

Observations on binocular spatial frequency reduction in random noise

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Abstract. Binocular spatial frequency reduction for random visual noise stimuli is contrasted with MacKay's (1964) homogenisation effect. Several observations lead to suggestions about the anatomical sites of these two perceptual effects.

1 Introduction

Random noise signals are useful in analysing unknown systems, because the system response may be derived from the ratio between the input spectrum and the output spectrum. In the study of the human visual system the output is the perception of the input stimulus. The perception of which observers are conscious and which they report is not measurable directly, but it is possible to obtain some information about this output by requesting a simple judgment to be made. In this paper the judgement required was of the mean perceived spatial frequency present in the display. The stimuli used were two-dimensional visual noise displays (Julesz 1962; MacKay 1957). All the observations described here were reported by at least four observers, naive to the purpose of the study, in response to neutral questions about the stimulus. An example of such a neutral question is "Does the noise look denser in one condition than the other or does it look the same density in both conditions?". Most of the observations may be verified directly by the reader.

2 Binocular frequency reduction

The present observations are designed to obtain some information on the spatio-temporal characteristics of binocular disparity units. The apparatus consisted initially of a detuned television receiver. This apparatus produces wide-band spatial frequency noise continually changing in time, at least 25 times per second. Although precise measurement of apparent bandwidth of such a complex stimulus is difficult psychophysically, rough estimates of pronounced changes may be made. A comparison of monocular and binocular perception of the stimulus has been noted by MacKay (1961) and is relevant to the present study. The average spatial dimensions of the noise elements in binocular view appeared approximately twice as large, or half the spatial frequency, as they appeared in monocular perception. MacKay also reported that, in addition, the mean binocular temporal frequency is about half that in monocular perception, to a first approximation. The rest of this paper reports a series of observations which help to pin down the anatomical location of these and related phenomena.

It is possible that such effects result from some complex spatio-temporal interaction, rather than being simple properties of binocular versus monocular perception. An example of such a complex interaction is the possibility that the dynamic noise changes so quickly that dots from overlapping frames stimulate detectors of disparities other than at the plane of the screen. The activated disparity detectors might then interact to produce spatial and temporal frequency changes. A simple demonstration that the frequency alterations are not produced by such factors is made by observations of static rather than dynamic visual noise (figure 1).

If one eye is alternately covered and uncovered while the other views the figure continuously at 1 m, there appear to be more dots, which are also more closely spaced, in the monocular condition than in the binocular condition. The effect occurs if the fixation position is continually changed. Of course, careful examination of a particular dot cluster can verify that the same number of dots is present, but the clear impression of a greater density of dots in the monocular condition is hard to avoid. Thus static visual noise does not conform to Fechner's paradox in which a uniform field seen with two eyes appears the same as with one eye. There is a further paradox, however, since when twice as many dots are presented to the visual system (in binocular view) fewer are perceived than in the monocular condition.

