Stereoscopic Tilt and Size Aftereffects

Article *in* Perception · June 1975

DOI: 10.1068/p040187

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Perception, 1975, volume 4, pages 187-192

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Received 9 August 1974

Abstract. Adaptation to a random-dot stereograting with no monocularly visible contours produces a tilt aftereffect in a briefly-viewed test stereograting. The effect is maximal for adapting orientation at ±20–30° from the test orientation. Similarly, the perceived spatial frequency of a stereograting is altered by adaptation to a stereograting of adjacent spatial frequencies.

1 Introduction

It is possible to distinguish several levels of the human nervous system which may be selectively investigated by means of sensory adaptation. Adaptation at each level can be arranged so as to avoid simultaneous adaptation at lower levels but not usually at higher levels (with the exception of adaptation during the occlusion phase of binocular rivalry). An example of a hierarchy of levels of neural adaptation and the aftereffect produced is:

(i) adaptation to luminance (retinal afterimage);
(ii) adaptation to contrast with no correlated luminance adaptation (contrast aftereffects);
(iii) adaptation to depth with no correlated contrast or luminance adaptation (cyclopean depth aftereffect);
(iv) adaptation to cyclopean form with no correlated depth, contrast or luminance adaptation (hypercyclopean aftereffect).

It is the fourth class of aftereffect that is the subject of the present investigation. The term *hypercyclopean* aftereffect may seem a trifle unwieldy, but it is necessary to distinguish this high-level aftereffect from the cyclopean (depth) aftereffects established by Papert (1964) and Julesz (1971), which themselves needed to be distinguished from conventional depth aftereffects produced by monocularly visible stimuli (e.g. Köhler and Emery 1947). The nomenclature is chosen to echo the neural hierarchy described in monkey cortex by Hubel and Wiesel (1968).

An example of a hypercyclopean aftereffect is the stereograting tilt aftereffect. This is produced by exact analogy with the contrast grating tilt aftereffect (Campbell and Maffei 1971) and is demonstrated in the anaglyph shown in figure 1. The reader should adapt to the left-hand pair of stereogratings by scanning up and down near the centre of the left-hand pair of stereogratings, so as to eliminate any depth aftereffect. Since there are no monocular cues to the stereograting associated luminance or contrast effects are also absent. On fixating at the centre of the test gratings on the right of figure 1 a tilt may be observed in the opposite direction to the adapting tilts.

The hypercyclopean aftereffect may also be elicited by adaptation to contrast gratings again using the cyclopean stereogratings as a test figure. This is an interesting example of transfer from one modality of stimulation to another. Experiments were carried out to explore the limits of the hypercyclopean tilt aftereffect as a function of relative orientation of the adapting stereograting or contrast grating.

