squint is also suggested by the differences between the dorsal lateral geniculate neurons, this abnormality should an ordinary cat in which squint has been induced artificially after birth. In the latter case, there is no disorganization of the laminae in the lateral geniculate (*16*).

Although the anomaly in the retinogeniculate pathway is especially prominent, in part because it involves a marked rearrangement of lateral geniculate neurons, this abnormality should not diminish the fact that the projection of the retina to the pretectum and superior colliculus is almost entirely crossed. Thus, any single factor responsible for the neuroanatomical defect cannot be specific to the formation of retinogeniculate connections.

We wish to emphasize that all of the major retinal pathways in the Siamese cat are abnormal (*17*). As a result, this animal must possess but a limited ability to process spatially correlated binocular information, with a consequent loss of stereoscopic depth perception. Any residual ability for stereoscopic depth perception must depend almost solely on the remaining ipsilateral input to the lateral geniculate nucleus, for the ipsilateral projections to the pretectum and superior colliculus are meager or absent. Thus, the limited ipsilateral retinogeniculate projection would appear to be the most significant factor in providing binocular information for the control of symmetrical eye movements (*18*).

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References and Notes

1. R. G. Scobee, in *Strabismus Ophthalmic Symposium*, J. H. Allen, Ed. (Mosby, St. Louis, 1950), pp. 194–196; P. J. Waardenburg, *Genetics and Ophthalmology* (Royal Van Gorcum, Assen, Netherlands, 1963), p. 1009.
2. F. B. Chavasse, *Worth's Squint or the Binocular Reflexes and the Treatment of Strabismus*, ed. 7 (Blakiston, Philadelphia, 1939); W. Richards, *Exp. Brain Res.* (*Berlin*) **10**, 380 (1970).
3. R. W. Guillery, *Brain Res.* **14**, 739 (1969).
4. The retina also makes entirely crossed connections with the nuclei of the accessory optic tract, and sends a relatively weak bilateral projection to the ventral lateral geniculate nucleus. Studies on the ordinary cat include M. C. Singleton and T. Peele, *J. Comp. Neurol.* **125**, 303 (1965) [see also (*5*) and (*6*)]. For review of earlier literature see T. H. Meikle, Jr., and J. M. Sprague, *Int. Rev. Neurobiol.* **6**, 149 (1964).
5. L. J. Garey and T. P. S. Powell, *J. Anat.* **102**, 189 (1969).
6. A. M. Laties and J. M. Sprague, *J. Comp. Neurol.* **127**, 35 (1966).
7. Crossed projections of the temporal retina have been reported [see (*6*) and (*8*)].
8. J. Stone and S. M. Hansen, *J. Comp. Neurol.* **126**, 601 (1966).
9. R. P. Fink and L. Heimer, *Brain Res.* **4**, 369 (1967).
10. W. R. Hayhow, *J. Comp. Neurol.* **110**, 1 (1958). A second zone in the dorsal lateral geniculate, which lies between lamina *B* and the optic tract, also receives ipsilateral retinal input. J. C. Hedreen, *Anat. Rec.* **166**, 317 (1970) [see (*11*)].
11. R. W. Guillery, *J. Comp. Neurol.* **138**, 339 (1970).
12. W. J. Kinston, M. A. Vadas, P. O. Bishop, *ibid.* **136**, 295 (1969).
13. Additional ipsilateral degeneration is often seen in the geniculate ventral to the lateral cell cluster in lamina C1 of Guillery [see (*11*)].
14. R. W. Guillery and J. H. Kaas, *J. Comp. Neurol.*, in press.
15. In the Siamese cat the projection of the retina to the ventral lateral geniculate nucleus appears entirely crossed.
16. D. H. Hubel and T. N. Wiesel, *J. Neurophysiol.* **28**, 1041 (1965).
17. Only the projections of the retina to the nuclei of the accessory optic tract appear normal in the Siamese cat.
18. Man, more than other primates, also exhibits marked individual variations in the organization of the lateral geniculate nucleus. The individual variations in the definition of the laminae of human lateral geniculate may be seen in S. Polyak, *The Vertebrate Visual System*, H. Klüver, Ed. (Univ. of Chicago Press, Chicago, 1957), pp. 701–731. These variations should be contrasted with the more consistent uniformity and clarity of lamination seen in the monkey, an animal not known by us to possess a congenital squint.
19. Supported in part by a grant-in-aid from Fight for Sight, Inc., New York City, and by a PHS fellowship F10NSo2391. Additional support from an Alfred P. Sloan Foundation grant to H.-L. Teuber.

