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A SHORT-RANGE PROCESS IN APPARENT MOTION

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Abstract—A region in an alternated pair of random-dot patterns was uniformly displaced. It was perceived as a segregated, coherently moving shape only if the displacement was small. The limit on the displacement was its absolute size (maximum about 15′) rather than the number of elements' widths. Segregation due to apparent motion did not occur if the two patterns were exposed to different eyes.

These conditions for segregation differ from those classically found for apparent motion. Perceptual segregation may be due to the activity of low-level motion detectors of limited spatial range, while classical apparent motion with larger displacements involves a different process. The problem of selection among alternative possible interactions of stimulus elements in apparent motion is discussed.

INTRODUCTION

Pairs of random-dot patterns, similar to those used as stereoscopic stimuli (Julesz, 1960, 1971), may also be used as stimuli for apparent motion (Anstis, 1970; Julesz, 1971). A region of the dots is identical in the two patterns of a pair, except for a uniform displacement; when the two patterns are presented alternately at an appropriate rate, this region appears to oscillate to and fro.

The oscillating region is visible as a shape segregated from the surround by clear boundaries. No such shape is present in either pattern taken alone, since each is a homogeneous random array; the shape is defined only by the relationship of displacement between the two patterns. For it to be perceived, the visual system must be performing a comparison of successive patterns that enables it to extract this relationship. A comparison that detects displacement over time is a motion-detecting process, and indeed the shape is seen as moving. The visibility of the shape itself, then, can be used as an indicator of the operation of this motion-detecting process (Braddick, 1973).

"Local" and "global" processes

Within the displaced region, each dot in one pattern has its shifted "partner" in the other pattern. For the displaced region to be perceived as a coherently moving shape, the visual system must derive the motion signal from the relationship between partner dots in the two patterns. Now such patterns conventionally consist of 50 per cent white and 50 per cent black dots. Thus if we consider any particular white (or black) dot in one pattern, it will have a partner of the same colour in the other pattern, but also there is a probability of 0·5 that *any* nearby position in the other pattern will be occupied by a dot of the same colour. Why then should the perceived motion correspond to the relationship between partners, rather than between any other pairs of identical nearby dots, since such pairs will arise very commonly by chance?

An exactly analogous problem has been recognized in the perception of stereoscopic depth in random dot patterns (Julesz, 1971). If one pattern is viewed by each eye, there will be many cases where dots of the same colour fall by chance on nearly corresponding retinal points. One might expect that the retinal disparities of these fortuitous pairs would be detected, leading to the perception of some dots as standing out in depth, others as receding, and some, where dots of the same colour happened to fall on corresponding points, appearing in the plane of fixation. In fact, however, a region displaced in one pattern is invariably seen as a plane area of uniform depth. Some process must therefore be acting to select the pairs of partner dots as those from whose disparity perceived depth is derived. Pairs of partners can only be distinguished from other possible pairings in that they, unlike the chance pairings, will yield a uniform disparity over an extended area of the field. The selective process must therefore be one that can use information from a spatially extended area. Julesz refers to it as a "global" process which resolves the ambiguities of the "local" process of disparity detection.

The question immediately arises: is there also a global process which resolves the potential ambiguities in the perception of apparent motion?

Preliminary observations suggested that stereopsis and apparent motion behave differently. A central square was displaced by four elements' width in one pattern of the pair, the surrounding area being identical in the two patterns. When viewed stereoscopically the displaced square clearly appeared as a plane figure in uniform depth. However, when the patterns were exposed alternately to both eyes together, the central square did not appear to move as a coherent whole. Instead, it appeared as a region in which individual dots

Table 1. Parameters of the stimulus patterns

Element size (minutes of arc)	2·7	5·4	10·8
Matrix size (elements)	200 × 200	100 × 100	50 × 50
Size of displaced region (elements)	41 × 81	21 × 41	11 × 21
Displacements used (minutes of arc)			
1 element	2·7	5·4	10·8
2 elements	5·4	10·8	21·6
4 elements	10·8	21·6	43·2
8 elements	21·6	not used	not used

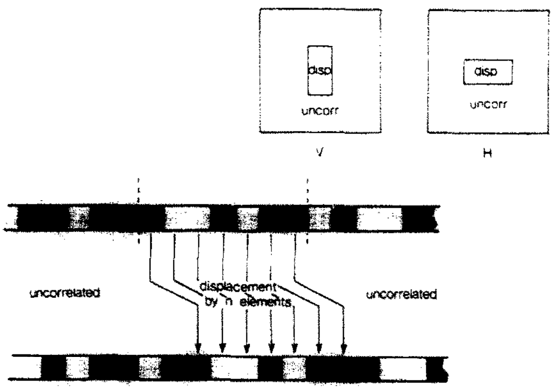


Fig. 1. Below: principles of generation of a single row of each pattern. The dotted lines mark the boundaries of the central rectangle. Above: illustrating the size and position of the displaced horizontal (H) or vertical (V) rectangle within the uncorrelated surround. Overall size of the patterns: 9 × 9°.

or clusters of dots were oscillating independently in different directions ("incoherent motion"). This is what would be expected if chance pairings of similar dots were leading to motion perception, without a global process preferentially selecting the pairing of partner dots. In contrast, in a pair of patterns in which the central square is shifted by only one element's width, the square does appear to oscillate as a coherent figure.

