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SHAPE AND COLOR IN APPARENT MOTION[1]

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Abstract—The resolution of disparity between two shapes that are flashed at appropriate spatial and temporal separations is smooth and continuous. The present inquiry was directed at the corresponding resolution of disparate colors. Presented with a red and a green, say, the visual system could desaturate one to a neutral point and then saturate the other from that point; or it could allow the red to change through orange and yellow to green, for example. Neither of these occurred. No intermediaries were found between two discriminably different colors: rather, one changed abruptly to the other. The abrupt change of color occurred even when the stimuli were doubly disparate, in shape and color. Then the shape was seen to change gradually, the color to change abruptly, but color was always seen filling in the contours of the apparently changing shape.

Illusions of motion occur under many circumstances, such as a slow blink of the eyes, their mechanical movement, their slow traverse of a surface, and many others (Carr, 1906). In some cases, such as the waterfall illusion and the rotating Archimedes spiral, the illusory motion and its after-effect require the physical movement of a contour's image across the retina; others do not require such a stimulus (Stoper, 1973). Of all the illusions of motion, and one not dependent upon a moving stimulus, surely the best known is the illusion of motion that occurs when two discrete stimuli are flashed at the proper intervals. In the more than 140 yr during which this phenomenon has been studied, no wholly satisfactory theoretical account of it has been offered.

The question motivating the present work on apparent motion was put by Nelson Goodman, who has long been concerned with descriptions of perceiving (Goodman, 1951). His query followed the report that two disparate contours flashed at the proper interval undergo a plastic deformation in appearance, so that the first (say a square) appears to become the second (a triangle), over a wide range of disparate shapes (Kolers and Pomerantz, 1971). The query was directed at the corresponding occurrence for color. If two flashes present first a red square and then a green one, for example, how is the disparity of color resolved by the visual system? Does the red change through orange and yellow to become green (and vice versa); does the red seem to desaturate to a neutral gray and the green grow out of this zero point; or does the visual system use still some other means to resolve the disparity? In fact, what rules does the visual system follow to resolve disparate colors?

A few reports in the literature on apparent motion are directed to the question of color. Wertheimer (1912), van der Waals and Roelofs (1930, 1931), and Squires (1931) among others all reported that apparent motion was seen between disparately colored flashes, but they did not systematically address the question of how the colors appeared to change. More recently Foster and Idris (1974) reported that motion effects occurred with spectral lights presented near threshold, but with their procedure they could not study appearance of color change. Hence while the literature confirms that colored as well as achromatic stimuli can be seen in apparent motion, similarities or differences that might exist in the resolution of colors and shapes have not been studied. The present research is on this topic.

EXPERIMENT I: COLOR DISPARITIES

To answer the question of the nature of the color change, we matched the appearance of an illusory stimulus with a physical stimulus that was presented at various points along the apparent path of the illusory one. We did this when colors were held constant and shapes were disparate, when shapes were held constant and colors were disparate, and when both shape and color were disparate. This first experiment studied disparities of color.

METHOD

Apparent motion conditions are created by the pulsed flashing of stimuli, which may be either superposed or laterally displaced. We used a four-channel timer, as previously (Kolers and Pomerantz, 1971), which controlled the duration of each of two flashes and the intervals between the offset of each and the onset of the other. The flashes appeared in a tachistoscope on a white field of approx 4 mL luminance. The visual extent of the field was approx 6·65° wide and 3·3° high (see Fig. 1). The flashes appeared within this field, with center to center distance of approx 3·6°. To create a perception of apparent movement two pieces of colored art paper from the Color Aid set were each illuminated for 150 msec; a pause of 50 msec intervened between the offset of the first flash and the onset of the second, and a pause of 1·5 sec came after the offset of the second flash. With these conditions all subjects saw movement of the first stimulus to the second, across the empty field separating them.