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Interocular Apparent Movement in Depth: A Motion Preference Effect

Abstract. *A new phenomenon is reported in which alternate stimulation of either nasal or temporal hemiretinas produces, respectively, apparent oscillation in depth either behind or ahead of the frontal plane. This control over the perceived movement is dependent on the proper positioning of stimuli presented interocularly and in horizontal arrangements.*

Apparent or stroboscopic movement is perceived when two separate visual stimuli are presented successively. This report describes a new apparent movement phenomenon which occurs when stimuli eliciting apparent movement in depth are presented interocularly. When the two triangles of Fig. 1A are alternately presented, the observer generally perceives a single triangle moving to and fro in depth about a vertical axis (*1*). The situation is ambiguous, since the vertex of the triangle, which appears to swing through an arc of about 180°, may oscillate either ahead of or behind the frontal plane. However, an experiment revealed that the type of movement perceived may be brought under control when the triangles are presented interocularly (each eye is stimulated by only one of the two triangles).

Two arrangements for presenting stimuli interocularly are illustrated in Fig. 1B. When the right and left figures are combined stereoscopically, the vertical fixation lines fuse and a triangle is perceived on each side. Although the visual fields for the upper and lower arrangements appear the same, the upper arrangement gives rise to stimulation of the two nasal hemiretinas and the lower arrangement gives rise to stimulation of the two temporal hemiretinas. In the experiment, 55 undergraduates individually viewed two stimulus cards in a Brewster stereoscope. The two cards each contained a nasal and temporal arrangement, but differed with respect to the position on the card (upper or lower) of each arrangement. The figures were white, 1.27-cm equilateral triangles on a black background. The right and left figures were each illuminated from behind by a separate neon bulb. Each bulb was illuminated for 500 msec; the interval between presentations was ap-

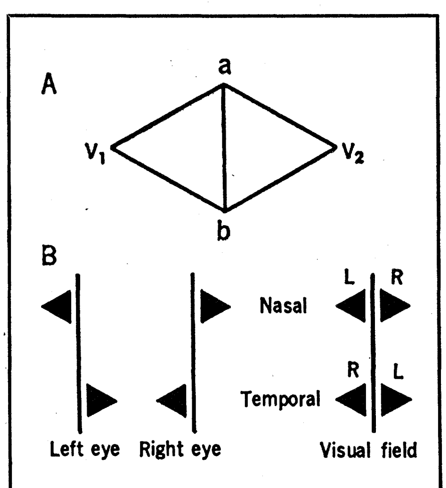

Fig. 1. (A) Stimulus arrangement for producing apparent oscillation in depth. When triangles abV_1 and abV_2 are alternately presented, the vertex of a single triangle oscillates between V_1 and V_2 about axis ab. (B) Arrangements for producing stimulation of nasal and temporal hemiretinas. Fixation is on the vertical line between the L (left-eye) and R (right-eye) triangles.

proximately zero. The sequence (left bulb on, left bulb off, right bulb on, right bulb off) cycled repetitively.