What, then, are the constraints determining which dots are paired for motion detection, if they are not analogous to those in stereopsis? One possibility is that each dot is paired with its nearest neighbour of the same colour in the other pattern. For this hypothesis the relevant difference between the cases of one and four elements' displacement is the greater number of elements intervening in the space between partners' positions in the latter case. The "nearest neighbour hypothesis" is one of a class of possibilities, in all of which the displacement expressed as a *number of elements' widths* is a critical variable. An alternative possibility is that the pairing of dots for apparent motion can only occur over a limited absolute spatial range. In this case the critical variable is the displacement expressed as a *visual angle*. These two possibilities can be distinguished by varying the element size as well as the displacement. This was done in the experiment reported below.

In the observations described above, the displaced square was discriminable by the observer even when the motion was incoherent; it was seen as a patch of random activity within the static surround. If the surround, instead of being identical in the two patterns, is uncorrelated, it too is seen as an area of random activity. In this case, perceptual segregation of the displaced zone can only occur when the latter is seen in coherent motion. Thus in the experiments reported below, such segregation was used as an indicator of the occurrence of coherent motion.

COHERENT MOTION AS A FUNCTION OF DISPLACEMENT

Method

The stimuli were matrices of square elements, with each element having an equal random probability of being black or white. For each element size used, there was one standard pattern. Each of the patterns with which this could be paired had a central region which was identical but displaced horizontally by an integral number of elements' widths, the rest of the pattern being an independent (and hence uncorrelated) random array. The element sizes used, and the displacements available in each case, are indicated in Table 1.

The displaced region was a rectangle, with one dimension twice the other. For each displacement, this rectangle could be either vertically or horizontally oriented. The angular size of the rectangle was the same in every case. Figure 1 illustrates the principles of construction of the patterns.

The patterns were generated on a storage display oscilloscope by means of a digital computer, and high contrast photographs were made from the screen. These were exposed in a three-field tachistoscope (Electronic Developments Ltd.). Two channels were used for the pair of patterns exposed on a particular trial. The patterns were mounted in metal frames machined to fit accurately into the card-holders of the tachistoscope; this ensured that they could be rapidly changed between trials and yet be accurately located. The patterns of each pair were initially aligned within these frames by visually superimposing strips of identical dots that had been generated at the edges of both patterns: these strips were masked from the subjects' view in the experimental trials. The third tachistoscope channel was used for the adaptation field and fixation mark.

The luminance of white elements in the patterns, and of the adaptation field, was 0·2 log ft-L. Viewing distance was 52 cm.

A trial began with the adaptation field and central fixation mark visible. The subject initiated the stimulus exposure by depressing a push-button. So long as he held the button down, the pair of patterns were exposed in continuous alternation, each pattern being illuminated for 75 msec. with a dark inter-stimulus interval of 10 msec. following each pattern. The subject was instructed that as soon as he could discriminate the orientation of the oscillating rectangle, he was to release the button, terminating the exposure. He then reported (i) whether the rectangle was vertical or horizontal (a forced choice being required) and (ii) a numerical rating of the perceived clarity of its boundaries. The rating was on a scale from one to five, with one representing the case of maximum clarity. The response time for the discrimination (i.e. duration of the button-press) was measured by a millisecond counter and recorded by the experimenter together with the subject's response.

The experimental trials proper were preceded for each subject by up to thirty practice trials, to ensure familiarity with the shape and position of the rectangles and with the use of the rating scale. Experimental trials for the patterns of different element sizes were given in separate sessions. Within each session, there were ten trials for each combination of rectangle orientation and displacement in random order, making two hundred trials overall.

Five subjects were used. All had experience as observers in psychophysical experiments.

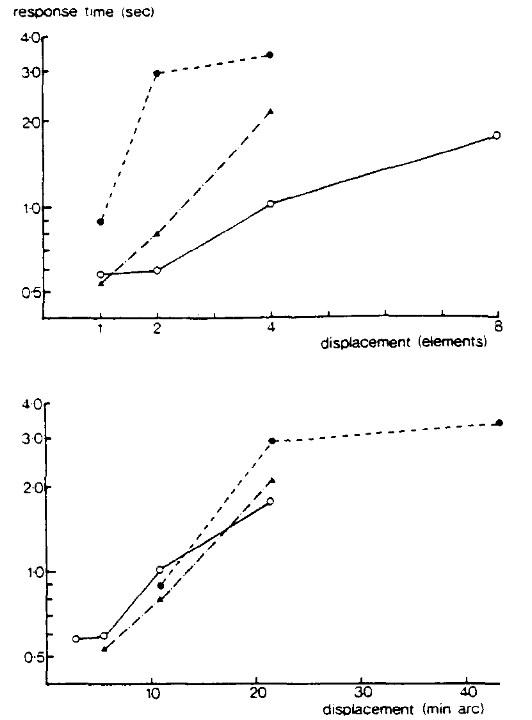


Fig. 2. Response time for report of orientation of the displaced rectangle, as a function of displacement. Data are mean of a log transform for five subjects. The ordinate is logarithmic. Above: displacement in units of one pattern-element's width. Below: displacement in units of visual angle.

