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Vergence amplitudes with random-dot stereograms*

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SUMMARY Random-dot stereograms were found to be capable of producing fusional vergence amplitudes in the absence of monocular contours. These vergence amplitudes are not an artefact of monocular contours provided by the target borders or test instrument and are comparable in range to vergence amplitudes measured clinically with second degree fusion targets in an amblyoscope. We conclude that diplopia of monocularly recognisable contours is not necessary for producing fusional vergence amplitudes.

Fusional vergence amplitudes reflect the ability of the oculomotor system to maintain sensory fusion in spite of varying vergence requirements. Traditionally this has been regarded as a diplopia avoidance mechanism. However, Hyson *et al.*[1] have recorded vergence responses to divergent misalignment of random-dot stereogram targets which do not feature monocularly recognisable contours which could give rise to diplopia.[2] The purpose of this paper is to show that these vergence amplitudes are not artefacts due to target borders or an optokinetic response. We also compare these vergence amplitudes with those obtained clinically with second degree fusion targets in an amblyoscope.

Subjects and methods

EXPERIMENT 1

The ability of random-dot targets to produce vergence amplitudes at the amblyoscope was tested for five normal subjects. The random-dot targets included a stereogram with nonius lines[3] (Fig. 1), a positive/negative stereogram[4] with nonius lines (Fig. 2), and a stereogram with ragged edges (Fig. 3). One

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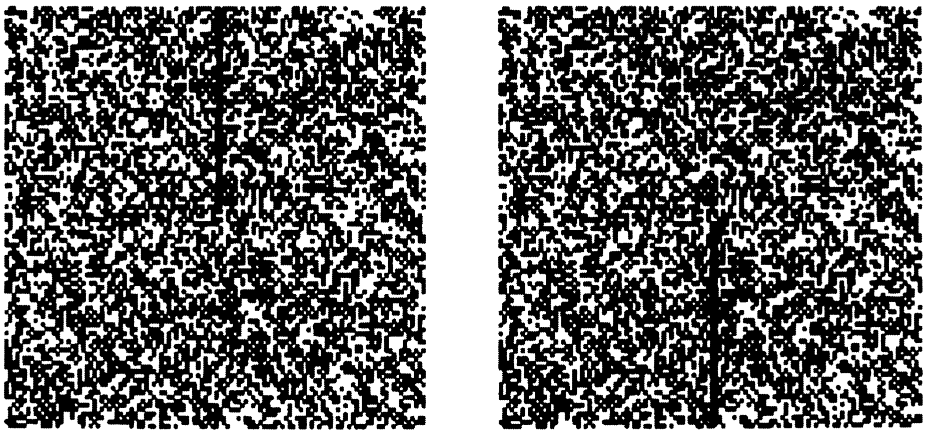

Fig. 1 *Random-dot stereogram with nonius lines added (narrower and in red on actual targets used). Images subtended 18° by 18° with 6·5° by 7·5° central rectangle in 40' crossed disparity. Exchange right and left images for viewing in a mirror haploscope.*

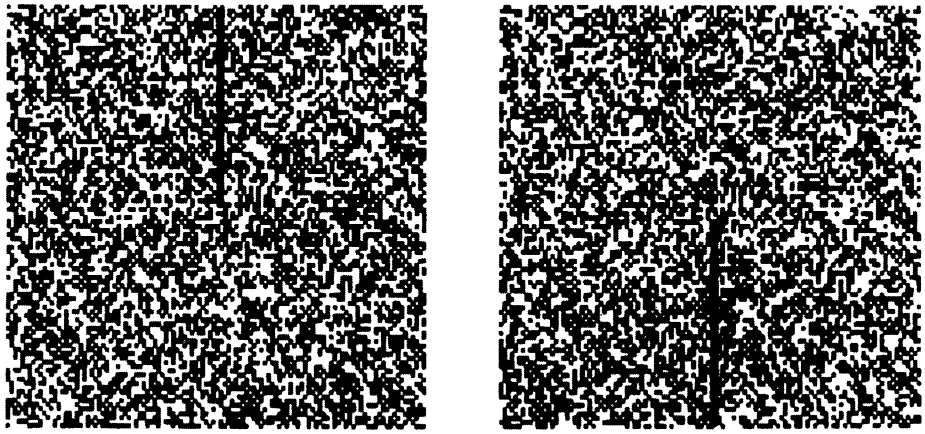

Fig. 2 *Positive and negative image stereogram with nonius lines. Identical to Fig. 1 except that all points in left image have been complemented (after Julesz[4]).*