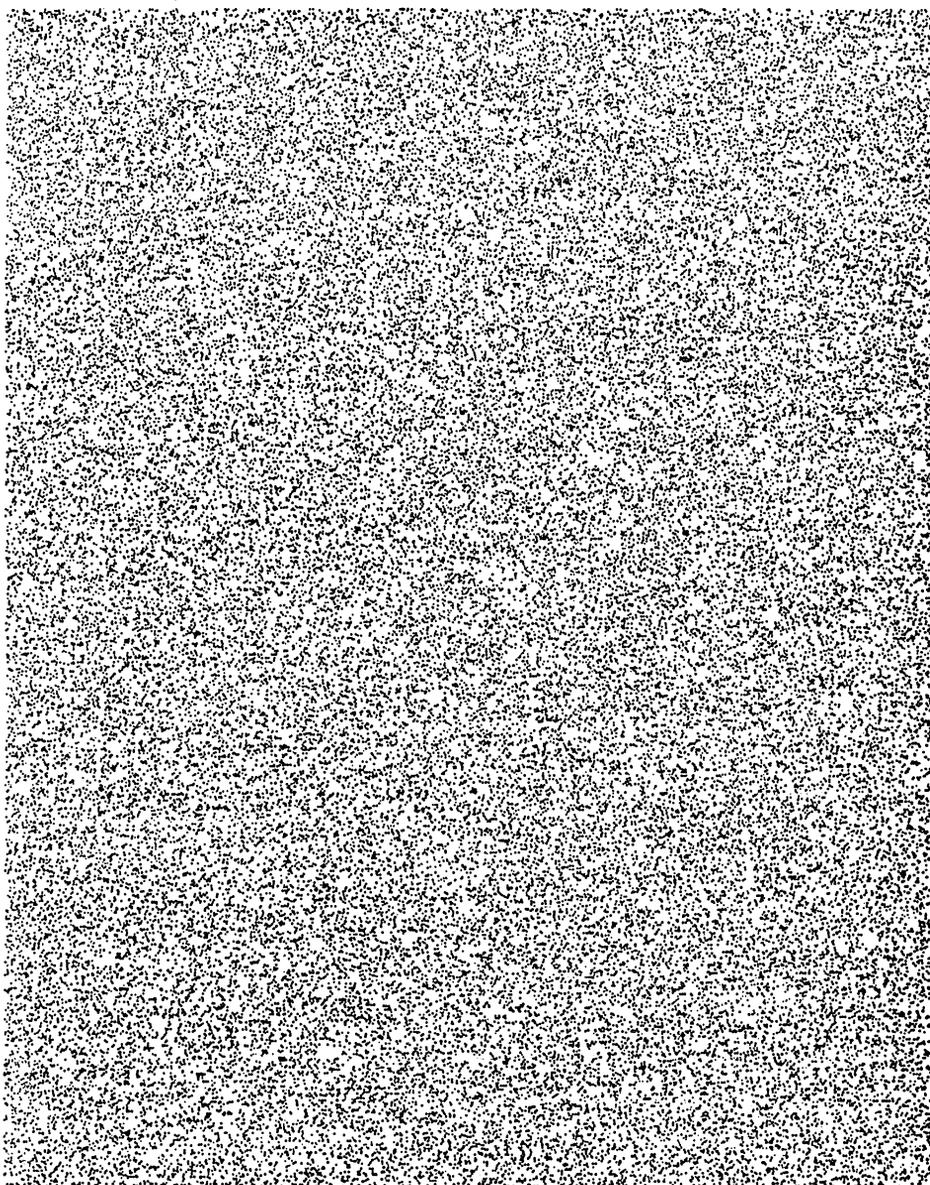


Figure 1. Random-dot noise used in experiments described in the text.

Both the dynamic and static noise percepts could be explained if binocular form detectors in the cortex had larger receptive fields than monocular form detectors, and hence tended to be optimally stimulated by larger features of the random noise. This hypothesis is borne out by studies of single cell responses in monkey cortex (Hubel and Wiesel 1968), where predominantly binocular complex and hypercomplex cells have receptive fields from 1.5 to 2 times the size of the predominantly monocular simple cells. It is also in accord with psychophysical measurements of the spatial limitations of stereoscopic vision (Tyler 1973, 1974, 1975), in which the maximum spatial frequency for depth perception is much lower than that for resolution of spatial frequency of luminance differences.

3 Homogenisation

Binocular frequency reduction in random noise is not the same as MacKay's (1964) homogenisation effect of fixation on a noise field. In the homogenisation effect, steady fixation produces an apparent increase in regularity of a random pattern or a narrowing of the spatial frequency bandwidth. This narrowing tends to affect mainly lower frequencies, so there is an accompanying increase in mean frequency. Although the spatial frequency increase on closing one eye is rather similar to homogenisation (since it is the lower spatial frequencies which produce the large scale irregularities), the two effects are produced under entirely distinct conditions. Homogenisation requires adaptation with good fixation over a certain duration, while binocular frequency reduction occurs instantly and with the eyes continuously changing fixation. Nevertheless the similarity of the resulting phenomena suggested that there might be common ground between them. Several possibilities immediately seemed worth testing.

4 Adaptation in binocular frequency reduction

If the observer fixates a point in the noise field binocularly for about 30 s, a strong homogenisation effect is observed. On alternately covering and uncovering one eye while maintaining fixation, the binocular frequency reduction seems at least as pronounced than before. A similar result is obtained with monocular fixation. The two effects can therefore occur simultaneously and are approximately additive.

5 Rivalrous binocular noise fields

If two fields of different visual noise are presented dichoptically to the two eyes, rivalry between the two fields would be expected to occur. In practice it is difficult to perceive rivalry because one noise field looks much like another, but rivalry may be observed between identifiable micropatterns. The question of interest in relation to binocular frequency reduction is what dot density is perceived. My subjects reported that dot density in dichoptic view did not appear different from that in the monocular fields, and therefore rivalry is presumably occurring. Since rivalry must occur only between monocular detectors, it is clear that stimulation of monocular detectors alone (through one or two eyes) is insufficient for binocular frequency reduction. This supports the idea that the reduction occurs when binocular form detectors with larger fields are stimulated in place of, or as well as, the monocular detectors.

In contrast, homogenisation is clearly obtained with rivalrous noise fields, and can be activated independently by monocular fixation on the field presented to the same eye, but not to the other eye. Homogenisation must therefore be occurring in monocularly activated detectors in the rivalrous condition.

6 Interocular transfer and position contingency

It makes no sense to speak of interocular transfer of binocular frequency reduction, but transfer may readily be tested for homogenisation. Definite interocular transfer may be observed (for example when using figure 1), by fixating on the pattern with one eye during the adaptation period and then testing for the effect with the other eye fixating on the same point while the first eye is closed. Interocular transfer is also reported by MacKay and Beasant (personal communication). It is most readily observed, by comparing fixation on the adaptation point with fixation on a neighbouring point, where enhanced irregularity is seen. The effect is very position specific, so that it is important to ensure that each eye views the pattern from the same angle.