—○—: 2·7′ elements. -·-▲-·-: 5·4′ elements.- - -●- -: 10·8′ elements.

Results

Four measures derived from the subjects' responses are plotted in Figs. 2–5. These are: mean logarithm of response time (Fig. 2); mean variability (i.e. S.D./mean) of response time (Fig. 3); mean clarity rating (Fig. 4); and percentage of incorrect reports of the orientation of the rectangle (Fig. 5). In each figure the data are plotted two ways; in the upper graph as a function of the displacement of the rectangle expressed as a number of pattern elements, and in the lower graph as a function of the displacement expressed as a visual angle. On each graph the data for each element size are plotted as separate curves. The data for horizontal and vertical rectangles are combined.

Consider as an example the data for the intermediate element size (black triangles on the figures). For the smallest displacement the responses were fast (about 500 msec; Fig. 2), consistent in speed (Fig. 3), and invariably correct (Fig. 5), and subjects gave ratings corresponding to maximum clarity (Fig. 4). In other words, the displaced shape was immediately, clearly, and unambiguously perceived. In contrast, for the largest displacement subjects viewed the stimuli for several seconds before responding, and this duration showed much more variation. Their ratings of clarity were close to the minimum, and a considerable number of their reports of orientation were incorrect. That is, there was no clear segregation of a coherently moving shape, and insofar as subjects could make the discrimination at all they did so by cues that were unreliable and required prolonged inspection. Subjects reported that the decision to terminate exposure in this case was largely arbitrary, and indeed their response times showed high variability between as well as within subjects. It is to avoid giving undue relative weight to these variable slow responses that the response times have been averaged and plotted logarithmically.

A similar transition, from an immediately discriminable moving shape to a slow, uncertain response indicating the absence of segregation by coherent motion, can be seen in the data for the other two element sizes.

Comparing the data for the different element sizes, it will be seen that when the plot is in terms of displacement as a number of elements, the curves are quite widely separated (upper graphs). When plotted in terms of the displacement as a visual angle, however, the curves coincide much more closely (lower graphs). That is, the appearance of coherent motion is limited by the absolute spatial displacement of partner dots,

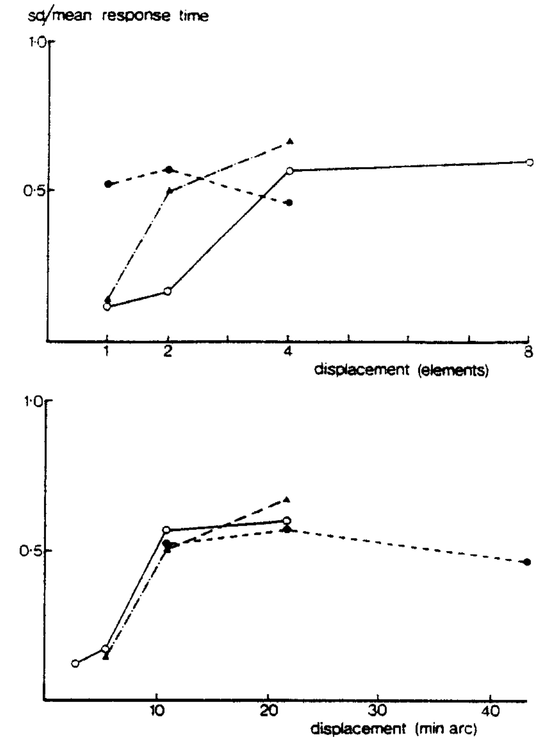


Fig. 3. Variability of response time (i.e. S.D./mean). Mean data for five subjects. Upper and lower graphs, and symbols, as in Fig. 1.

