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GRATING INDUCTION: A NEW TYPE OF AFTEREFFECT*

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Abstract—After adaptation to a spatiotemporal counterphase flickering grating, a fine grating of the same orientation may be perceived in a uniform blank field. The spatial frequency of the induced grating remains approximately constant at about 18 c/deg regardless of the spatial frequency of the adapting spatiotemporal grating. It does not exhibit interocular transfer. The induced grating is not produced by contingent aftereffects, spatial frequency doubling, retinal afterimages, spatial frequency inhibition, Fourier harmonics or any other known type of aftereffect. It therefore represents a new class of aftereffect in the human visual system, suggesting unsuspected neuronal interactions in monocular pathways.

INTRODUCTION

The purpose of this paper is to introduce a new class of visual aftereffect in which the characteristics of the aftereffect (other than its strength) are essentially independent of many of the characteristics of the adapting stimulus. The aftereffect we observed is obtained by adapting to a spatiotemporal counterphase grating for a period of about 1 min. On observing a homogeneous blank field, a fine static grating is perceived with a frequency of about 18 c/deg and the same orientation as the adapting counterphase grating (Fig. 1). Some irregularity in the orthogonal direction is observed, so the fine grating appears in patches. It is absent or much reduced in the central 2–3° of the retina. This aftereffect has been spontaneously observed by each of six observers, and was the subject of a preliminary report (Tyler and Nakayama, 1976).

The remainder of this paper is devoted to exploring the characteristics of this aftereffect, which will be called grating induction since the aftereffect takes the form of a grating induced in the blank field. We feel that it establishes a new class of visual aftereffect because it does not accord with the characteristics of previously known aftereffects: (a) No afterimage is formed by the counterphase grating; (b) the occurrence of a strong perceived aftereffect removes it from the class of mere sensitivity reductions, such as the spatial frequency adaptation of Blakemore and Campbell (1969); (c) there is no reciprocity between the inducing and induced grating, as described in the results and discussion section below; (d) it cannot be classified as normalization because the induced grating appears on a blank field, rather than in the adaptation stimulus and finally (e) it is not contingent on the presence of an attribute of the counterphase grating in the test field, such as its flicker rate or spatial frequency, and is therefore not a contingent aftereffect.

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METHODS

Experimental

An experiment was performed to measure the spatial frequency and contrast of the induced grating as a function of spatial frequency of the adapting counterphase grating. Spatial frequency and contrast were measured by matching the induced grating to a comparison grating of variable spatial frequency and contrast.

The stimuli were produced by function generators controlling the luminance profile on two cathode ray oscilloscopes (CRO) with P31 phosphors, separated by a 2 cm gap. The lower CRO displayed the counterphase grating with a contrast of 0.8, a temporal frequency of 8 or 16 Hz and spatial frequency variable from 0.1 to 20 c/deg. The comparison grating was shown on the upper CRO having variable contrast with a fixed spatial frequency of 2 c/deg. Both screens had an average luminance of 50 cd/m^2 and an angular subtense of 8 × 10° at 114 cm viewing distance.

The counterphase grating was initially presented for six consecutive 10 sec epochs to optimize grating induction. Then a test period of 1 sec followed, during which the counterphase grating was replaced by a blank screen, and the comparison static grating was presented on the upper CRO. The comparison grating was matched in frequency to the induced grating, with the aftereffect being refreshed in further 10 sec epochs until the observer was satisfied with the match. Then a similar procedure was repeated for matching the induced grating contrast.