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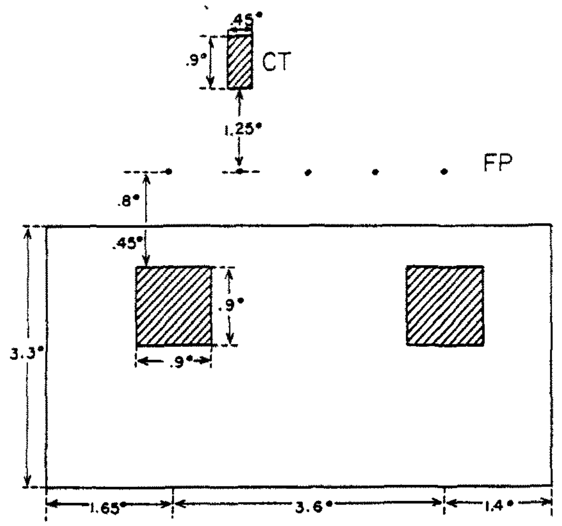

Fig. 1. Observer's view of the display. A screen 6·65° wide × 3·3° high was continuously illuminated by cycles of white light from gas-discharge lamps. During two parts of the four-part cycle, patches of colored paper appeared at the two places indicated by hatched lines. Above the illuminated rectangular field was the row of fixation points (FP), only one of which was luminous during a trial. Above the fixation points was the movable aperture (CT), a patch of spectral light. The size and shape of the movable aperture are shown as for Experiment 1.

The main purpose of the experiment was to measure the color of the illusory object in its passage across the intervening space. This was accomplished by having the subject "match" a patch of spectral light to the color of the illusory object. The match was made in the following way. A movable neon glow lamp was positioned at one of several locations above the rectangular stimulus field (the points marked FP in Fig. 1). Above this row a movable aperture exposed spectral light from a Bausch and Lomb grating monochromator (CT in Fig. 1). The subject first aligned the movable aperture with one fixation point; cycling of the stimuli was then initiated and the subject adjusted the setting of the monochromator until the patch of spectral light (the comparison target) approximated the color of the illusory object as it seemed to pass immediately below the luminous fixation point. Typically, 3–6 cycles of stimulation sufficed to make the match, and five such matches were made for each position, the experimenter changing the monochromator setting in a haphazard fashion after each match. Cycling was then interrupted, the fixation point was changed, and the aperture was moved to alignment with the new point of fixation before cycling was resumed. The positions fixated were presented in random order; and in addition to the measurements just described, measurements were also made of each of the flashes alone, the eye fixated on the point directly above the patch of colored paper.

The matching was of course only approximate. Colored papers are polychromatic, not spectral, but they have a dominant wavelength. Spectrophotometric measurement of the papers was assumed to be irrelevant to the purpose of the present experiments. In the figures, both means and standard deviations of the matching settings of the monochromator are shown; thus the dominant wavelength of the papers can be estimated from the matches made to the papers when they were flashed singly. Color Aid papers are commercial artists' papers; we do not know their Munsell equivalents.

Before beginning the tests the subjects were dark-adapted for about 15 min, and then light-adapted to the level of the white background for 2 min. All observations were monoptic with the right eye. A chin and forehead rest supported the head during measurements.

Three subjects were tested, the two authors and a female undergraduate at the University of Toronto who was paid for her services. This third subject, JW in the figures, came to the experiments naive as to their purpose and to psychophysical observation. She was given several hundred training trials as practice before measurements were taken, but remained uninformed of the purpose of the tests. All three subjects had normal color and spatial vision, as measured with the H-R-R pseudoisochromatic plates and the Bausch and Lomb Orthorater.

First measurements were made to assess the visual system's resolution of disparate colors when their shapes were identical. For this purpose two squares or two triangles were presented, one at each of the positions indicated in Fig. 1. The four colors tested were red, green, blue, and yellow, Color Aid 49, 177, 129, and 17, respectively. The shapes were a square and an equilateral triangle of approximately the same area as the square, 0·81 deg². To reduce the permutations of shape, color, and direction of motion to a manageable number, each subject was tested at only a few conditions, but with enough overlap between subjects to permit comparisons. Figure 2 summarizes the conditions that were tested. The shapes in the figure show the shape tested, and the arrows indicate the direction of apparent motion. For example, a red triangle was alternated with a yellow triangle, the direction of motion from red to yellow; and a yellow square was alternated with a red square, the direction of motion from yellow to red. Both shapes and both directions of motion were tested with red and green, and with blue and yellow.