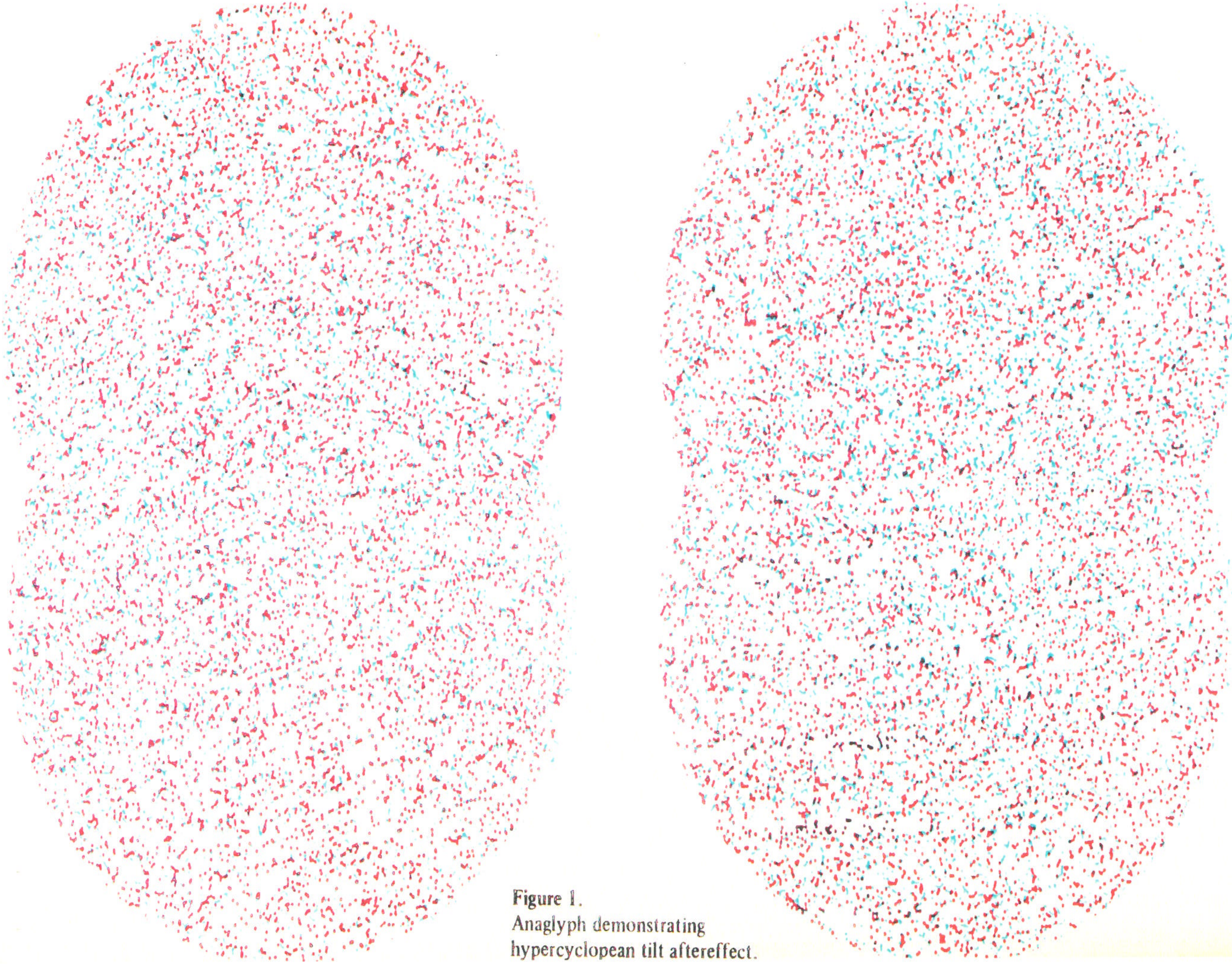

Figure 1.
Anaglyph demonstrating
hypercyclopean tilt aftereffect.

2 Method

The horizontal stereogratings were generated on a Calcomp plotter as described previously (Tyler and Raibert 1974). They were viewed stereoscopically at a distance of 50 cm. Each grating subtended 5 deg at the eye and had a spatial frequency of 1 cycle/deg. Horizontal reference lines were visible either side of the test grating. The tilt aftereffect was measured by the null method of adjustment under three experimental conditions.

(a) Hypercyclopean adaptation. For adaptation the stereograting was scanned orthogonally to the bars of the grating to prevent adaptation to depth.

(b) Cyclopean depth adaptation. A cyclopean depth aftereffect was produced by scanning the grating parallel to the bars.

(c) Contrast adaptation. A random-dot contrast grating of the same spatial frequency was produced by modulating the dot density instead of horizontal displacement. This grating was viewed binocularly and scanned orthogonally to the bars to produce a grating aftereffect. The tilt aftereffect was measured with the same stereograting as before, to study the transfer from contrast to cyclopean domains.

Adaptation procedure was the same for all conditions. After 30 s of adaptation the subject glanced at the test grating and made an adjustment. This was followed by a series of 10 s re-adaptations and test glances until the grating appeared horizontal. Four readings were taken for each data point.

3 Results

3.1 *Tilt aftereffect*

Orientation specificity of the hypercyclopean tilt aftereffect is shown in figure 2a for two observers. It is the same order of magnitude as the contrast grating tilt aftereffect measured at much higher spatial frequencies (Campbell and Maffei 1971). The peak effect occurs about 20–30° of adapting orientation, which is about three times the angle of that for the contrast gratings.

The tilt aftereffect from cyclopean depth adaptation and transfer from contrast adaptation (figure 2b) both have similar orientation specificity to the hypercyclopean aftereffect. Whereas the depth adaptation procedure results in little change in the magnitude of the aftereffect, transfer from the contrast grating is reduced by about 50%.

