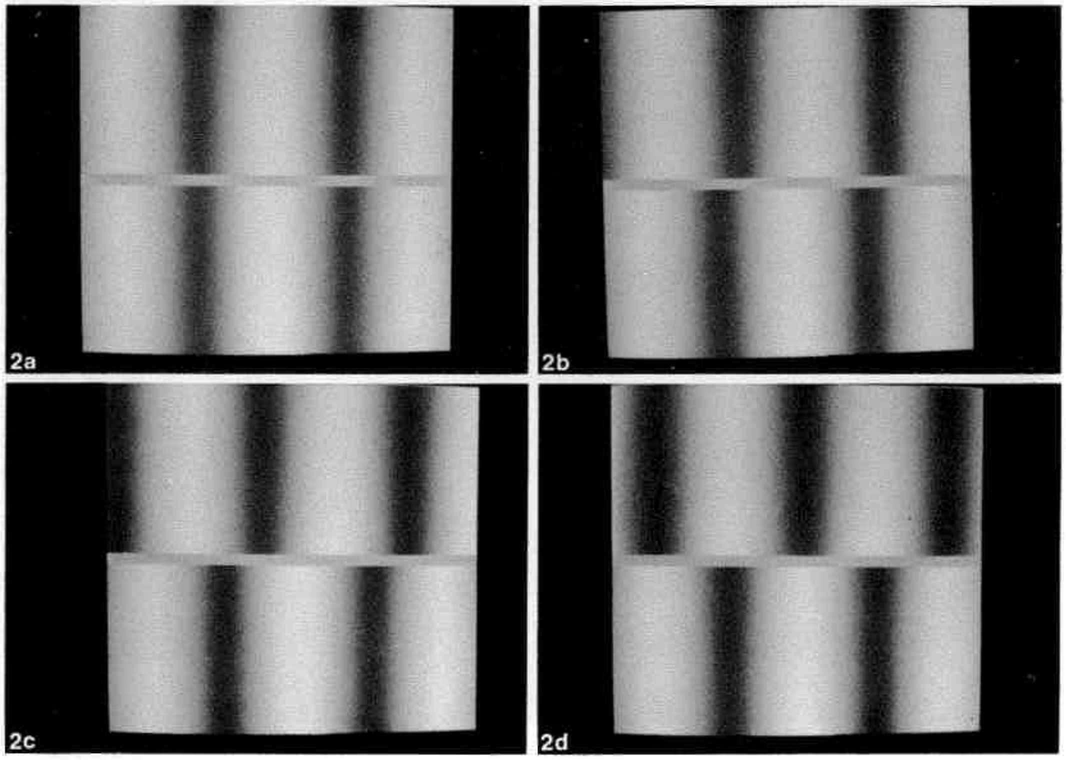

Fig. 2. Displays showing similar effects as Fig. 1 for sinusoidal gratings of a lower spatial frequency.