RESULTS AND DISCUSSION

The results for subject MvG are shown in Fig. 3 for blue squares and triangles alternated with yellow squares and triangles (broken lines), and for green squares and triangles alternated with red squares and triangles (solid lines). There are no systematic differences between squares and triangles (symbols). The arrows in the figure point to the measurement of each of the two flashes in the absence of the second; the vertical bars through the symbols mark ± 1 S.D. The similarity of measurement when a single colored paper appeared (arrows) and when it was followed after 50 msec by another to give a sense of apparent motion shows that the dynamic condition induced no distortion on the reference condition. The standard

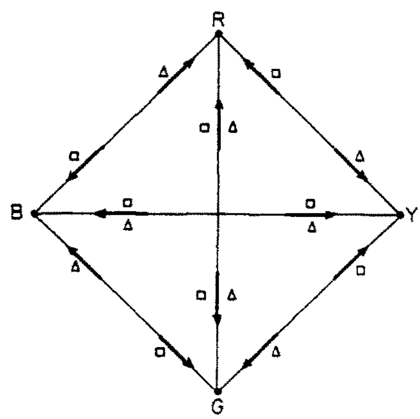

Fig. 2. Combinations of color and shape that were tested.

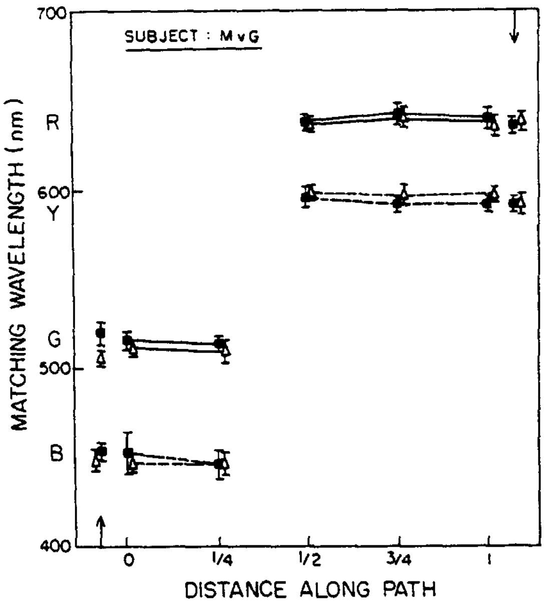

Fig. 3. Results for MvG matching the color of triangles and squares. Green squares or triangles were alternated with red ones (solid lines), and blue ones were alternated with yellow (dashed lines). The arrows point to matches of the stimuli when they were presented singly; the short vertical bars through the symbols mark ± 1 S.D. The abscissa marks off portions of the path of illusory motion (the distance separating the two patches in Fig. 1) and the ordinate indicates the wave length setting of the monochromator when the spectral patch "matched" the apparently moving illusory object.

deviations show that the judgments were fairly stable. The main result therefore was that the transition between green and red, and between blue and yellow, was always abrupt; there were no intermediary colors. With this person the illusory object retained its initial color appearance through one-quarter of its traverse of the path, and then shifted abruptly to the color of the terminus.

The results for all three subjects matching the color change between two squares is shown in Fig. 4, in one case between a red square and a green one (solid lines), in the other case between a blue and a yellow (dashed lines). Notice that for MvG and PAK the transition in appearance occurred before the half-way point, but for JW it occurred after the half-way point. For all three subjects the transition was abrupt. Matching color appearance with a monochromator would not, of course, reveal a change in which the first color gradually desaturated to gray and the second grew out from the gray. This possibility was inquired after, but was never reported. Morever, its occurrence would have been revealed by an inability to match monochromator settings to appearance of the illusory object, but subjects were always able to make chromatic matches.

It could be argued that the "distance" between the disparate colors accounts for the abruptness of the color change. Perhaps two plane shapes are in some sense more similar to each other, and thus more readily interchangeable, than two colors. On this reasoning if the two colors were more similar, the transition might be seen as continuous rather than abrupt. To test this possibility subjects MvG and JW each matched the transition between two reds, and between two greens (Color Aid 49 and 65, and 161 and 177, respectively). In addition, the measurements were made at smaller separations along the path. The results are shown in Fig. 5. The arrows again mark the measurements of a single flash, and the curves mark the results for various points along the path of illusory motion.

For both subjects the transition between the two reds and between the two greens was abrupt. Subject MvG again reported the color change as occurring before the half way point, but for subject JW it occurred after the half way point. With these stimuli, and with all others tested, the finding was that if a difference in color between the two flashes was distinguishable at their physical locations, the termini of movement, that difference would be resolved in an abrupt manner. This observation held for all the chromatic combinations illustrated in Fig. 2; and it held also for achromatic stimuli differing in gray level.

EXPERIMENT II: COMPARISON OF COLOR AND SHAPE

The cited work reported that disparities between plane shapes were resolved smoothly and continuously (Kolers and Pomerantz, 1971); the present work found that disparity of color was resolved abruptly. Considerable evidence has been put forward supporting a notion of seriation in visual processing: color is said to be a channel-specific process, for example, hence must occur in some sense "prior to" encoding of shape, which is both channel-specific and "central" (Julesz, 1971; Turvey, 1973). The question must thus be put as to the resolution of disparate shapes in disparate colors. How are these dual disparities resolved?