In figure 3a the mean of positive and negative tilt aftereffects for hypercyclopean (open circles) and cyclopean depth (filled circles) adaptation are replotted in terms of the percentage of adapting tilt for comparison with the threshold elevation data, using contrast gratings described by Blakemore and Nachmias (1971). The relative aftereffect is fitted empirically by a straight line with the equation

$$\Delta\theta = a - b\theta\,, \qquad \theta > 0\,,$$

where $\Delta\theta$ is the aftereffect of adaptation to a tilt of $\theta°$, and $a = 0{\cdot}17$ and $b = 0{\cdot}0037$ for the present conditions of adaptation. The half-bandwidth for the effect may be defined as half the value of the intercept of this equation with the abscissa when $\theta = 0$, i.e. $a/2b$, which under the present conditions is 24°. As a comparison, and to provide further justification for this procedure, figure 3b shows the interocular transfer tilt aftereffect for contrast gratings replotted from the graphical data of Campbell and Maffei (1971). This is the most central indication of tilt aftereffect prior to the present data, and it can be seen to fit the straight line function reasonably well with $a = 0{\cdot}55$ and $b = 0{\cdot}022$. The half-bandwidth by the above definition for these results is therefore 12·1°, which is about half the value for the hypercyclopean tilt aftereffect. This method of presentation also reveals that for small tilts the contrast aftereffect is a much higher proportion of adapting tilt than the hypercyclopean aftereffect, although the two showed a similar absolute magnitude of about 2°.

It is not clear whether this difference in orientation specificity is attributable to the rather coarse spatial resolution of the stereoscopic system (Tyler 1973; 1974), or whether it arises merely from some factor such as the difference in spatial frequencies used in the two experiments.