The observation of interocular transfer supports MacKay's (1964) contention that homogenisation is a central phenomenon, rather than a simple retinal afterimage effect. A second experiment that might exclude retinal adaptation is a test for position contingency. Careful fixation alternately on each of two positions in the noise field should tend to cancel afterimages formed on the same set of retinal receptors from either fixation. If high-level form detectors are involved in the effect, homogenisation could still occur because each fixation would stimulate a different set of form detectors. A dual fixation experiment was performed by fixating alternately on two fixation points for 10 s each for a total duration of 60 s. Position-contingent homogenisation is then clearly obtained, as the reader may verify, which again points to a central origin.

7 Interactions with stereopsis

Binocular frequency reduction may be tested with the noise field viewed at a small disparity, by fixating on a pen held a few centimetres in front of figure 1, which should be viewed at about 1 m distance. Binocular frequency reduction is obtained when the disparity is small enough to fuse the monocular patterns. For larger disparities there seems to be an intermediate region between fusion and rivalry, where a doubled pattern is perceived. The binocular view now contains twice as many dots as the monocular view, and the frequency effect is reversed to become a binocular frequency increase. This intermediate region of pattern doubling is most easily obtained with greater dot separations, for example by viewing figure 1 at a distance of 30 cm.

It is difficult to test the interaction between homogenisation and depth perception in random-dot stereograms because prolonged fixation abolishes the depth effect (Fender and Julesz 1967). However, if the subject makes a brief eye movement followed by a return to the precise original fixation point, it is possible to obtain a transitory perception of stereoscopic depth in a stereogram that has been homogenised by prolonged fixation. This raises the question whether homogenisation precedes stereopsis or follows it in the visual system. A further test may be made by obtaining homogenisation by fixation with one eye only, after which the retinal shift produced by homogenisation would tend to reduce stereopsis if the homogenised field is acting as the input to disparity detectors. No reduction in stereopsis should be obtained if homogenisation is occurring either after or independently of stereopsis. In fact monocular homogenisation for 1 min considerably reduced depth perceived in a stereogram for the four observers, in stereograms where the texture was large relative to the disparity of the stereofigure. This suggests that homogenisation can occur prior to disparity processing.

8 Conclusion

The results of the series of tests on the relationship between homogenisation and binocular frequency reduction may be summarised succinctly as follows. Homogenisation occurs after the site of binocular fusion but prior to stereopsis, and under conditions antagonistic to stereopsis. Binocular frequency reduction occurs only for stimuli in the range of stereoscopic fusion, and is therefore probably associated with binocular disparity detectors. The reduction in perceived frequency is additional evidence for the low-frequency preference (or large receptive fields) of human disparity detectors suggested by other methods (Tyler 1973, 1974, 1975).

In monkeys (and therefore probably in man) the earliest stage in the visual pathway for disparity processing is area 18 of the visual cortex (Hubel and Wiesel 1970) whereas the earliest site of inhibitory binocular interaction is the lateral geniculate nucleus (see Tyler 1973, note 1). The observations reported here suggest that homogenisation occurs in binocular interaction in the lateral geniculate nucleus or area 17 and also in monocular pathways which are most likely to be at the same level in the visual system. Binocular frequency reduction does not seem to be possible prior to the disparity sensitive neurons in area 18. This detailed localisation may assist physiologists in their endeavours to characterise the organisation of neuronal responses.

References

- Fender D H, Julesz B, 1967 "Extension of Panum's fusional area in binocularly stabilised vision" *Journal of the Optical Society of America* **57** 819-830
- Hubel D H, Wiesel T N, 1968 "Receptive fields and functional architecture of monkey striate cortex" *Journal of Physiology* **195** 215-243
- Hubel D H, Wiesel T N, 1970 "Stereoscopic vision in macaque monkey" *Nature* **225** 41-42
- Julesz B, 1962 "Visual pattern discrimination" *IRE Transactions on Information Theory* **IT-8** 84-92
- MacKay D M, 1957 "Moving visual image produced by regular stationary patterns" *Nature* **180** 849-850
- MacKay D M, 1961 "Visual effects of non-redundant stimulation" *Nature* **192** 739-740
- MacKay D M, 1964 "Central adaptation in mechanisms of form vision" *Nature* **203** 993-994
- Tyler C W, 1973 "Stereoscopic vision: Cortical limitations and a disparity scaling effect" *Science* **181** 276-278
- Tyler C W, 1974 "Depth perception in disparity gratings" *Nature* **251** 140-142
- Tyler C W, 1975 "Spatial organisation of binocular disparity sensitivity" *Vision Research* **15** 583-590