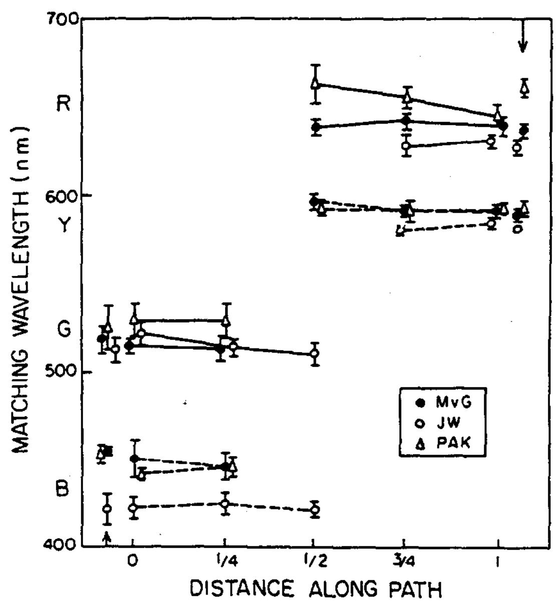

Fig. 4. Results for three subjects matching the color when a red square alternated with a green one (solid lines) or a yellow square alternated with a blue one (dashed lines).

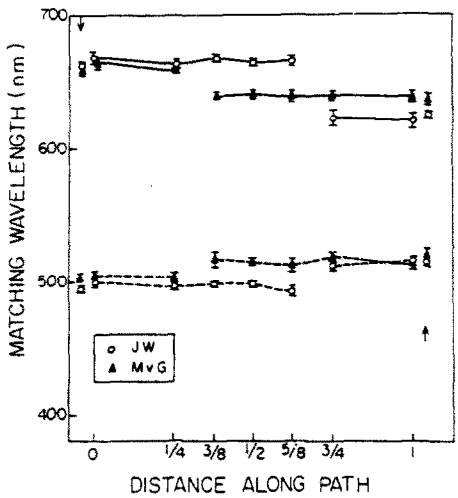

Fig. 5. Results for two subjects matching the transition between two shades of red (solid lines) or two shades of green (dashed lines). The abscissa was divided more finely than in Figs. 3 and 4. Subject MvG reported a transition before the half-way point; subject JW reported it after the half-way point.

METHOD

To test the question the apparatus was modified so that a variable trapezoid could be changed in a continuous way to change the shape of the patch of spectral light (CT in Fig. 1). The trapezoid was a right isosceles triangle as one limit and a square as the other. The square subtended 0·9° on each side, closing down to the triangle with a base and height of 0·9°. Thus when a square and triangle were the disparate shapes positioned as in Fig. 1, the viewer could match the color of the illusory object by changing the color of the spectral patch, and match the shape of the illusory object by changing the shape of the patch.

The variable part of the aperture changed the top and side of a square into the hypotenuse of an isosceles right triangle, and vice versa, by pivoting around the bottom-right corner of the aperture (a pivoting "hypotenuse"). When the aperture was square, the adjustable line measured 90° to the horizontal; when the aperture was triangular, the adjustable line measured 45° to the horizontal. Settings of this line therefore ranged between 45° and 90°, designating appearances ranging from a triangle through various trapezoids to a square.

The stimuli presented were the same colors as in Experiment I; their shapes were triangle and square. For two subjects (MvG and JW) apparent change from square to triangle and the reverse was well matched by rotation of the triangle's hypotenuse. For the third subject (PAK) the appearance more often was of the hypotenuse of the triangle bending in the middle and moving upward and outward to become side and top of the square, or top and side of the square contracting to become the hypotenuse of the triangle. This subject matched the area of the physically presented shape to the apparent area of the illusory one; the other subjects matched appearance of shapes more directly.

Measurements were made in a fashion similar to that of Experiment I except that as well as adjusting the monochromator to match apparent color, the subject also adjusted the aperture to match apparent shape. Five measurements were made of each variable at each of the distances along the path of illusory motion in various random orders. In addition to the measurement during apparent motion, the two termini were measured for apparent shape and color when each was presented alone; the arrows in the figures mark the latter measurements.