subject had eye movements recorded electro-oculographically during amblyoscope testing. The details of the vergence testing are described in experiment 2. These five subjects were also tested with a dynamic random-dot stereogram.[5] The stereo image pair was displayed on two television monitors which were mounted on the arms of a Wottring Troposcope.

EXPERIMENT 2

The vergence amplitudes of 16 normal subjects were tested with conventional amblyoscope fusion targets and random-dot stereogram targets (Fig. 4). Subjects were excluded from the study if they showed any heterotropia, a heterophoria in excess of 6 prism dioptres, or any abnormality of ductions or versions. Vergence amplitudes were measured with an amblyoscope (American Optical Wottring Troposcope). No attempt was made to control accommodation. With the conventional second degree fusion targets the divergence break point, divergence recovery point, convergence break point, and convergence recovery point were measured by slowly and symmetrically diverging and converging the haploscope arms. The random-dot stereogram slides were then placed in the haploscope, the subjects were allowed time to obtain stereopsis while viewing at their subjective angle, and the same sequence of measurements was repeated. Reported loss and recovery of the stereoscopic form were taken as the break and recovery points. Informed consent was obtained from all subjects.

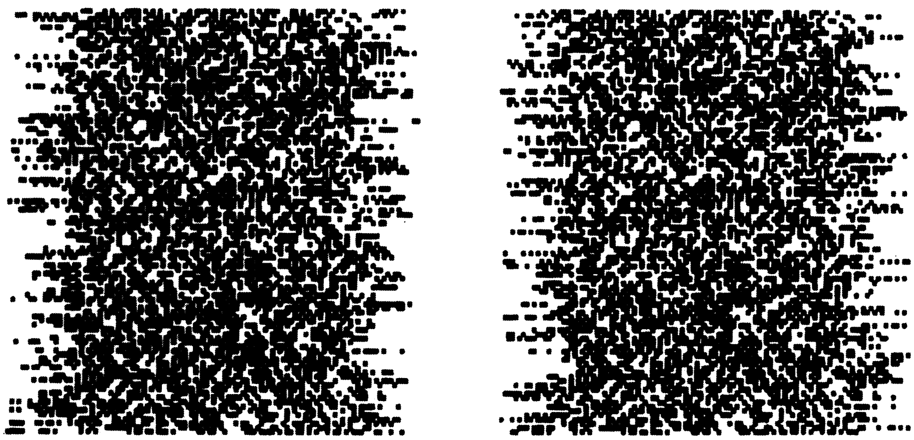

Fig. 3 *Stereogram with ragged edges. Identical to Fig. 1 (without nonius lines) except that all vertical borders have been randomly indented from 1 to 20 dots.*