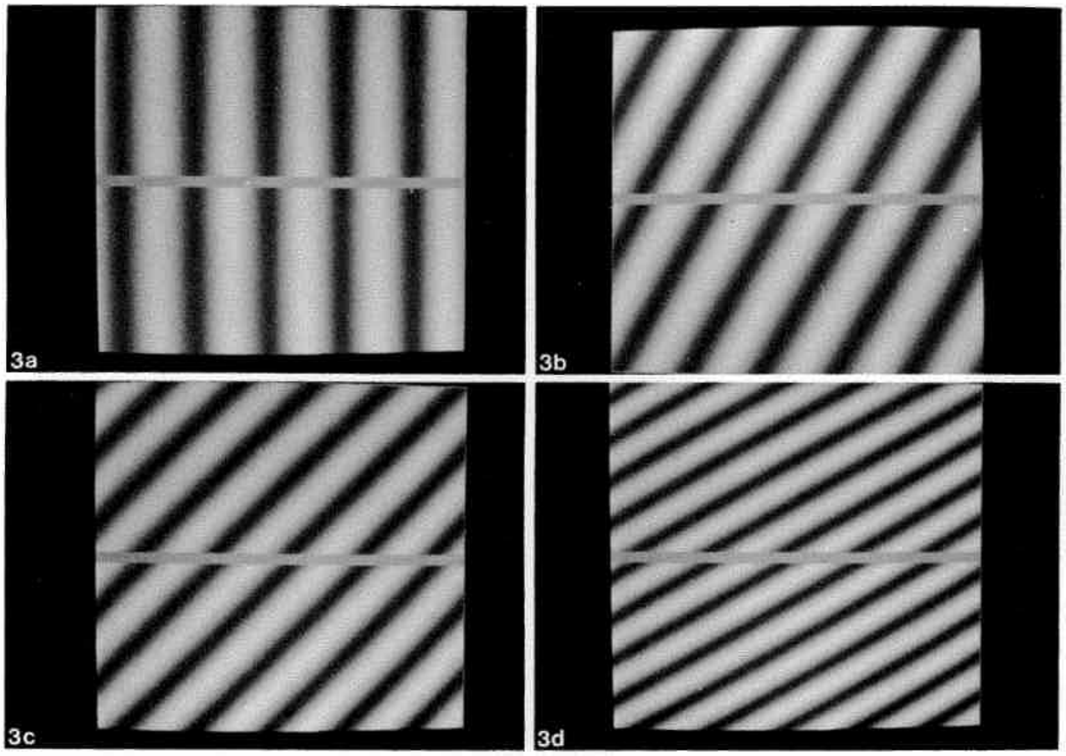

Fig. 3. Displays showing induced gratings with the same orientation and spatial frequency in (a–d). The inducing gratings have orientations of (a) 90°, (b) 60°, (c) 45° and (d) 30°. The spatial frequency of the inducing gratings increases from (a) to (d).

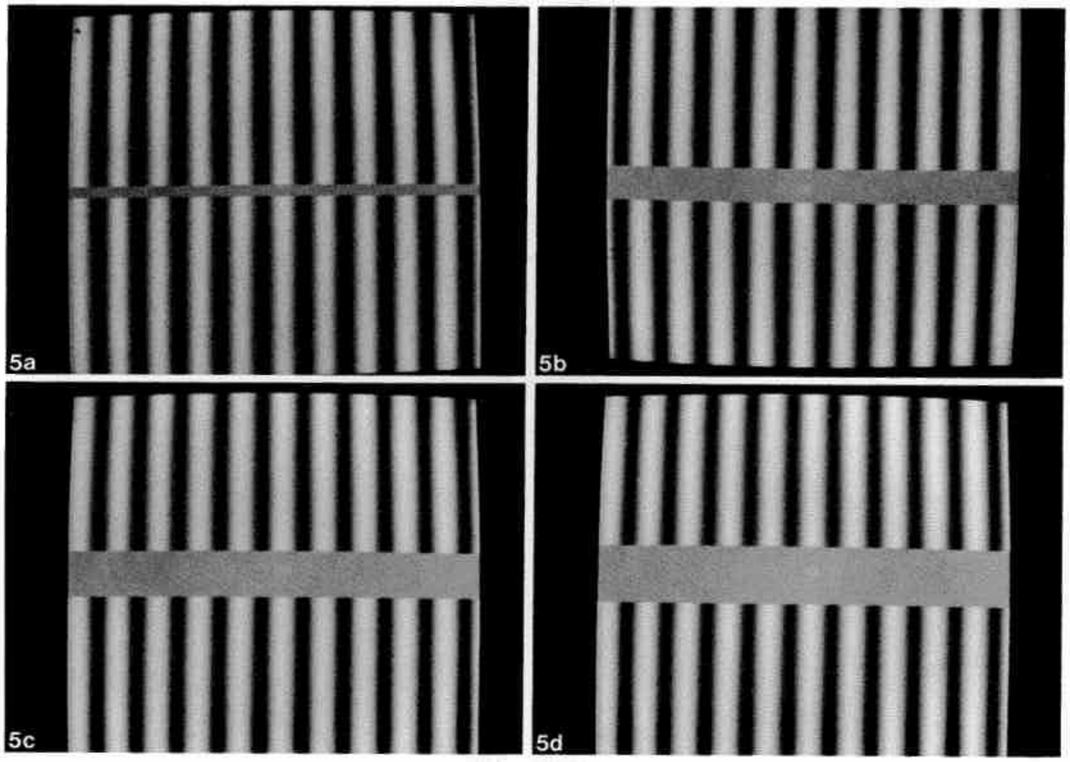

Fig. 5. Displays showing identical inducing stimuli and test fields of different heights. The induced grating is cohesive in (a), fainter in (b) and patchy in (c) and (d).

considerably, they were designed so that the row of pixels directly above the test field is identical in all four figures, as is the row directly below the test field. These local identities lead to the similarity in the induced percept, demonstrating the primacy of proximal elements of the surround in visual grating induction.