RESULTS

Figure 6 is divided into quadrants, the two on the left for color and the two on the right for shape. The top left panel shows the matching values from MvG for change of color of a blue triangle appearing to become a yellow square; the top right panel shows the matching values for change of shape. The color change was abrupt, the shape change was continuous. In the bottom half of the figure the results are shown for a yellow square alternated with a red triangle, and for a red triangle alternated with a yellow square. Again, the color changes were abrupt, the shape changes were graded.

Figure 7 presents the results for subject JW. The top panels are for a green triangle changing into a red square, and a red square changing into a green triangle. The middle panels show the corresponding results for yellow to blue and blue to yellow; and the bottom panels show the results for change from blue to red. In all cases the color changed abruptly, the shape changed in a graded way. For this subject changes of color usually occurred after the half-way point; thus in the middle left panel the illusory object appeared to be yellow through three-quarters of the distance along the path (upper curve) and then abruptly changed to blue (bottom right of the panel), and the blue object appeared to be blue through three-quarters of its path (bottom curve of the middle left panel) and then abruptly changed to yellow.

Figure 8 shows data from the third subject. Again the color changes were abrupt and the shape changes were graded. For the transition from green to blue the change was well-marked; when yellow and green

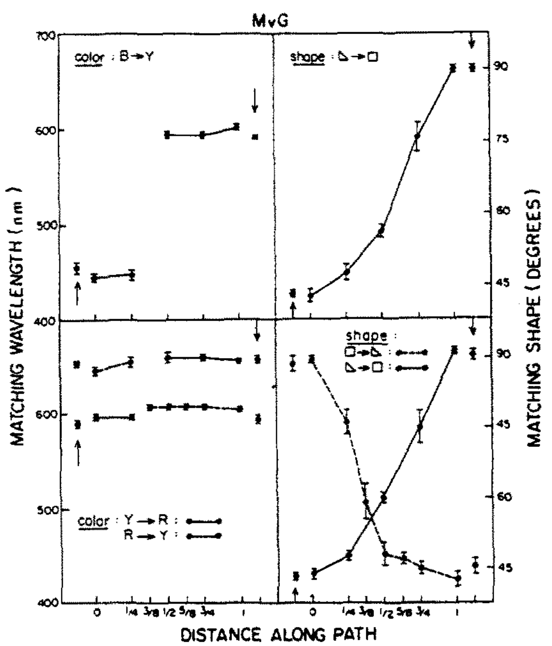

Fig. 6. Results for MvG matching color and shape. The left panels show the results for color, the right panels show the results for shape. Arrows point to measures of single stimuli flashed briefly; vertical bars mark ±1 S.D.

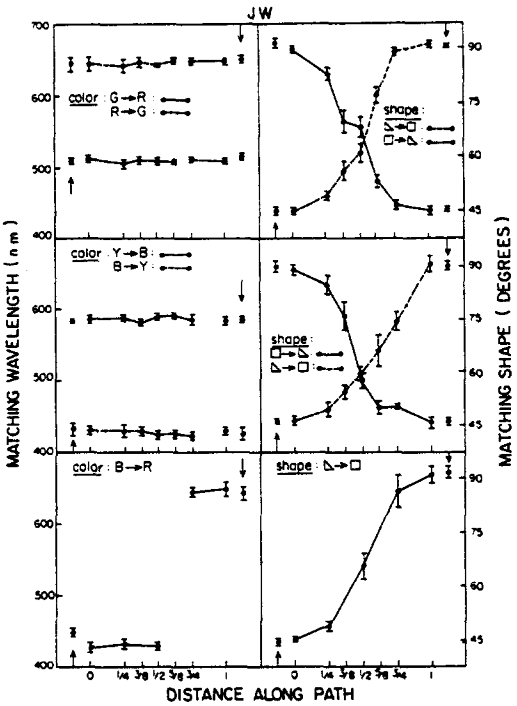

Fig. 7. Results for JW matching color and shape. The transitions in color always occurred beyond the half-way point.

were alternated, however, the results were less consistent and sometimes yellow was matched at the three-eighths point on the abscissa, and sometimes green, hence both values are shown.

There is some suggestion in the data for all three subjects that the square underwent more than half of its apparent shrinkage before the half-way point, and the triangle underwent less than half of its apparent growth before the half-way point. Thus the measurement of the illusory shapes underestimated the area they would have acquired or lost if their graded changes across the path were made up of equal increments and decrements.