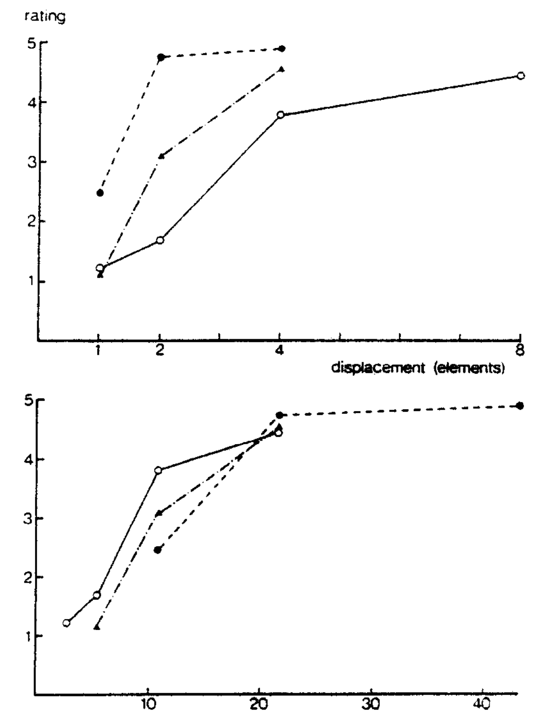


Fig. 4. Ratings of clarity of the rectangle. 1—maximum clarity; 5—minimum clarity. Means of five subjects' data. Upper and lower graphs, and symbols, as in Fig. 1.

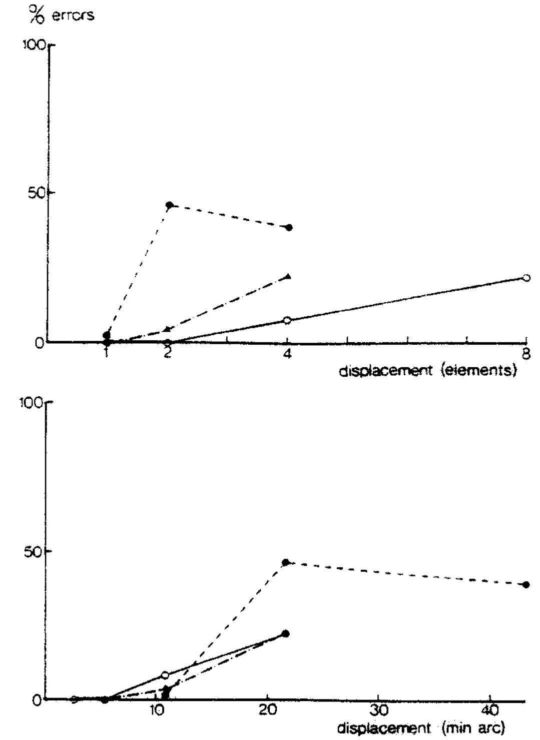


Fig. 5. Percentage errors in reports of rectangle orientation. Means of five subjects' data. Upper and lower graphs, and symbols, as in Fig. 1.

and not by the number of pattern elements intervening between partners' positions.

This conclusion is supported by statistical analysis. Two analyses of variance were performed on the log. response times: (a) (element size) × (displacement in elements) × (subjects); (b) (element size) × (displacement in min arc) × (subjects).

In neither case are all combinations of the factor levels available; therefore in (a) all the data were used except for the eight elements' shift with the smallest elements, while in (b) the 10·8 and 21·6′ shifts were used for all element sizes, and the other data omitted. In both cases the effect of displacement was significant: [(a): $F = 17{\cdot}49$; $df = 2, 16$; $P < 0{\cdot}01$; (b): $F = 15{\cdot}50$; $df = 1, 8$; $P < 0{\cdot}025$]. In analysis (a), where displacement in elements was analysed as a factor, element size had a significant effect ($F = 19{\cdot}49$; $df = 2, 16$; $P < 0{\cdot}001$) as did the interaction of element size with displacement ($F = 5{\cdot}07$; $df = 4{\cdot}16$; $P < 0{\cdot}01$). In (b), where displacement was measured as a visual angle, neither element size nor its interaction with displacement had a significant effect (main effect: $F = 0{\cdot}64$; $df = 2, 8$, interaction: $F = 1{\cdot}80$; $df = 2, 8$). That is, the curves for different element sizes do not differ significantly when plotted in terms of displacement as a visual angle.