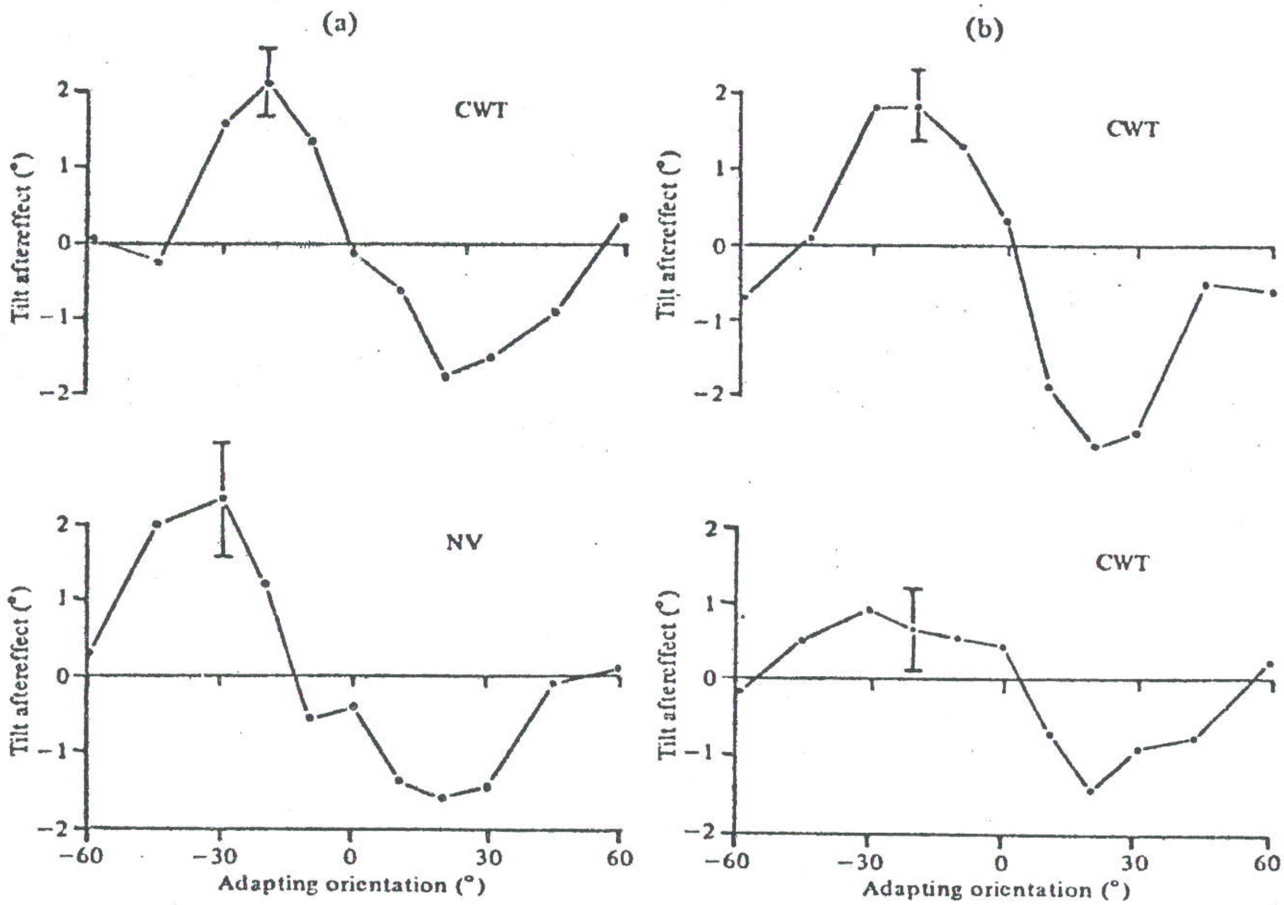

Figure 2. (a) Orientation of test grating required to null hypercyclopean tilt aftereffect as a function of adapting orientation for two observers, CWT and NV. (b) Null orientation as in (a) but for cyclopean tilt aftereffect (upper), and null orientation for transfer of tilt aftereffect from adapting contrast grating to test stereograting (lower); CWT.

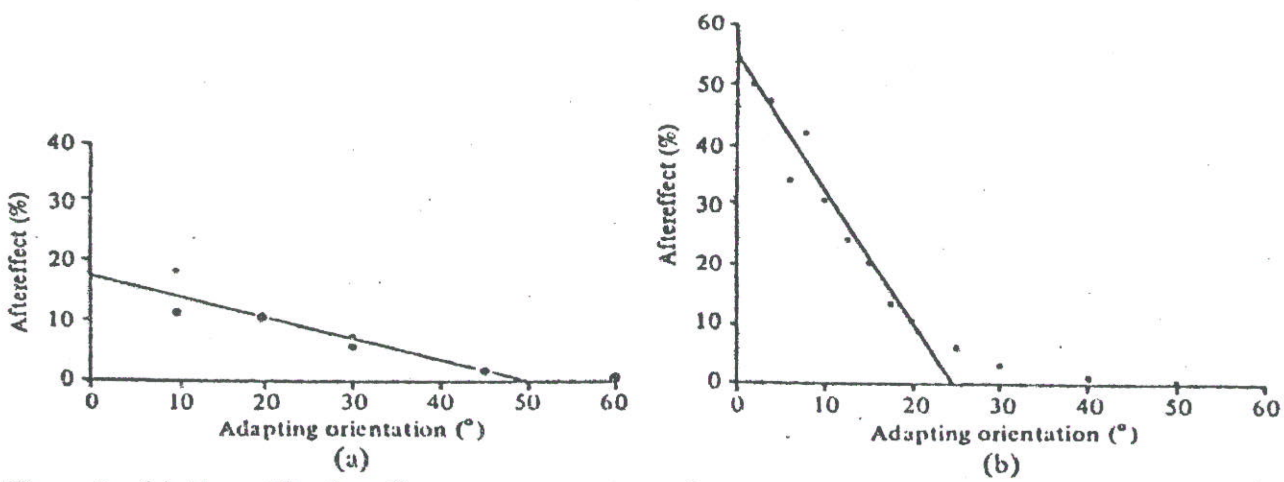

Figure 3. (a) Mean tilt aftereffects as a percentage of adapting orientation for hypercyclopean (open circles) and cyclopean (filled circles) depth adaptation, as a function of adapting orientation; subject CWT. (b) Interocular transfer of contrast grating tilt aftereffect replotted from Campbell and Maffei (1971, figure 3); the data are approximated well by a linear function (see text).