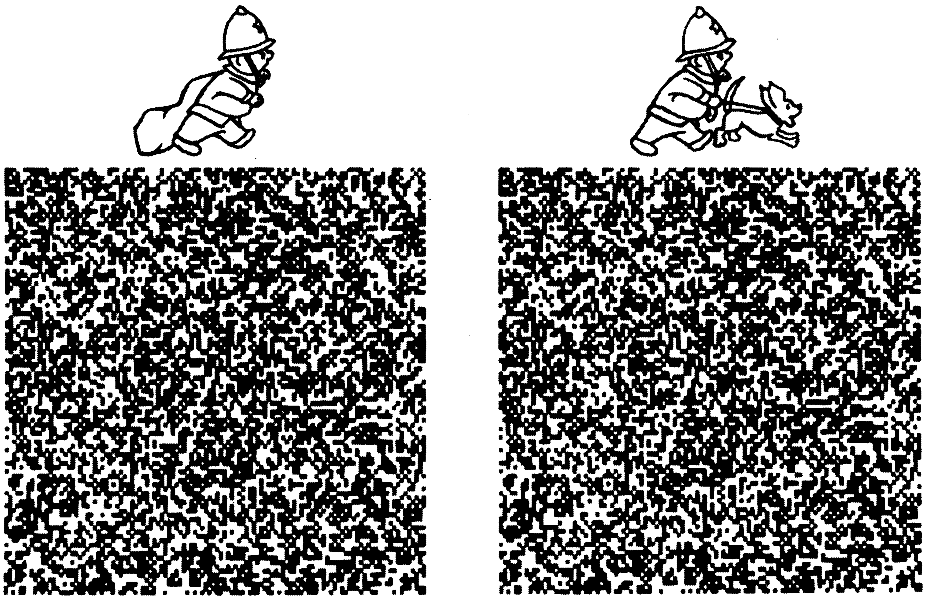

Fig. 4 *Amblyoscope target pairs. Top, second degree fusion targets subtending 7·25° by 5·2°. Bottom, random-dot stereogram targets subtending 15° by 15°. A 9° by 9° block letter T is portrayed in 35′ crossed disparity (after Julesz[2]).*

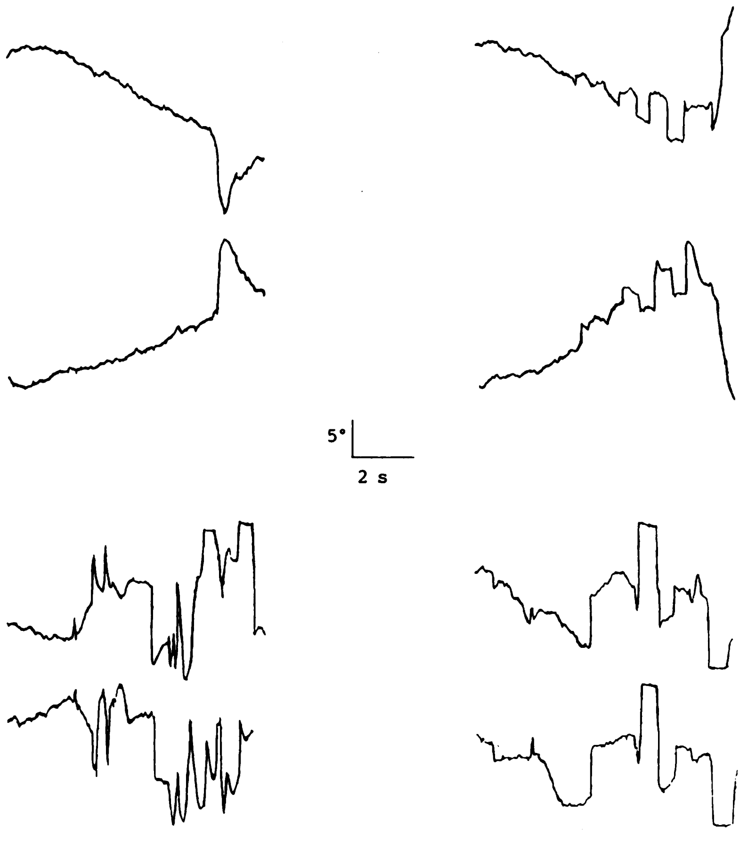

Fig. 5 *Electro-oculographic records of convergence testing. Top tracing is right eye, upward deflection is right. Targets tested were conventional fusion target (top left), ragged-edge stereogram (top right), positive/negative stereogram with nonius lines (bottom left), positive/negative stereogram without nonius lines (bottom right).*

Results

All five subjects gave the same results in experiment 1 and will be reported as a group. In brief, vergence amplitudes comparable to those with conventional second degree fusion targets were elicited by the stereogram with nonius lines, the stereogram with ragged edges, and the dynamic random-dot stereogram. Only a minimal vergence response could be elicited with the positive/negative stereogram.