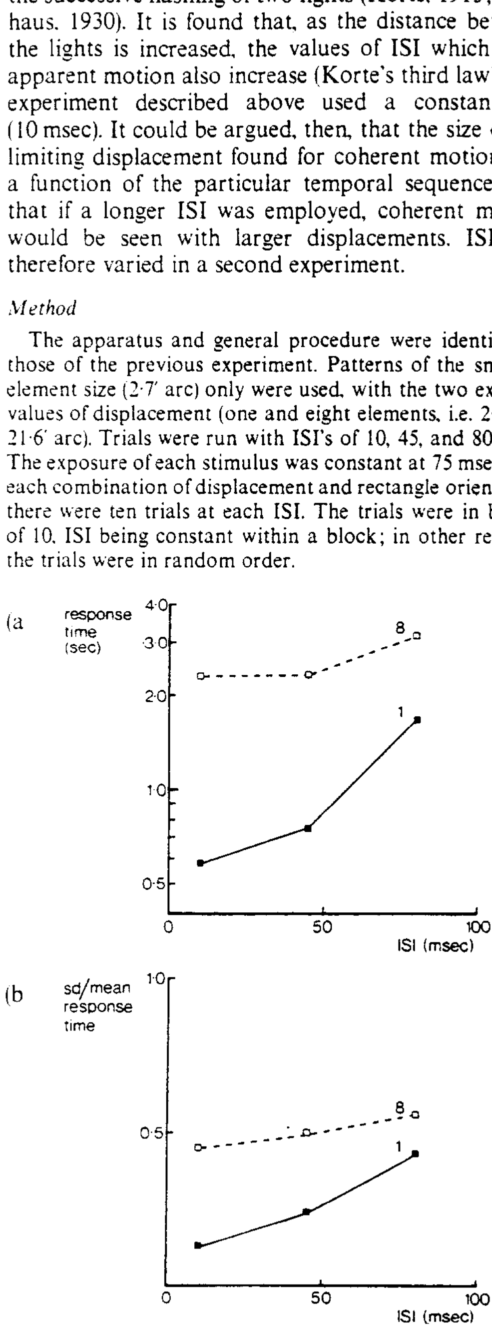
Quantitatively, it may be seen from the graphs that, by all four measures, the perceptual segregation of the rectangle began to deteriorate at a displacement of about 5′ arc. This deterioration was complete for displacements of about 20′ arc. Thus it is over this range of displacements that coherent motion is lost.

EFFECTS OF INTER-STIMULUS INTERVAL

Classical studies of apparent motion have studied the values of stimulus duration and inter-stimulus interval (ISI) which yield the appearance of motion from the successive flashing of two lights (Korte, 1915; Neuhaus, 1930). It is found that, as the distance between the lights is increased, the values of ISI which yield apparent motion also increase (Korte's third law). The experiment described above used a constant ISI (10 msec). It could be argued, then, that the size of the limiting displacement found for coherent motion was a function of the particular temporal sequence, and that if a longer ISI was employed, coherent motion would be seen with larger displacements. ISI was therefore varied in a second experiment.

Method

The apparatus and general procedure were identical to those of the previous experiment. Patterns of the smallest element size (2·7′ arc) only were used, with the two extreme values of displacement (one and eight elements, i.e. 2·7 and 21·6′ arc). Trials were run with ISI's of 10, 45, and 80 msec. The exposure of each stimulus was constant at 75 msec. For each combination of displacement and rectangle orientation there were ten trials at each ISI. The trials were in blocks of 10, ISI being constant within a block; in other respects the trials were in random order.



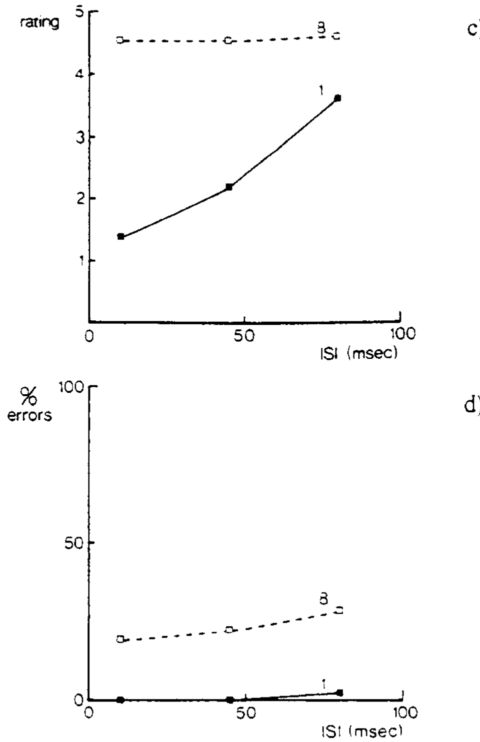


Fig. 6. (a). Response time for report of orientation of the displaced rectangle, as a function of inter-stimulus interval. Data are mean of a log. transform for five subjects. The ordinate is logarithmic.
—■—: one element's width displacement. - - □ - -: eight elements' width displacement. Element size: 2·7′.
(b). Variability of response time (i.e. S.D./mean). Means of five subjects' data. Symbols as in Figure 6(a).
(c). Ratings of clarity of the rectangle. Means of five subjects' data. Symbols as in (a).
(d). Percentage errors in reports of rectangle orientation. Means of five subjects' data. Symbols as in (a).

After the sequence of trials, a range of ISI's up to 200 msec was informally explored with the larger displacement, the subject being asked to report any point at which there was an improvement in the clarity of the rectangular shape.

Five subjects were used, all with experience as observers in psychophysical experiments. Three had been subjects in the previous experiment.

Results

Figures 6(a–d) show the same measures that were plotted for the previous experiment in Figs. 2–5. For one element displacement, it will be seen that the discriminability of the central rectangle declined as the ISI was increased from 10 to 80 msec. For eight elements' displacement, the rectangle was very poorly discriminable for 10 msec ISI, as it was in the previous experiment, and the discriminability declined somewhat further as the ISI was increased. Nowhere in the range did clear segregation, comparable to that found with the smaller displacement, occur. Nor was there any indication of any increase in clarity for any of the subjects when longer ISI's were explored. It appears, then, that the failure of coherent apparent motion with the larger displacement was not contingent on the particular timing sequence used, but was due to a spatial limit that is less than 20′ arc over a wide range of ISIs. This is not to claim that there is no variation of the spatial limit with ISI.