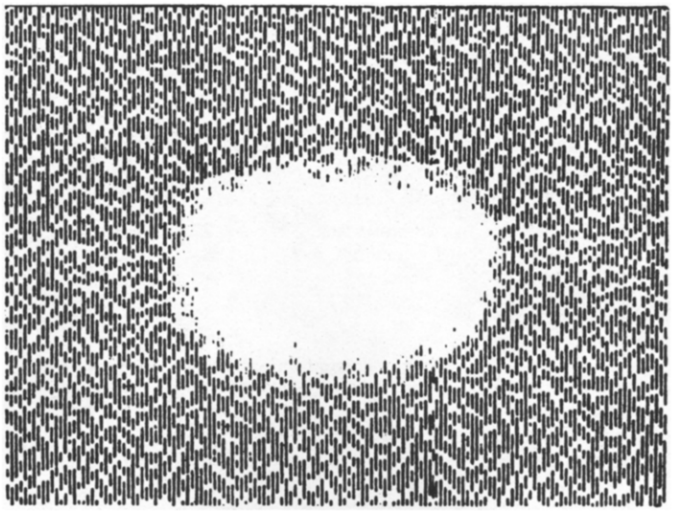

Fig. 1. Depiction of the perceived grating induced by adaptation to a medium spatial frequency counterphase grating. No grating is induced in the central 2–3° of the retina.

The display was viewed binocularly in the dark with natural pupils. The observer was instructed to fixate between the two screens during adaptation and testing. The induced grating faded slightly during the 1 sec test period, so the observer was instructed to make the contrast match to the mean during the 1 sec period. Each point on the graphs is the mean of two readings, with mean standard errors of ± 0.06 dB for the frequency matches and ± 0.09 dB for the contrast matches.

Control for afterimages

The induced grating should not be related to any retinotopic afterimage, because the time-average luminance of the counterphase adapting grating is spatially invariant. Therefore no afterimage should be produced. Even if the *off*-transient of the counterphase grating had produced a small afterimage (and none was observed during the experiment), the adapting grating profile was sinusoidal, and hence contained no components at the high spatial frequency of the induced grating.

As a control, the spatial frequency of the afterimage from fixation on a static grating was measured by the matching procedure for two observers. The results (solid circles, Fig. 2) show that the matching procedure is veridical within the range of experimental error (continuous line).

RESULTS

Frequency-independence of the induced grating

The circled points in Fig. 2 show the estimated spatial frequency of the induced grating as a function of the spatial frequency of the adapting 8 Hz counter-

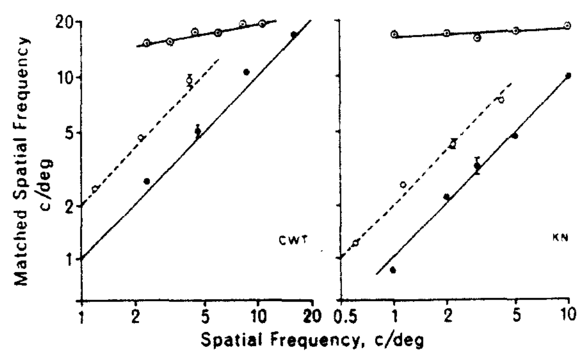

Fig. 2. Circled points—Matched spatial frequency of the induced grating as a function of spatial frequency of the adapting grating. Note that the matched spatial frequency is essentially independent of adapting spatial frequency.

Solid circles—Matched spatial frequency of the retinotopic afterimage of a static grating. The points fall close to the linear function indicating a one-to-one correspondence, as should be expected.

Open circles—Matched spatial frequency for the perceived spatial frequency doubling of a 16 Hz counterphase grating. The points fall close to the linear function indicating a two-to-one ratio between matched spatial frequency and the basic spatial frequency of the counterphase grating.

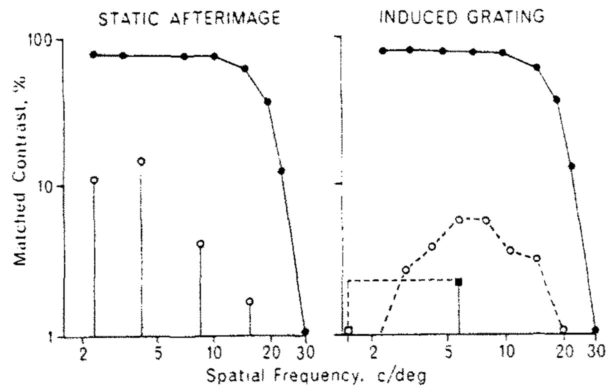

Fig. 3. Matched contrast of the grating as a function of adapting spatial frequency in the case of retinotopic afterimages and induced gratings, for observer CWT.