In the first stereogram nonius lines served as non-fusible indicators of ocular alignment in addition to the report of fusion. When initially fused at the subjective angle the nonius lines showed an uncrossed displacement of four picture elements, which was equal to the number of dots by which the central target area had been shifted in this particular target. That is, for a stereogram with crossed target disparity in which the target appears in front of the background, the vergence position assumed was such that the dots in the target region actually had zero disparity while the background dots were left in a state of uncrossed disparity. (However, when the target region was portrayed in uncrossed disparity, only one subject reported any displacement of the nonius lines and then only with conscious effort after viewing the target for considerable time.) This displacement of the nonius lines was stable and maintained over the entire range of vergence tested except just prior to the break points. There was a shift of the nonius lines while the arms of the haploscope were in motion from one vergence angle to another, but the same stable nonius line displacement was promptly restored when the movement stopped.

It was not possible to appreciate the embedded stereogram in the positive/negative random-dot target pair, so the nonius lines served as the only indicator of whether or not a correct vergence position was being maintained. The nonius lines were aligned when the targets were presented at the subjective angle. When the amblyoscope arms were moved within a small range round this position, it was possible to keep the lines close to each other, but this was unstable and required some effort. Alignment was not possible outside this small range.

Eye movements were recorded electro-oculographically in one subject (Fig. 5). They were consistent with the eye movements inferred from the previous subjective responses. Convergence was recorded with the conventional second degree fusion targets and the ragged-edge stereogram. Minimal convergence was seen with the positive/negative random-dot targets with nonius lines. There was frequently no response at all to the positive/negative targets without nonius lines, but when a response was present it was an ill-defined version movement (Fig. 5, bottom right). These latter two findings indicate that the minimal amplitudes observed subjectively with the positive/negative target with nonius lines were probably due solely to the nonius lines.

Quantitative results obtained from 16 normal subjects comparing conventional second degree fusion targets with random-dot stereogram (Fig. 4) were as follows: the average divergence amplitude was 9 prism dioptres (5°) for both second degree fusion targets and random-dot targets with standard deviations of 2 and 1 prism dioptres respectively. The average convergence amplitude was 22 prism dioptres (12·4°) for both second degree fusion targets and random-dot targets with standard deviations of 13 and 11 prism dioptres respectively. The distribution of individual differences in performance between random-dot and second degree fusion targets (Fig. 6) does not indicate any systematic difference between the two target types.

The difference between maintaining fusion and

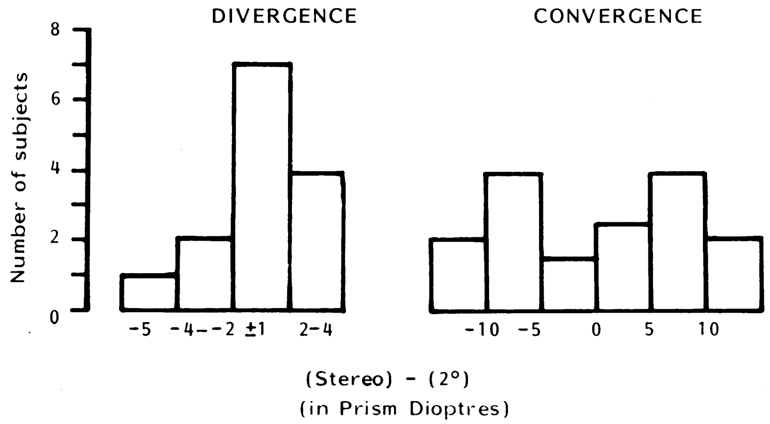

Fig. 6 *Histograms of vergence amplitude differences with second degree and random-dot targets. Absolute vergence amplitude with stereogram minus amplitude with second degree targets for divergence (left) and convergence (right).*