The subjects, who had no prior experience with the experimental situation, reported what they perceived for the nasal and temporal arrangement of each card. The results for both cards were similar. About 90 percent of the 220 spontaneous reports were of oscillation in depth (*2*). Of these oscillation reports, about 73 percent of those pertaining to nasal stimulation were of oscillation behind, and about 78 percent of those pertaining to temporal stimulation were of oscillation ahead. Thus nasal stimulation elicited a preference for oscillation behind, and temporal stimulation elicited a preference for oscillation ahead (*3*). This motion preference phenomenon was examined in greater detail in a subsequent series of experiments.

Sixty-four undergraduates served as subjects. None had any prior experience with the experimental situation. Each subject took part in one or more experiments, and 37 returned for a second experimental session. One of two instruments, a three-channel tachistoscope (Scientific Prototype, model GB) and a stereoscope (Keystone No. 64 Telebinocular), was used in each experiment. Polarizing filters were used with the tachistoscope to permit interocular stimulus presentation. The stereoscope was modified and connected to a four-channel timing relay (Hunter model 1514) so that the right and left fields could be independently illuminated by two neon bulbs. For both instruments, the stimuli presented to the right and left eyes were alternately illuminated for 500 msec, with an interstimulus interval of 50 msec. Alternation cycled continuously and automatically. Each of the stimulus arrangements of a particular experiment was presented ten times in random order. Prior to each trial, the right and left figures were illuminated simultaneously to ensure proper initial fusion. Alternation was then introduced and the subject was required to report whether the figure appeared to oscillate ahead or behind. The number of "ahead" reports in ten presentations served as the measure of motion preference for each subject.

Since a Brewster stereoscope had been used in the initial experiment discussed above, the possibility existed that motion preference was a function of this particular model. In addition, triangles were the only figures presented. Hence, in the first of the new series of experiments, the Keystone stereoscope was used to present triangles, and semicircles as new figures, to nasal and temporal hemiretinas (see Fig. 2A). The triangles (0.95-cm equilaterals) and semicircles (1.59-cm diameter) were black outline drawings on white cards. Twenty subjects were used. Temporal stimulation produced about three times as many "ahead" reports as nasal stimulation for both shapes. A replication of this experiment with the tachistoscope and 20 different subjects produced very similar results (*4*).

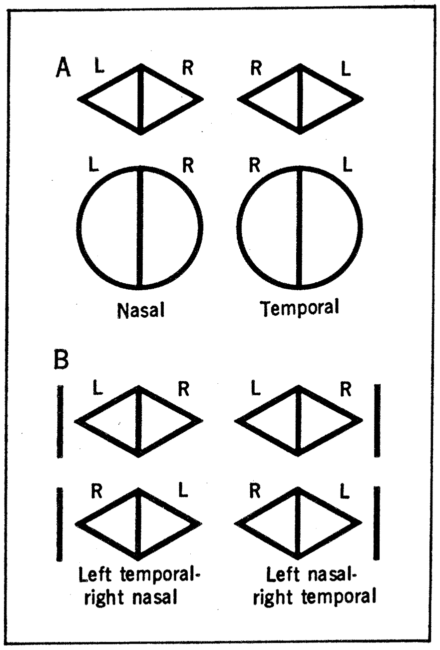

Fig. 2. (A) Visual fields produced by triangle and semicircle arrangements which give rise to nasal and temporal stimulation. Fixation is on the common vertical side of the L (left-eye) and R (right-eye) figures. (B) Visual fields produced by arrangements which give rise to stimulation of left temporal and right nasal hemiretinas, and to stimulation of left nasal and right temporal hemiretinas. Fixation is on the vertical line to the left or right of the triangles.