OTHER OBSERVATIONS

Other conditions were explored qualitatively to test the limits of the results, subjects reporting their observations verbally. The conditions included (1) alternating achromatic contours on a white ground, such as squares or triangles of various shades of gray; (2) alternating black or gray outline figures with colored outline figures, all on a white ground; (3) alternating black, gray, or white squares on a 50% gray ground with colored triangles on the same gray ground; and (4) alternating black or gray outline figures on a white ground with patches of color on a white ground. In all these tests the colors changed abruptly, the shapes changed continuously. In still other tests the presentations were superposed rather than separated. When the stimuli differed both in color and in shape, it was very easy to see outcomes consistent with all of the preceding conditions: the shape changed in a smooth and continuous way, the color changed abruptly. For example, when a green square was alternated with a red triangle at the same physical location, triangle changed to square and square to triangle in a graded way, but green changed to red abruptly. However, color was always present in the changing shape. The colored area of the square seemed to shrink as the square changed into a triangle, and the colored area filled in as the triangle grew into a square. The change from one color to another was abrupt, that is to say, but a single color filled in, in a continuous way, the "boundaries" of the apparently changing shape.

DISCUSSION

One long-standard explanation of apparent motion was that the visual nervous system perceived a form in two different locations and created a sense of motion to resolve the disparity; another was that the objects in two disparate locations were perceived in a single time-based Gestalt. In both of these accounts perception of form was primary and perception of location and "change" of location was secondary. Anstis (1970) and Kolers and Pomerantz (1971) independently demonstrated that these accounts are not correct; perception of form plays very little role in the perception of apparent motion.

More recently other views have been put forward, extrapolated from neurophysiological findings. The proposal has been made that the action of motion detectors within a receptive field accounts for apparent motion. This proposal has been shown to be erroneous as to receptive fields, for objects with similar stimulatory properties for a receptive field were not seen similarly in motion (Kolers, 1972a). In an intended "proof" of the value of the neurophysiological explanation, moreover, Frisby (1972) found that the readiness of two briefly presented lines to be seen in apparent motion was actually independent of their orientation, results exactly counter to what the neurophysiological analogy would require. (Breakdown of apparent motion following repeated stimulation of

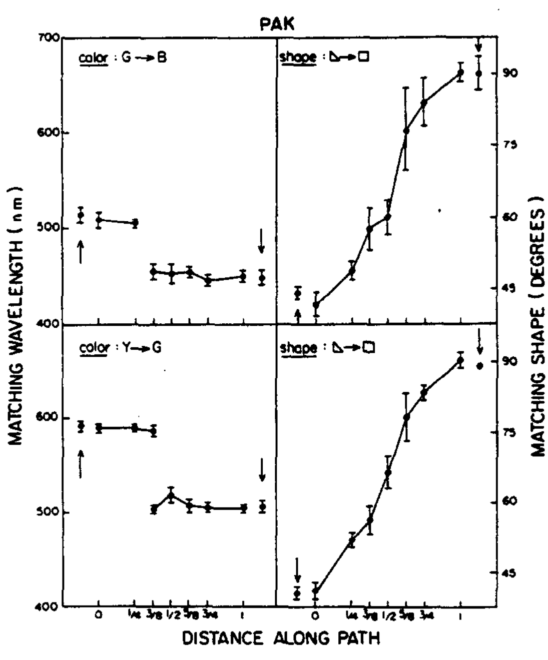

Fig. 8. Results for PAK matching color and shape.

a fixed retinal region did vary with orientation of the lines. Frisby may have been measuring not the perception of motion, therefore, but a figural after-effect of repeated stimulation.) Thus a theory emphasizing the perception of form as primary is not valid, nor is its opposite, a theory based only on excitatory fields or even on the responses of motion-sensitive and orientation-sensitive detectors.

Subtractive difference-field model

Anstis's (1970) more sophisticated proposal was that two correlated regions of stimulation that differed in their local brightness was the requirement for the motion percept. Using random-dot figures as the stimuli, he found that whenever depth was seen with a pair presented stereoscopically, movement was seen when the two were presented to one eye sequentially. Building on Julesz's (1971) difference-field model of depth, Anstis argued as described.

Both Julesz's and Anstis's accounts are of course incomplete, Julesz's because many conditions in addition to local regions of excitation yield perceptions of depth, temporal asynchrony of spatially separated points, for one (Kolers, 1963); and Anstis's on three counts at least. The first is that although perception of form is not required for and is in no sense prior to the perception of apparent motion, form does play a role in the perception nevertheless. Kolers and Pomerantz (1971) found that although form accounted for only a few per cent of the total variance of their data, those few per cent were stable; in other experiments it was shown that the way apparent movement resolved the difference between two shapes depended upon the particulars of their disparity (Kolers, 1972b, Figs. 7.1, 7.3 and 7.4). This should not have been the case on a simple brightness difference-field or excitation model.