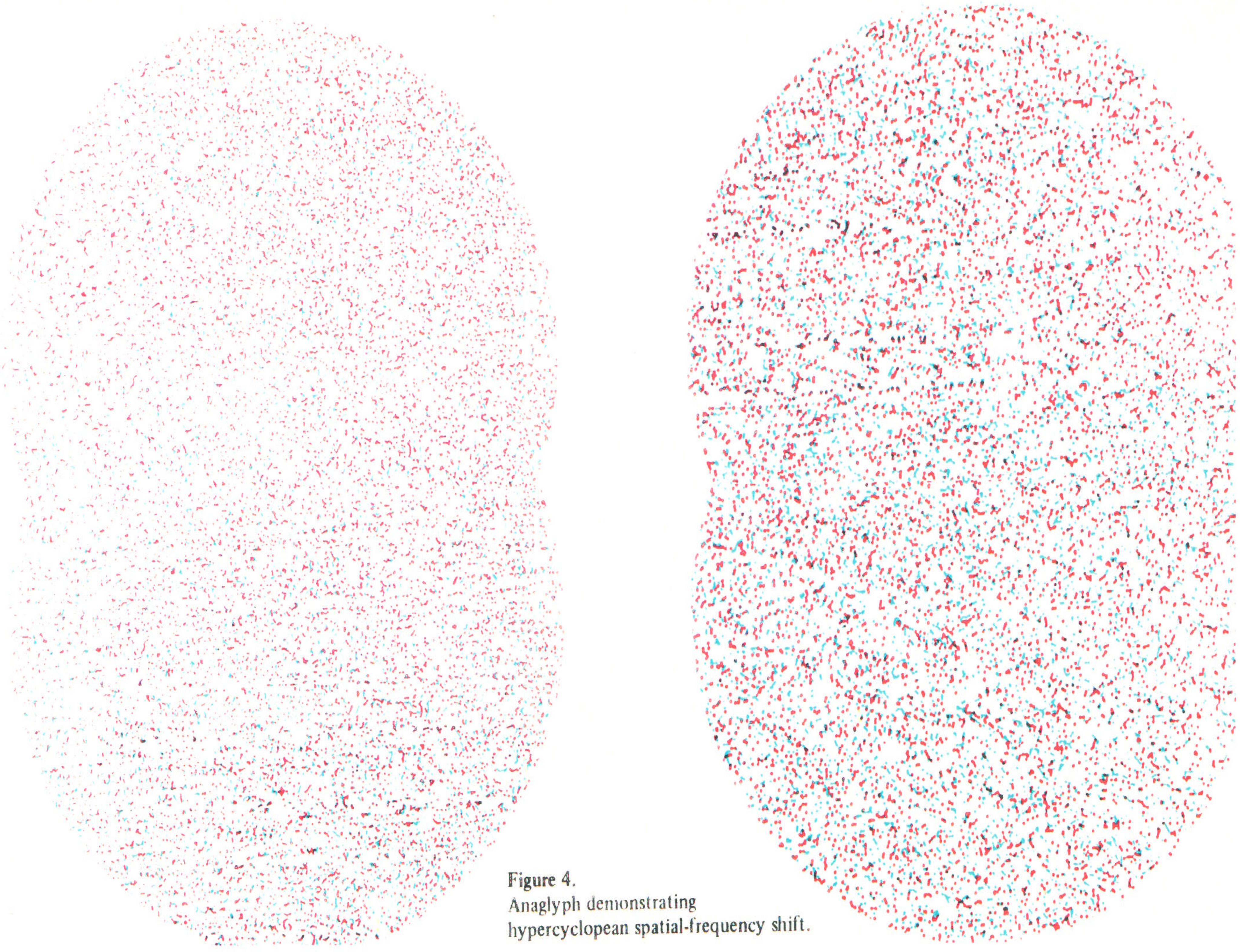

Figure 4.
Anaglyph demonstrating
hypercyclopean spatial-frequency shift.

3.2 *Size aftereffect*

For sinusoidal gratings an aftereffect of stimulus size is perceived as a shift in spatial frequency of the grating following adaptation to a slightly different spatial frequency (Blakemore and Sutton 1969). By analogy with the analysis of spatial-frequency shifts for contrast gratings (Blakemore et al 1970) the observation of a spatial-frequency shift in any modality may be taken to imply the existence of size-tuned channels in the neural processing of that modality. In particular, a spatial-frequency shift following hypercyclopean adaptation to stereogratings is evidence for channels tuned to stimulus size at the hypercyclopean level of processing, independently of any size tuning prior to that level.

The anaglyph in figure 4 demonstrates the existence of a hypercyclopean spatial-frequency shift. It should be viewed in a similar manner to the anaglyph in figure 1. After one minute of adaptation to the upper stereogratings by scanning the bar, the centre stereogratings will appear different in spatial frequency or bar width, although they are physically the same. The spatial-frequency shift is not obtained after adaptation to the similar adapting gratings but with a tilt of 45° from the test gratings (bottom of anaglyph in figure 4). The hypercyclopean size aftereffect is therefore also tuned for orientation.

4 Discussion

The experiments described here suggest that visual processing at the hypercyclopean level involves feature-selective channels tuned for both size and orientation of stimulus elements. Transfer of the aftereffect from contrast gratings indicates that these channels are also sensitive to spatial frequency of contrast, but the fact that the transfer is incomplete shows that the same mechanism is not responsible for both aftereffects, even though the two mechanisms may have similar characteristics.

Acknowledgements. This work was supported by Science Research Council grant B/SR/4836. My thanks to Nicolette Vincent for acting as an observer.

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