DICHOPTIC PRESENTATION

The preceding experiments have shown that the appearance of coherent motion is limited by the displacement of dots within the patterns. Another possible constraint was investigated: do both patterns have to be presented to the same eye?

Method

A single pair of patterns was used, of the smallest element size (2·7′ arc), containing a central horizontal rectangle displaced by one element's width. There were two conditions: binocular viewing of both patterns, as used in the preceding experiments, and dichoptic viewing. In the latter case opposed Polaroid filters were inserted in the light paths from the two patterns, and a Polaroid in front of each eye selected one pattern. The illumination of the patterns was adjusted to match the brightness in the two conditions.

In both conditions the stimuli were alternately exposed for 75 msec each. The inter-stimulus interval was either 10, 30, 50, 70 or 90 msec.

In the dichoptic case, the results can only be of value if the intended retinal disparity is maintained, i.e. if convergence is on a point in the optical plane of the patterns. The third channel of the tachistoscope was therefore used to provide a continuously visible white fixation cross, which was present in both conditions. Subjects were instructed to maintain fixation on this cross.

The preceding experiments had shown that the four measures of perceptual segregation used were highly consistent. In this experiment, therefore, subjects were simply required to give a rating of the clarity of the rectangle. They were explicitly told to use the value "five" on the rating scale for cases where the rectangle was not discriminable. They were also asked to say whether the rectangle appeared static or oscillating, and whether it appeared to be in a different depth plane from the surround. As before, they initiated the exposure sequence themselves, but could continue to view it for as long as they wished.

In preliminary tests, subjects were tested for normal stereopsis with a standard random-dot stereo pair (i.e. identical surround, disparate central square). They were then shown the same pair in alternating dichoptic presentation (10 msec ISI). Only subjects who in both cases readily perceived the disparate square as in a different depth plane from the surround were used in the experiment.

Results

Figure 7 shows the mean rating as a function of ISI for both conditions. The binocular data effectively replicates that for the one-element shift plotted in Fig. 6(c); the clarity of the rectangle gradually declines over the range of increasing ISI. The dichoptic ratings show that for ISI's of 50 msec and longer, the rectangle is in-

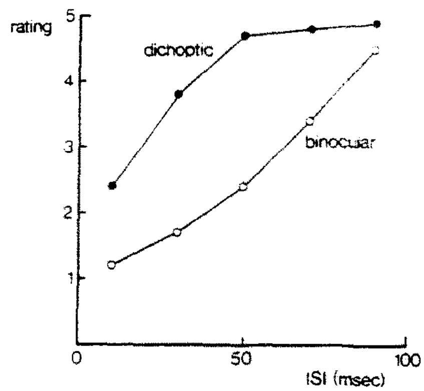


Fig. 7. Ratings of clarity of the rectangle, for binocular and dichoptic viewing, as a function of inter-stimulus interval. 1 = maximum clarity; 5 = indiscriminable. —○—: binocular viewing. —●—: dichoptic viewing.

discriminable (rating 5) on most of the trials. Thus the process underlying perceptual segregation in the dichoptic case does not operate over the same range of ISI's as the motion-detecting process in the binocular case. For ISI's where dichoptic segregation did occur, clarity was poorer than for binocular viewing.

With binocular viewing, when the rectangle was discriminable all subjects described it as oscillating. In contrast, the rectangle visible dichoptically with ISI's less than 50 msec was reported to appear quite static on all but two trials (2 per cent of the total). Thus not only does the process acting the dichoptic case differ from the binocular motion-detecting process in its maximum ISI; it is not a motion-detecting process at all. The motion-detection process underlying segregation does not operate dichoptically.

The displaced region in the dichoptic pair of patterns has a uniform retinal disparity, while the surround region has no correlation between the two eyes. It is well known (Efron, 1957; Ogle, 1963; Dodwell and Engel, 1963) that disparate stimuli can give a stereoscopic depth sensation even when they are presented successively rather than simultaneously to the two eyes. Thus the discrimination of a static rectangle for short ISI's can arise from a variant of this effect.

We are not dealing with an ordinary stereoscopic depth difference between the rectangle and surround, since the surround had no consistent disparity. However, the stereoscopic mechanism might be expected to respond differentially to a disparate region and one uncorrelated for the two eyes. In fact, three of the five subjects perceived the central rectangle as clearly standing in front of the uncorrelated surround. (One subject saw it as further than the surround, and one could not describe the way in which it was differentiated from the surround). The appearance of binocularly uncorrelated areas as more distant than correlated areas is widely observable, and may be related to the observation of Julesz (1971, p. 259) that the monocular strips at the boundaries of areas of different disparities in a random-dot stereogram are seen in the plane of the more distant of the adjacent binocular areas.