Second, the difference-field explanation would seem to hold only for superposed stimuli of considerable figural density (microstructure). But apparent motion is also perceived when two stimuli are side by side, even a few degrees apart, as in Figs. 6–8, above. With two squares as the stimuli, a difference field model would have to predict that near parts of the figures moved together, the right vertical of the left-hand square and the left vertical of the right-hand square, for example. As the neighboring verticals moved, the more distant ones would be left on their own, precluding perception of a whole moving figure. Alternatively, the attraction between the near verticals might compel movement of the more distant ones and the squares might be seen to rotate in depth around the near verticals. But this is a difficult perception to attain (Kolers, 1972b). In fact, and third, Braddick (1974) has shown that an account based on a difference-field could hold only across-spatial separation of the correlated regions of less than 15' of angle on the retina, yet apparent movement can be seen across several degrees of spatial separation. In fine, a point-by-point difference-field model does not do full justice to the data partly for the very reason that the Gestalt psychologists first emphasized: figure is an important property of visual stimuli. Excitation and figural properties both enter into the processing of objects in apparent motion.

Two components model

The way in which they enter is not yet wholly clear. Kolers (1972b) proposed that two "systems" mediated apparent motion, one based on signals regarding location of stimuli (called H signals), the other based on signals regarding shape or form (V signals). In the present work we found that the H component affected both color and shape equally, whether the flashes were chromatic pairs, achromatic pairs, or a mixture of chromatic and achromatic colors. The V component did not affect color and shape equally; indeed, perhaps does not affect color at all. In addition to supporting the earlier claim that the perception of motion is not due to a single mechanism (Kolers, 1963), these results further limit the applicability of a brightness-difference model. These various arguments have implications for a theory of visual perception of form.

One line some accounts have taken is a serial processing model. It is supposed that perceptions are due to operations at successive locations in a chain, each working on the product of the process immediately preceding. Theories that propose that color is coded before shape, or shape coded before or after movement, or movement before or after depth are the kind of stage-wise account that is meant. The compelling counter-evidence from the study of apparent motion is that the mechanisms for form and motion interact, and similarly those for color and form interact. For example, when the red square and green triangle were alternated, the shapes were seen to change continuously, the colors to change abruptly, but color always filled in the contour of the form undergoing apparent alteration of shape. Since, despite the abruptness of the color change, the color mechanism did fill in the gradually changing shape, the color system must have monitored the operations of the shape system. Color information cannot be coded before shape information if it can follow change of shape in this way. A similar argument can be made for the shape and location systems (Kolers, 1972b). Rather than linear or serial decomposition or analysis (theories of perception proposed on the basis of the electrophysiological evidence), these results implicate substantial interaction and mutual modulations of signals in the development of a visual perception.

Two theories

One account of the present findings would maintain that the visual system uses two different principles to resolve disparities, digital or quantal for color and brightness, analog or graded for shape and location. This difference could be due in part to differential processing of figural and non-figural properties of stimuli. Color and brightness are properties of surfaces, while edges are boundaries between them. The surface and the edge of some achromatic shapes are affected differentially by masking flashes (Kolers, 1962, 1968). For the reduced case of color of a single object, Arend (1973) revived and evaluated positively the notion that the visual system detects only "difference signals" at edges and supplements this information to fill in the surface the edge bounds. In the present more elaborate case the transition *between* colors is described, an event beyond Arend's discussion except as it is consistent with the notion that the visual system uses different procedures to encode edges and surfaces. Hence, a difference in the active principle is one possible account of the results. A second account proposes an experiential basis for the difference.

As one moves his head in a natural environment, retinal illuminance changes somewhat, even when one fixates the same object, and shades or tints also seem to change slightly. Large chromatic changes are the exception rather than the rule, however. A large chromatic change is more likely to be associated with a change in the object fixated, except in a poorly tuned television set. The retinal image of an object changes shape continuously, however, with every movement of the eye, yet the object retains its identity. Hence the perceived abruptness of color change and the perceived continuity of shape change need not necessarily be due to fundamentally different principles of visual resolution. Perhaps abruptness is the standard resolution that has been modified for shape by long experience with frequently varying inputs. If a person were provided with equivalently varied chromatic inputs that decoupled color and object over many hundreds or thousands of exposures, the experience might induce a tendency for color change also to be resolved in a continuous way. An experimental program in which many kinds of chromatic change characterized stimuli whose shape did not change simultaneously could resolve the issue. Children exposed to a great deal of color television might be suitable subjects; tests of color-deficient eyes could also prove interesting.

