Vision Research 51 (2011) 1058–1063

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Path dissociation of visual signals entering the cortex: Disparity, contour orientation and position

Gerald Westheimer *

Division of Neurobiology, University of California, 144 Life Sciences Addition, Berkeley, CA 94720-3200, USA

A R T I C L E   I N F O

Article history:
Received 20 December 2010
Received in revised form 19 February 2011
Available online 26 February 2011

Keywords:
Spatial vision
Stereoscopy
Interocular transfer
Visual cortex

A B S T R A C T

Whether position and orientation shifts induced by monocular context also act as a disparity for purposes of stereoscopy was investigated experimentally in order to examine the extent to which lateral spatial localization and stereoscopic depth share circuitry. A monocular tilt illusion in a line does not lead to a commensurate depth tilt of that line in binocular view, nor does a position shift in a bisection task caused by a gap within monocular dynamic random noise produce the commensurate depth displacement. Interocular transfer of monocularly-induced shifts, which might explain such findings, was eliminated as a factor. The results can therefore be interpreted as indicators of channeling and ordering of spatial signals paths in the visual cortex and imply that two-dimensional contextual interactions operate at a processing level beyond where disparity has already been extracted.

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1. Introduction

In 1922, Lau raised the question: Suppose a tilt is induced in a target line by cross-hatches in the manner of the Zöllner illusion and this is done in only one eye and not in the line's binocular counterpart in the other eye (Lau, 1922). Will the resulting binocular stimulation appear with a depth tilt, i.e., does an orientation shift induced by a monocular context manifest itself as a disparity in binocular vision? Lau could not arrive at a clear answer, and the proposition has only occasionally been explored since.

The high precision of orientation and position of seen contours arises from the operation of specialized cortical circuitry which may also be the site of contextual interactions such as the apparent orientation shift induced by temporally or spatially adjoining contours. Processing for stereoscopic depth shows similar properties and one wonders, since both are carried in the first instance by retinal location signals, what circuit elements might be shared. For example, is the position or orientation attributed to a given line stimulus the same when used in judging its two-dimensional disposition with respect to another line as it is when judging relative stereoscopic depth? This proposition, raised by Lau and occasionally explored since (Westheimer, 1986a), is here re-examined and answered for two specific conditions: when there is no transfer between eyes, the stereoscopic depth of a line is not that predicted from the induced position or orientation shift in its uniocular components.

2. Methods

In psychophysical experiments in normal observers the effect of contextual interaction on the apparent orientation and position of simple line targets under monocular and dichoptic viewing conditions was measured and compared with the depth in its binocular view.

Changes in two kinds of configurations were investigated. One was based on the demonstration by Kapadia et al. of a pronounced shift in the seen position of a line when superimposed on the edge of a peripheral "artifical scotoma" within a background of dynamic random-dot noise (Kapadia, Gilbert, & Westheimer, 1994). Fig. 1, top, shows the observer's view of such a display. It consists of a field of dynamic random dots, 4% coverage, refreshed at 30 Hz, a square portion of which could be blocked out for specific durations, the "scotoma." A line triad, whose timing was separately controlled, could be superimposed, one outer line in the center of the scotoma, the middle one near the edge and the other outer one within the random-dot noise. The major difference between the current experiment and the one reported by Kapadia et al. is that in a dichoptic arrangements, it was possible to control to which eye (right, left or both) the stimulus components (random-dot noise, the scotoma and the line triad) was shown and in what combination. By mirror reversing the displacement of the middle line in the two eyes, the observation became of one of stereoscopic depth rather than lateral shift. The patterns for the right and left eyes were displayed on the monitor side-by-side. Some observers were able to achieve binocular superposition by free fusion, others had the aid of a mirror stereoscope. In runs of 150 trials in which the middle line was shown at random in a range of lateral

* Fax: +1 510 643 6791.
E-mail address: gwestheimer@berkeley.edu

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doi:10.1016/j.visres.2011.02.020