DISCUSSION

Classical and random-dot apparent movement

The results of the first two experiments show that the pairing of dots in successive exposures, yielding motion detection and hence perceptual segregation, is limited to a spatial range of about a quarter of a degree of visual angle. Classical studies of the spatio-temporal limits of apparent motion have generally used the successive illumination of two isolated spots, with subjects required to report the appearance of simultaneity, motion, or succession. This method yields reports of motion over much larger spatial ranges. For example, Neuhaus (1930) used 27′ as his smallest separation, and found some appearance of motion up to 4·5°, his largest separation; Zeeman and Roelofs (1953) obtained apparent motion throughout their range of separations from 2 to 18°; and Smith (1948) even reports it when one light is presented to the temporal margin of each eye. Tyler (1973), however, found an upper limit of 10′ at the alternation frequency used here.

The random-dot display differs from the classical in two important ways: the presence of a dense array of dots, and the use of perceptual segregation as a criterion for the effect. The dense array might be expected to provide alternative interactions not present with an isolated stimulus. However, the constancy of the spatial limit with varying dot size suggests that the existence of near-neighbour alternatives is not the critical factor.

Two processes in apparent movement?

Segregation does not necessarily result when adjacent areas of the visual field have a discriminable difference on some dimension. Olson and Attneave (1970) have shown that an area of horizontal line segments is segregated from an area of vertical segments, but that areas of upright and inverted V-shapes do not appear segregated; Julesz and Hesse (1970) found that in arrays of rotating line segments, areas of different speeds of rotation were segregated, while areas of opposite directions of rotation but equal speeds were not. It appears that the visual system can only use certain specific stimulus properties as the basis of this sort of figural segregation, properties which are probably extracted at a fairly low level in the processing of the visual input. This leads to a hypothesis for the divergence of classical and random-dot experiments on apparent motion. A low-level motion detecting process, with a very limited spatial range, may underly the occurrence of perceptual segregation in random-dot arrays. A second, higher process may lead to the perception of motion from the succession of two more widely separated stimuli, but the output of this process cannot be used to segregate an area of the field.

The notion that the process leading to segregation occurs relatively early in the visual pathway is supported by the finding that such segregation cannot be produced by dichoptic presentation of relatively displaced areas of dots. Again, this is in contrast to classical apparent motion experiments, where dichoptic presentation does lead to the perception of motion (Shipley, Kenney and King, 1945).

It is tempting to identify the low-level short-range process leading to segregation with the activity of directionally selective neurones in the visual pathway, which in other species are known to respond to suitable discontinuous sequences of retinal illumination (Barlow and Levick, 1965). The higher system involved in long-range apparent motion behaves in ways that do not seem readily explicable by this kind of mechanism, but rather involve more complicated processes of interpretation of the stimulus configuration (Rock, 1970).

Is there any other support for this distinction? Braddick (1973) found that the segregation due to apparent motion could be abolished by a bright uniform field exposed in the inter-stimulus interval, an effect which did not work dichoptically. There does not appear to be such a masking effect with classical apparent motion stimuli, suggesting that it may act on the low-level process selectively.

Kolers (1972, p. 37) displayed a line in a succession of positions. When only two positions were used, good apparent motion occurred with a separation as large as 7·5°. However, with more than two positions, smooth continuous motion was only perceived if the inter-line separation was as small as 14′ arc, a figure close to the spatial limits found here. This would suggest that the higher "interpretive" system cannot couple a series of displacements into a continuous perception of uniform motion, whereas the lower-level system can.

A difference between the effects of large and small displacements is implied by the observations of Kelly (1966) and Kulikowski (1971) on gratings of which the bright and dark bars alternated, at various combinations of temporal and spatial frequency. With high spatial frequencies (and hence small displacements of each bright or dark bar) apparent motion of the bars occurred up to the highest temporal frequencies for which the gratings were visible. With low spatial frequencies (large displacements) apparent motion was seen at low temporal frequencies, but for higher temporal frequencies "spatial frequency doubling" was observed. Kelly attributed this effect to a temporal integration following a non-linear transformation of the input. Why is this integration not observed at high spatial frequencies? Possibly with small displacements, but not with large, motion detection can occur at a relatively early stage in the pathway and can therefore pre-empt the later integration effect. In Kulikowski's results (where the temporal variation was square-wave and hence was most comparable to the abrupt changes in the random-dot displays), motion replaced doubling at spatial frequencies between 1·25 and 5 c/deg, i.e. displacements of 6–24′ arc, closely comparable with the spatial limits on the motion process responsible for segregation.