REFERENCES

Anstis S. M. (1970) Phi movement as a subtraction process. *Vision Res.* **10**, 1411–1430.

Arend L. E. (1973) Spatial differential and integral operations in human vision: implications of stabilized retinal image fading. *Psychol. Rev.* **80**, 374–395.

Braddick O. (1974) A short-range process in apparent motion. *Vision Res.* **14**, 519–527.

Carr H. (1906) The visual illusion of motion during eye closure. *Psychol. Rev. Monogr. Suppl.* No. 31.

Foster D. H. and Idris I. I. M. (1974) Spatio-temporal interaction between visual colour mechanisms. *Vision Res.* **14**, 35–39.

Frisby J. P. (1972) The effect of stimulus orientation on the phi phenomenon. *Vision Res.* **12**, 1145–1166.

Goodman N. (1951) *The Structure of Appearance*. Harvard Univ. Press. Cambridge, Mass. (2nd Edn, Bobbs-Merrill, Indianapolis, 1966.)

Julesz B. (1971) *Foundations of Cyclopean Perception*. Univ. of Chicago Press.

Kolers P. A. (1962) Intensity and contour effects in visual masking. *Vision Res.* **2**, 277–294.

Kolers P. A. (1963) Some differences between real and apparent visual movement. *Vision Res.* **3**, 191–206.

Kolers P. A. (1968) Some psychological aspects of pattern recognition. In *Recognizing Patterns* (Edited by Kolers P. A. and Eden M.). M.I.T. Press, Cambridge, Mass.

Kolers P. A. (1972a) A problem for theory. *Vision Res.* **12**, 1057–1058.

Kolers P. A. (1972b) *Aspects of Motion Perception*. Pergamon Press, New York.

Kolers P. A. and Pomerantz J. R. (1971) Figural change in apparent motion. *J. exp. Psychol.* **87**, 99–108.

Kolers P. A. and von Grünau M. (1975) Visual construction of color is digital. *Science* **187**, 757–759.

Squires P. C. (1931) The influence of hue on apparent visual movement. *Am. J. Psychol.* **43**, 49–64.

Stoper A. E. (1973) Apparent motion of stimuli presented stroboscopically during pursuit movement of the eye. *Percept. Psychophys.* **13**, 201–211.

Turvey M. T. (1973) On peripheral and central processes in vision. *Psychol. Rev.* **80**, 1–52.

van der Waals H. G. and Roelofs C. O. (1930, 1931) Optische Scheinbewegung. *Z. Psychol. Sinnesorg.* **114**, 241–288; **115**, 91–190.

Wertheimer M. (1912) Experimentelle Studien über das Sehen von Bewegung. *Z. Psychol.* **61**, 161–265. Translated in part in T. Shipley (Ed.), *Classics in Psychology*. Philosophical Library, New York (1961).

Zusammenfassung

Zwei unterschiedliche Formen, die in den geeigneten räumlichen und zeitlichen Abständen kurzzeitig beleuchtet werden, verwandeln sich glatt und kontinuierlich in einander. Die gegenwärtige Untersuchung hatte die entsprechende Verwandlung zweier unterschiedlicher Farben zum Ziel. Wenn zum Beispiel ein Rot und ein Grün dargeboten werden, könnte das visuelle System die eine Farbe zu einem neutralen Punkt hin desaturieren und dann die andere von diesem Punkt aus wieder saturieren; oder es könnte dem Rot gestatten, sich zum Beispiel über orange und gelb in grün zu verwandeln. Keine von beiden Möglichkeiten trat ein. Es wurden keine Zwischenstufen zwischen zwei unterscheidbaren Farben gefunden; vielmehr verwandelte sich die eine Farbe abrupt in die andere. Der abrupte Farbwechsel erfolgte sogar, wenn die beiden Reize in zweifacher Hinsicht ungleich waren, nämlich in Form und Farbe. Dann konnte man beobachten, dass sich die Form almählich änderte, während die Farbe abrupt wechselte; aber man konnte auch sehen, dass die Farbe immer die Konturen der sich scheinbar ändernden Form ausfüllte.