Left-hand graph—Solid circles show the matched contrast of a 2 c/deg grating to the perceived contrast of the static grating itself at each spatial frequency. Open circles show matched contrast for retinotopic afterimages of static gratings, plotted at the spatial frequency of adaptation.

Right-hand graph—Solid circles duplicate envelope of maximum contrast. The open circle, dashed line function shows the matched contrast of the induced gratings as a function of the spatial frequency of the *adapting* counterphase grating. Note that adapting spatial frequencies around 5 c/deg are most effective in grating induction. The single solid square on a stalk shows the matched contrast of the grating induced by the third harmonic of a square wave when presented alone. The open square on the abscissa indicates that when the same third harmonic is present in a high contrast square wave with a spatial frequency of 1.8 c/deg, no grating was induced (see text).

phase grating for two observers. The standard error of the readings is within the size of the symbols. It is clear that the frequency of the induced grating remains essentially constant at about 18 c/deg, regardless of the adapting spatial frequency, since the maximum variation is 0.1 log unit over a 0.7–1.0 log unit variation of inducing frequency.

Figure 3 compares the matched contrast of the induced grating with the matched contrast of a static grating and its static afterimage. The solid circles in sinusoidal grating of 0.8 objective contrast with a comparison grating of a fixed spatial frequency of 2 c/deg. This function gives the upper envelope of possible contrast that can be obtained with our apparatus.

We next measured the perceived contrast of the afterimage as a function of spatial frequency. The afterimage was produced by fixating on static gratings of various spatial frequencies with physical contrast of 0.8 for the 10 second epochs. The open circles in Fig. 3 (left-hand panel) show the matched contrast of the afterimage across spatial frequency. It falls at between 10 and 20% of the adapting contrast at all spatial frequencies.

For measurement of the contrast of the induced grating effect the adapting field was flickered in counterphase at 8 Hz. The matched contrast of induced grating for one observer (CWT) is shown in the right-hand panel of Fig. 3 (open circles, broken line) as a function of *adapting* spatial frequency. (The spatial frequency of the induced grating was always close to 18 c/deg; see Fig. 2.) These data show that the peak adapting frequency was about 5 c/deg and that the matched contrast is comparable with that of the static afterimage above this peak frequency.

DISCUSSION

The important aspect of these demonstrations is that they exhibit no tendency towards reciprocity between the adapting and induced spatial frequencies. In addition, the aftereffect has a different dimensionality than its precondition, in that the adapting stimulus is time varying, whereas the induced grating appears static. This begs analogy with some structural features, such as Maxwell's spot (1856) in the color domain, or perhaps more appropriately with the tinnitus of the ear perceived when blood pressure is raised.

Relationship to spatial frequency doubling

If a counterphase grating is modulated at a high temporal frequency, it can appear to have twice the spatial frequency of the sinusoidal contrast profile from which it is generated (Kelly, 1966; Tyler, 1974). Since the occurrence of this frequency doubling is dependent on the underlying spatial frequency (Richards and Felton, 1973), it is important to establish whether spatial-frequency doubling bears any relationship to the induced grating which we are describing.

The perceived frequency of the adapting stimulus was therefore matched by the static comparison grating as a function of spatial frequency by the two observers. Very little doubling was noted at the adapting frequency of 8 Hz, so the frequency was increased to 16 Hz to maximize doubling (although negligible grating induction was observed at this frequency). The data are shown in Fig. 2 (open circles). The broken line delineates the expected doubling of frequency, which provides a good fit to the data up to

5 c/deg. Beyond this point, the perceived spatial frequency of the counterphase grating approaches its underlying frequency (full line).

These data establish that the induced grating is not connected with spatial-frequency doubling for two reasons:

(a) The induced grating is strong when the adapting counterphase grating is modulated at 8 Hz and negligible at 16 Hz, whereas spatial-frequency doubling is negligible at 8 Hz and strong at 16 Hz.