THE ROLE OF DISTAL PARTS OF THE INDUCING STIMULUS

Local factors, however, are not the sole determinant of the induced percept, as shown by the following experimental results. Stimuli similar in appearance to Fig. 3, designed to induce vertical gratings of one spatial frequency, were displayed on a Tektronix 690SR monitor, run at 120 Hz, controlled by an Adage frame buffer generator. Experiments were run with two sets of stimuli. In the first set the perceived fundamental frequency of the induced grating was 1.0 c/deg and in the second 0.5 c/deg. The inducing gratings had elevations of 90, 60, 45 and 30°. The spatial frequency of the inducing gratings was set equal to the required spatial frequency of the induced grating divided by the sine of the elevation angle of the inducing gratings. The phase of the bottom grating was shifted relative to the top grating by a distance equal to the height of the test field divided by the tangent of the elevation angle. This method ensured that the spatial frequency in the horizontal direction of the row of pixels immediately above and the row immediately below the test was equal to the required spatial frequency of the induced grating, and that the two rows were in-phase along a vertical axis. The average luminance of both the test and inducing fields was 90 cd/m^2 and the Michelson contrast of all inducing gratings was 0.7. The complete display was 9 by 10 deg of visual angle and the height of the test field was 0.3 deg. The amplitude of induced modulation was measured by a nulling method similar to the one used by McCourt (1982). When a real modulation was introduced in the test field, the perceived modulation was the sum of the real and induced modulations. The observer used buttons to increase or decrease the amplitude of the real sinusoidal modulation in the test field to minimize the perceived modulation in the test field. The real modulation in the test had the same fundamental frequency and orientation as the induced grating, and was in counter-phase to it. In physical specifications, the real modulation in the test had a spatial frequency of 1.0 c/deg for the first set of stimuli and of 0.5 c/deg for the second set, the orientation was vertical, and the phase was identical with that of the row of pixels immediately above and below the test. Within a set of stimuli, different surround orientations were presented randomly. For each determination of the nulling modulation, the initial amount of real modulation was set randomly. There were no clues to the amount of real modulation except for the perceived modulation of the test. Two observers participated in the experiment with similar results. Both observers were able to cancel the induced modulation with the supplied real modulation. At the null point no residual periodic pattern could be perceived, indicating the absence of any induced harmonics other than the fundamental. The amplitude of the nulling modulation as a fraction of the amplitude of the inducing modulation is plotted versus the elevation of the inducing grating in Fig. 4. The amplitude of the induced modulation increases with the elevation of the inducing gratings. This fact is also observable in Fig. 3(a–d). The magnitude of the increase suggests that a large component of the induction mechanism operates at some distance from the edge. This increase in the induced amplitude is qualitatively similar to the combined effect of multiple surrounding annuli on a central test field (Zaidi & Krauskopf, 1987). Nonlocal factors are also responsible for the

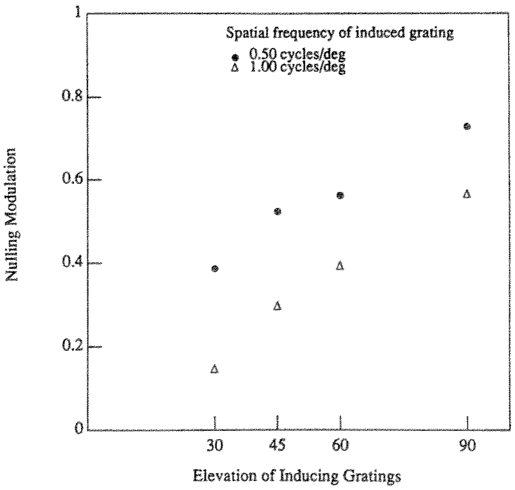

Fig. 4. Results of a nulling experiment for grating induction for observer AS. The amplitude of the nulling modulation as a fraction of the inducing modulation is plotted vs the elevation from the horizontal of the inducing gratings for displays similar to Fig. 3. The nulling modulation required was always vertically oriented with a spatial frequency equal to 1.0 c/deg in one set and 0.5 c/deg in the other. Each point is the mean of 10 determinations.

increase in the induced amplitude as the height of the inducing grating is increased (Foley & McCourt, 1985), or as the size of the surround is increased in a simple center-surround arrangement (Krauskopf & Zaidi, 1986). Distal elements of the surround, therefore, influence the amplitude of induced modulation, but not its perceived orientation or frequency.