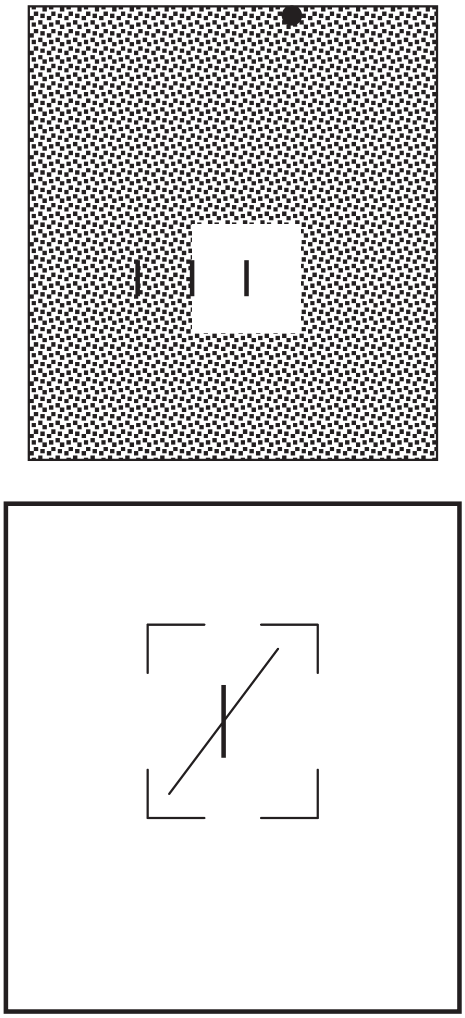

Fig. 1. Target configurations used in the experiments. Top: Dynamic random-dot noise field, 4 × 6°, in which a 2° square was blanked out, the scotoma. Fixation point near the middle of upper border. Observer's task was to judge the direction of the bisection error of the middle of the line triad. Random-dot noise, scotoma and triad could be presented to right, left or both eyes. Random-dot noise was shown continuously, scotoma and/or line triad for 250 ms. Bottom: Observers judged the direction of the tilt from the vertical of the 1° center test line that was induced by a simultaneously presented 2° high, 20° oblique inducer. Foveal fixation was assured by presence of the brackets in intertrial periods. The tilt illusion was measured by the difference in the means orientation of the test line for clockwise and for the counterclockwise inducers in series of randomly interdigitated trials. Contextual lines could be shown in either right or left eye, test lines in either right, left or, for stereoscopic measurements, both eyes.

positions, the observer had to register, without error signal, a judgment of whether it appeared closer to the right or left member of the line triad. The line's mean location for apparent exact bisection of the triad as seen with one eye was determined under several conditions: with and without a scotoma in the dynamic random-dot noise, and with the same and also with the other eye. For stereoscopic judgments the random-dot noise scotoma was shown monocularly and the line triad binocularly. The dynamic random-dot noise was shown continuously; the scotoma and test lines for 250 ms during the trials which occurred every 3 s. A fixation point along the upper edge of the frame containing the random dots was continuously visible to ensure that the display was presented to the desired peripheral location.

The other experiment was adapted from one of Lau's original demonstrations and involved the tilt illusion or, more precisely, simultaneous orientation contrast. It was implemented in the manner shown in Fig.1, bottom, and measured the actual orientation of a 1° "test" line for it to appear vertical when accompanied by a 2° "inducing" line, inclined at 20° from the vertical. Foveal viewing was ensured by the continued presence of a fixation bracket. The procedure for measuring the induced orientation shift was similar to one used earlier (Westheimer, 1990). The test line was presented for 400 ms (800 ms in the stereo conditions) during each 3-s trial randomly in one of seven orientations, 0°, 1°, 2° or 3° either clockwise or counterclockwise with respect to the vertical, and the observer made a binary response without feedback of the direction of the apparent tilt. In runs of 300 trials, the test line was seen with the inducing line inclined either clockwise or counterclockwise, at random, during each trial. Data were analyzed separately for these two conditions. The difference between the mean orientations at which the test line appeared vertical with inducing lines of clockwise and of counterclockwise inclination provided a bias-free estimate of the induced orientation shift of the line. Again, panels intended for the right and left eyes were shown side-by-side on the monitor and dichoptic viewing enabled by free fusion or, as needed, by a mirror stereoscope. The test and inducing lines together or separately could be shown in various monocular, dichoptic and binocular combinations. By mirror reversing the test line tilt for one of the two eyes, its stereoscopic depth tilt out of the apparent frontal plane ("top towards or away from observer?") was tested.

Stimuli were shown on display monitors at an observation distance of 57 cm (random dot experiments) or 89 cm (tilt effects) under computer control in a semi-dark room. Lines where white (~40 cd/m^2) against a dark background (~1 cd/m^2) and smooth, generated with an anti-aliasing protocol. The display was contained in a rectangle, 4° wide and 6° high (3 × 4° for the tilt effect), outlined by white lines on a dark monitor screen. Arrangements for monocular, dichoptic and binocular viewing and for fixation were provided as described in each experiment. The optometric status of the observers, which included the author and several undergraduate biology students naïve as to the immediate question of the research but who understood and consented to the general aims, was unremarkable. The protocol conformed to the Declaration of Helsinki and was approved by the Committee for the Protection of Human Subjects of the University of California, Berkeley. Results shown are averages for each observer of several runs for each condition obtained on different days.

3. Results

3.1. Monocularly-induced position shift does not act as a disparity

To begin with and as a control, the location of the center line of 3-line triad in the near periphery was determined at which it was seen accurately to bisect the distance between the outer lines with and without the presence of the artificial scotoma in a dynamic random dot field. It was done separately in each eye, the other remaining open but unstimulated. This showed the scotoma-induced displacement with substantially the same values as those found by Kapadia et al. (Fig. 2, "scotoma ipsilateral"). The next step was to determine whether the random-dot scotoma in one eye affects the bisection performed with the other eye, i.e., whether there is interocular transfer. These contralateral measurements revealed only a small fraction of the ipsilateral effect (Fig. 2, "scotoma contralateral"). Finally measurements were undertaking where the random-dot scotoma was shown in only one eye and the line triad in both eyes but with the middle line displaced in opposite directions in the two eyes, i.e. with binocular disparity. The observer judged whether the middle of the three lines appeared in front or behind the two outer ones. If the monocular scotoma-induced position shift – demonstrated to be confined

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