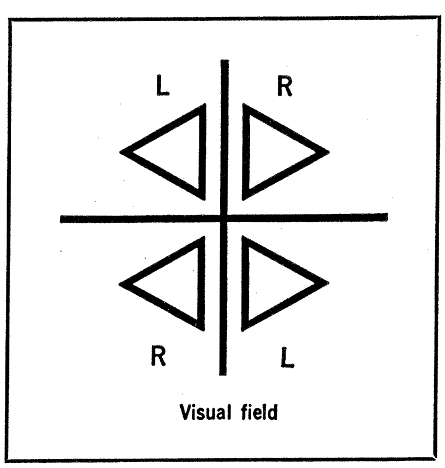

Fig. 3. Arrangement for the simultaneous viewing of LR and RL conditions. Fixation is on the intersection of the horizontal and vertical lines.

The next experiment was designed to determine if the motion preference phenomenon is unique to interocular presentation. The tachistoscope was used to present 3.81-cm equilateral triangles binocularly (both stimuli presented to both eyes) and monocularly (both stimuli presented to only one eye) as well as interocularly (*5*). The results for 20 subjects indicated the absence of motion preference for these presentations: binocular, right eye only, and left eye only. However, nasal versus temporal stimulation produced the expected difference in motion preference (*6*). Thus, interocular presentation is necessary for motion preference.

Another experiment was designed to determine if motion preference occurs for those interocular stimulus arrangements which do not produce either nasal or temporal stimulation of the two retinas. Four such arrangements were presented with the stereoscope to 15 subjects (see Fig. 2B). The two left temporal–right nasal arrangements (left fixation) differ with respect to the relative position in the visual field of the right-eye triangle (R) and the left-eye triangle (L). For one arrangement, L is to the left of R (an LR arrangement), and for the other, R is to the left of L (an RL arrangement). The same difference is true of the two left nasal–right temporal arrangements (right fixation). The results indicated that for both left and right fixation, the LR arrangement typically led to reports of motion behind, whereas the RL arrangement led to reports of motion ahead (*7*). Since the nasal and temporal arrangements tested previously (Figs. 1B and 2A) are of the same form (respectively, LR and RL), it may be concluded that the relative position in the visual field of the right-eye and left-eye figures (whether L is to the left or right of R) determines the motion preference.

The next experiment examined oscillation in depth with vertical presentation of stimuli. Eighteen subjects viewed two arrangements in the stereoscope which differed with respect to the relative position in the visual field of the right-eye and left-eye triangles (L above or below R). The results for the two arrangements were similar; there were no motion preferences (*8*). Therefore, horizontal presentation of stimuli is a necessary condition for obtaining motion preference.

The role of eye movement as a determinant of motion preference was examined in the final experiment. The LR and RL arrangements were presented in the stereoscope simultaneously, with a common point of fixation (see Fig. 3). Since an eye can move in only one direction at any moment, differential eye movement for the two arrangements could not occur. Twenty subjects were used. Both upper and lower triangles were perceived as oscillating; the motion preferences still occurred (*9*). Hence eye movement is excluded as a causal factor.

The theoretical significance of the motion preference phenomenon is as follows. An ambiguous percept of movement can be controlled by the positioning of stimuli when these stimuli are presented interocularly and in horizontal arrangements. The LR and RL arrangements appear identical when the right and left figures are presented simultaneously, but different types of movement generally result when the figures are presented successively. Furthermore, the phenomenon probably cannot be explained exclusively in terms of a retinal mechanism, because interocular presentation is a necessary condition for its production.