INDUCED GRATINGS VS CLASSICAL INDUCTION

There are two striking phenomenal aspects of classical induction. First, the appearance of colors is influenced by other colors in the field of view, and second, within a patch, there is a filling-in process that gives the patch a relatively uniform appearance. On the other hand, in grating induction, the uniform test patch appears modulated in space. There is, however, an interesting parallel to the filling-in process: in some conditions the test field appears as a grating, in others it appears as light and dark patches. Figure 5(a–d) display identical inducing gratings and homogeneous test fields that increase in height from (a) to (d). The test field in Fig. 5(a) appears as a cohesive grating, and as a fainter cohesive grating in Fig. 5(b). In Fig. 5(c) a low contrast grating may be perceived in the test area. In addition, prominent light and dark patches at the edges of the test are also evident. The change in contrast from the edges to the center of the test is particularly noticeable in the induced light sections. In Fig. 5(d), the locally induced patches are the most prominent aspect of the induced percept. This set of figures seems to demonstrate that locally induced contrast is combined into a cohesive grating percept when a small visual angle separates identical phases of the top and bottom inducing gratings, but not when the separating visual angle is large. However, a comparison of Fig. 1(a–d) vs Fig. 2(a–d) shows that the separating visual angle is not the only factor in this process. For example, a cohesive grating is induced in Fig. 2(c) but not in Fig. 1(d), even though a larger visual angle separates identical phases of the top and bottom inducing gratings in Fig. 2(c).

Spatial models of classical induction describe the effect of the surround on the test as a function of the amount of change in contrast at each element of the surround and the distance of that element from the center of the test. It is implicitly assumed that the induced appearance of the test field is uniform, so that the effect of induction can be described by a single variable (Yund & Armington, 1975). The induced percepts presented in Figs 1–3 make it clear that models of induction should consider the elemental structure of the test as well. It would be premature to propose a model on the basis of existing data, however, the patchiness versus the cohesiveness of induction may be used to rule out one class of possible underlying neural mechanisms. Foley and McCourt (1985) have proposed that elongated filters with narrow centers, oriented parallel to the inducing grating can account for several properties of induced gratings. Explanations of visual percepts in terms of receptive fields of neurons seem invitingly concrete and simple. However, the link between a percept and the filtering action of a receptive field invariably depends on a number of psychophysical linking hypotheses and auxilliary assumptions that cannot be independently justified. The images shown in Figs 1 and 2 were convolved with the proposed elongated filters. The convolution with Figs 1(a) and 2(a) produced vertical gratings in the test field, replicating the results of Foley and McCourt. The convolution with the stimuli in Figs 1(b, c) and 2(b, c), however, did not produce cohesive gratings in the test field. Therefore, such elongated filters are probably not the correct underlying mechanisms for visual grating induction even if the linking hypotheses implicitly assumed by Foley and McCourt (1985) are valid.

CONCLUSION

The demonstrations in this paper show, that contrary to previous assertions made on the basis of a more limited class of stimuli (McCourt, 1982), the spatial frequency and orientation of the induced grating does not have to be the same as the spatial frequency and orientation of the inducing field. Grating induction is probably another case of classical induction. Both local and distal factors of classical induction (Zaidi & Krauskopf, 1987) change the appearance of the test field. The present investigation of grating induction has revealed two new results about the role that different parts of the inducing stimulus play in simultaneous induction. The parts of the inducing stimuli that are proximal to the test field determine the spatial frequency and orientation, i.e. the shape of the induced percept. The parts of the inducing stimuli that are distal to the test field influence only the amplitude of the induced modulation. The appearance of cohesive gratings seems to be a counterpart to the filling-in process of classical induction and may be a profitable topic for further investigation.

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