(b) Against the possibility that the induced grating is some higher multiple of the adapting frequency, the doubled frequency of the counterphase grating shows a strong dependence on the underlying spatial frequency, whereas the induced grating does not.

Relationship to Fourier analysis

There is evidence (Blakemore and Campbell, 1969) that the human visual system contains mechanisms sensitive to band-limited ranges of spatial frequency. We therefore wished to test whether the grating aftereffect would be induced by the higher harmonics of a rectangular wave when its fundamental frequency was low enough to be out of the effective range for grating induction.

The adapting stimulus was a counterphase grating of rectangular contrast variations at 8 Hz. It was set at 1.8 c/deg so that its third harmonic would be at the optimal frequency for grating induction (5.5 c/deg). Presentation of this stimulus for 1 min of adaptation produced no report of an induced grating from either observer (open square in Fig. 3).

However, the contrast of the third harmonic is 1/3 that of the fundamental. Therefore, as a control, we measured the induced grating strength for a sinusoid counterphase grating of 5.5 c/deg, but a contrast of 0.27. A healthy grating was induced, as indicated by the matched contrast (solid square in Fig. 3).

These experiments show that a sinusoid alone can induce a grating, but that when it is present as the third harmonic of a rectangular counterphase, grating induction does not occur. This result poses difficulties for a theory of the mechanism that produces the induced grating based on independent band-limited spatial frequency channels.

Relationship to retinal eccentricity

The initial experiments were conducted with a field subtending 8 × 10°. We frequently observed that the induced grating had a hole in the middle, i.e. no grating was induced in the macular region. Subsequently, observations with a circular field of 2° diameter and a full range of spatial frequencies confirmed that it was very difficult to induce a grating in the foveal region alone. Grating induction would therefore appear to be essentially a peripheral phenomenon, even though the induced grating is of a rather high spatial frequency.

Interocular transfer

One important feature to establish for any new aftereffect is the degree to which it shows interocular transfer. Accordingly, we performed the experiment of adapting to the counterphase grating viewed with one eye and testing for the induced grating on viewing the blank field with the other eye. No grating induction was observed under these conditions by either observer. Although there may be some residual effect measurable by sophisticated threshold techniques, the salient point is that the strength of the induced grating is reduced by at least an order of magnitude in the interocular transfer condition.

It is well known that many aftereffects involving gratings show strong interocular transfer in observers with normal binocular vision. Transfer of 50% or more has been shown with gratings for the tilt aftereffect (Campbell and Maffei, 1970), motion aftereffect (Mitchell *et al.*, 1974), spatial frequency shift (Blakemore and Sutton, 1974) and contrast adaptation (Blakemore and Campbell, 1969). It is reasonable to conclude that a large proportion of cells in the human visual system involved in the perception of gratings are strongly binocular.

It is therefore surprising to find negligible interocular transfer in the grating induction aftereffect. In this respect, it resembles the retinotopic afterimage and some contingent aftereffects, such as the McCollough effect of color contingent on grating orientation. Since no orientation specificity is known to exist at the level of the retinal or lateral geniculate nucleus, the induced grating aftereffect must be cortical, but restricted to the monocular pathways.

Relationship to "psychophysical hallucinations"

During the course of this study, Georgeson (1976) published a report of the observation of fine gratings after adaptation to a static grating of medium spatial frequency. He has termed the fine gratings "psychophysical hallucinations", but it is unclear whether these represent the same phenomena as our induced grating since they differ in the following particulars:

(a) Georgeson's gratings were described as being of a spatial frequency 1.5 octaves higher or lower than the variable adapting frequency, whereas ours have an almost constant spatial frequency of about 18 c/deg.

(b) Georgeson explained his effects in terms of inhibition between spatial frequency channels. This explanation is inconsistent with our data because there is no reciprocity between adapting and induced spatial frequency.

(c) Our induced grating is not produced by the normal adaptation channels because it shows no interocular transfer, whereas normal grating adaptation shows marked interocular transfer.

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