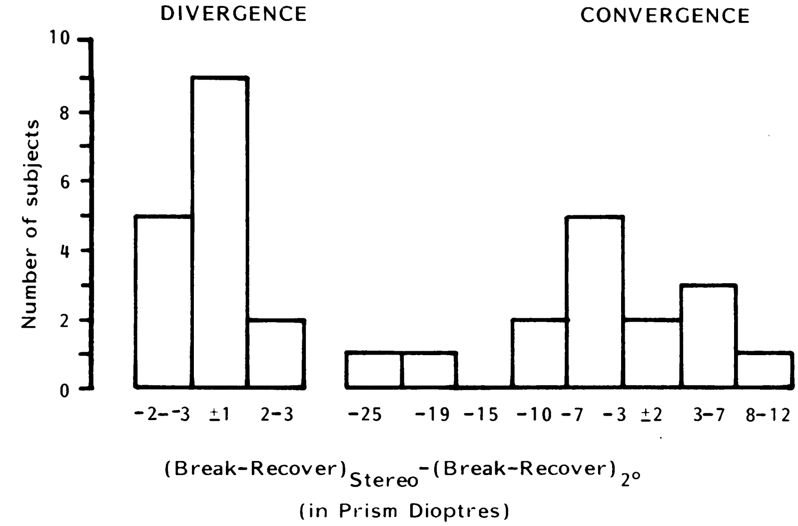

Fig. 7 *Histograms of hysteresis differences with second degree and random-dot targets. Difference between break and recovery with stereogram minus difference between break and recovery with second degree fusion targets for divergence (left) and convergence (right).*

acquiring fusion was demonstrated during vergence amplitude testing by the difference between the break and recovery points. Individual differences in this hysteresis with random-dot and conventional second degree fusion targets are shown in Fig. 7. Two subjects had essentially no recovery during convergence testing with the random-dot targets. The two target types gave similar hysteresis characteristics for the remainder of the subjects. The 95% confidence intervals (Student's *t* test) for the differences in hysteresis between stereogram and conventional fusion targets were $-0{\cdot}5\pm1{\cdot}0$ and $-3{\cdot}0\pm5{\cdot}5$ prism dioptres for divergence and convergence respectively. This reflects a slight skew toward earlier recovery with conventional fusion targets, but it is not significant statistically.

Discussion

Fusional vergence amplitudes are the result of eye movements directed towards maintaining sensory fusion. This is sometimes regarded as a diplopia avoidance mechanism. The stimulus for vergence amplitudes is generally described as disparity between a contour in the image from one eye and a similar contour in the image from the other eye (potentially diplopic contours). These experiments appear to show that disparity detected by global processes is also capable of producing a motor response resulting in vergence amplitudes. However, care must be taken to rule out other possible explanations, since global disparity detection is widely recognised as being associated only with the sensory process of stereopsis (as demonstrated with random-dot stereograms).

One possible objection might be that all contours have not been eliminated. The borders of the dot patterns or the instrument tube edges might produce the observed vergence amplitudes. However, normal vergence amplitudes with the ragged-edge stereogram and the lack of real vergence amplitudes in the control case of the positive/negative stereogram would indicate that these residual contours are not necessary, nor are they adequate for producing vergence amplitudes.

An alternative explanation is that some sort of optokinetic vergence response to the shifting fields of dots produced the observed vergence amplitudes. This could not be the case with the dynamic random-dot stereogram in which the entire pattern is replaced every 1/60 second and no dot is on the screen long enough for its movement to be detected.

If diplopia of extended contours is not the motivation for the observed vergence with random-dot targets, is it possible that diplopia on a dot-by-dot basis serves this function? This explanation does not seem adequate. For diplopia to occur, pairs of dots (one from each retinal image) must be recognised as associates representing two images of the same dot. However, this diplopic pair would have to be recognised from among a large number of incorrect but equally likely dot pair possibilities (this is the ambiguity problem[2] which lies at the root of the distinction between local and global stereopsis). Apart from the subjective appreciation of diplopia, correct dot pairings are needed to generate the correct magnitude and direction for compensatory vergence movements. Moreover, subjective diplopia seems not to occur when random-dot patterns are not fused. A rivalry avoidance mechanism could be postulated, but again this could not provide information for compensatory vergence movements of the correct magnitude and direction.

To summarise, extended monocular contours and diplopia are not essential to the production of fusional vergence amplitudes. Our results confirm previous reports of vergence amplitudes with random-dot targets.[1-6] We have extended these findings by showing that (1) the reported vergence amplitudes are not artefacts of monocullar contours which arise from target borders or the testing apparatus, (2) vergence amplitudes can be produced by dynamic random-dot stereograms and are therefore not the result of an optokinetic vergence response to a shifting field of dots, and (3) while initial fusion of random-dot targets may be more difficult than fusion of targets with monocular contours,[7,8] once fusion has been obtained the motor 'fusion lock' is equally robust and can maintain fusion over the same range of vergence angles.

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