The existence of selective aftereffects has been widely used as an argument for selective neural detector mechanisms, and in particular the movement aftereffect has been interpreted as due to the fatigue of directionally selective neurones (Sutherland, 1961; Barlow and Hill, 1963). Banks and Kane (1972) measured the aftereffect of apparent motion and found that it became vanishingly small when the spatial discontinuity of the stimuli was 12·5′ arc. The concluded that this value approximated to the separation of input channels to motion detectors, a value close to the limit for segregation. However, Anstis and Moulden (1970) obtained a motion aftereffect from apparent motion stimuli with a spacing of about 1°. A more severe problem in linking the aftereffect to the mechanism responsible for segregation comes from the fact that Anstis and Moulden found the aftereffect to be present following dichoptic stimulation, though they also found evidence for a monocularly driven mechanism.

Selective processes

The introduction to this paper raised the question of whether a global process, analogous to that postulated in stereopsis, was necessary to select the perceived motion from among the potential local interactions. This question is not satisfactorily resolved by the results. An effectively selective process has been found, namely the upper limit on the spatial range of such interactions. This limit is sufficiently small, relative to the element sizes used, to leave little scope for further selection by either a global process, or a "nearest-neighbour" principle. For the smallest element size, however, clear coherent motion was seen for displacements greater than a single element's width. This at least leaves open the possibility that some selective principle acts within the limiting spatial range of a quarter of a degree.

Two important differences from the stereoscopic case can be stated: (i) the low upper limit on the spatial range of interaction (although there is certainly some upper limit of disparity for stereopsis in random-dot patterns) (ii) the fact that, when the displacement is too large for coherent motion, incoherent motion due to fortuitous pairings of dots is seen. In contrast, "incoherent stereopsis", i.e. a perception of individual dots in haphazard depth planes, is never observed.

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Note added in proof

An observation by Regan and Spekreijse (1970) supports the conclusions of this paper. As a control for an experiment on stereopsis, they presented the two members of a random-dot stereo pair alternately to the same eye at a rate of 0·45 alternations/sec (ISI = 0). They noted that the displacement of the central region gave an illusion of apparent motion if it was 10′, but not if it was 20′ or 40′. Further, the 10′ displacement, but not the others, yielded a marked cortical evoked potential. These figures show excellent agreement with the limit on coherent motion found here.

I thank Dr. D. Regan for bringing this observation to my attention.

Résumé—On déplace uniformément une région dans une paire alternée de dessins à points au hasard. On perçoit, si le déplacement est petit, une forme cohérente et séparée en mouvement. La limite de ce déplacement est sa taille absolue (maximum 15' environ) plutôt que le nombre de largeurs d'éléments. La ségrégation due à ce mouvement apparent est supprimée si les deux dessins sont exposés à des yeux différents.

Ces conditions de ségrégation diffèrent des données classiques du mouvement apparent. La ségrégation perceptive est peut-être due à l'activité de détecteurs de mouvement a faible niveau et domaine spatial limité, tandis que le mouvement apparent classique avec de plus grands déplacements met en jeu un autre processus.

On discute le problème de délection parmi diverses interactions possibles des éléments du stumulus dans le mouvement apparent.

Zusammenfassung—Ein Bereich in einem ungleichen Paar ungeordneter Punktmusterbilder wurde gleichmässig verschoben. Dieser Bereich wurde nur dann als getrennte, sich gleichmässig bewegende Erscheinung wahrgenommen, wenn die Versetzung gering war. Die Begrenzung der Versetzung war gegeben durch ihre absolute Grösse (maximum etwa 15') und nicht durch Anzahl der Elemente. Versetzung durch Scheinbewegung trat nicht auf, wenn die beiden Muster verschiedenen Augen angeboten wurden. Diese Voraussetzungen zur Trennung unterscheiden sich von denen, die in den klassischen Arbeiten zu Scheinbewegungen gefunden wurden. Die Wahrnehmung der Trennung kann durch periphere Bewegungsdetektoren mit begrenzter örtlicher Empfindlichkeit vermittelt werden, während klassische Augenbewegungen mit grosser Versetzung einen anderen Prozess bedingen. Das Problem einer Unterscheidung zwischen alternativ möglichen Wechselwirkungen von Reizelementen bei Scheinbewegungen wird diskutiert.

Резюме—Определенная область пары паттернов, состоящих из точек расположенных в случайном порядке и предъявляемых попеременно, одинаково смещалась. Это воспринималось как выступающая, когерентнодвижущаяся форма, но только в том случае, если смещение было небольшим. Пределы этого смещения зависят скорее от абсолютной величины его (максимум около 15°), чем от числа злементов включенных в эту область. Выделение, дающее кажущееся движение, не возникает, если два паттерна предъявляются разным глазам.

Эти условия выделения отличаются от тех, которые находили в классических работах, посвященных кажущемуся движению. Воспринимаемое выделение может возникать вследствие активности детекторов низкоамплитудного движения ограниченного пространтственного диапазона, тогда как классический вид кажущегося движения, когда дается большое смещение, определяется другими процессами. Обсуждается проблема отбора альтернативных возможных взаимодействий элементов в стимуле при восприятии кажущегося движения.