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References and Notes

1. See G. D. Higginson, *J. Exp. Psychol.* **9**, 228 (1926); K. Koffka, *Principles of Gestalt Psychology* (Harcourt, Brace, World, New York, 1935), p. 301; M. D. Vernon, *Visual Perception* (Cambridge Univ. Press, New York, 1937), pp. 172–173.
2. The remaining 10 percent were divided among reports of alternation (no movement), a planar movement which the subjects had difficulty in describing, and a pendulum-like planar rotation in which a vertex of the triangle served as the axis of rotation. It is of interest that with prolonged viewing, some subjects reported perceiving changes in the form of motion, such as from oscillation in depth to rotation in the plane. Others reported motion reversals in which the initial type of oscillation in depth changed from ahead to behind or vice versa. Also, some subjects reported perceiving complete rotations (360°) of the triangle.
3. The motion preference phenomenon may be observed by means of the following procedure. On a piece of paper, draw two pairs of triangles in arrangements similar to those in Fig. 1B, but with only a small separation between left and right triangles, and without the separate vertical lines. In order to separate the right and left visual fields, hold a cardboard partition between the right and left figures, perpendicular to the paper. Look down at the triangles (one pair at a time) and converge the eyes to obtain proper fusion. The triangles should appear joined by a common vertical side. Now alternately open and close each eye, and determine whether the vertex of the moving triangle swings ahead or behind the plane of the paper. If available, a stereoscope may be used to facilitate proper fusion.
4. For the stereoscope, the mean numbers of "ahead" reports for nasal and temporal arrangements, respectively, were 2.00 and 5.60 for triangles, and 1.25 and 3.80 for semicircles. The corresponding values for the tachistoscope were 2.10 and 5.85 for triangles, and 1.10 and 3.50 for semicircles. In these and in all subsequent experiments, individual differences were apparent. Some subjects were perfectly consistent with the preference effect (10 "aheads" for temporal stimulation and 0 "aheads" for nasal stimulation), whereas others showed a preference for either movement ahead or behind regardless of the stimulus arrangement presented. But most subjects reported more "aheads" for temporal stimulation than for nasal stimulation. A difference in the opposite direction was very rare.
5. The viewing distance was 121.92 cm; the stimuli subtended horizontal retinal angles of 1.5°. Retinal sizes for stimuli presented in the stereoscope were comparable, but were not accurately determined.
6. The mean numbers of "aheads" for the five conditions were as follows: binocular, 5.5; right eye, 5.1; left eye, 4.5; nasal, 3.1; temporal, 5.7.
7. The mean numbers of "aheads" for left fixation were 2.27 for LR and 7.07 for RL. The corresponding values for right fixation were 2.33 and 7.13.
8. A mean of 4.67 was found for the R above L arrangement and a value of 4.72 for the L above R arrangement.
9. Means for LR and RL, respectively, were 1.80 and 8.55. The very strong preferences found in this particular experiment have generally been found to occur whenever LR and RL arrangements are presented simultaneously, but with separate fixation points.
10. Based in part on a Ph.D. dissertation by Steven H. Ferris (City University of New York, 1970). Supported by grants to both authors from the City University of New York. We thank J. Orbach for the use of his tachistoscope, and E. Heinemann for his suggestions.

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Extremely Rapid Visual Search: The Maximum Rate of Scanning Letters for the Presence of a Numeral

Abstract. *Subjects searched a rapid sequence of computer-produced letter arrays for the presence of a numeral in one of the arrays. The subjects' scanning rates were computed from their precentage of correct detections of the location of the numeral. Scanning rates were very high and approximately the same for a wide variety of conditions; the highest scanning rates (125 and 75 letters per second for two subjects) occurred when there were 9 or 16 letters in each of the arrays and when new arrays were presented every 40 to 50 milliseconds. Giving the subject advance knowledge of the numeral to be presented made little difference in the scores.*

How fast can an array of letters be scanned to see whether it contains a numeral? This is a special case of a more general question: How quickly can a subject decide that an item from set A does not belong to set B? The answers to questions of this kind can give us basic data about the processes that underlie human pattern-recognition. In his classical experiments, Neisser (*1*) attempted to answer this kind of question by means of a procedure in which subjects searched a long list of items for the presence of a critical item. Because this procedure requires subjects to make eye movements, it is open to the criticism that the limiting factor in search is the rate of eye movements rather than the rate of information processing. Alternatively, search has been studied in exposures too brief to admit eye movements (*2*). Unfortunately, the effective visual duration of a brief stimulus is difficult to estimate unless post-exposure fields composed of visual noise (which looks like scattered bits and pieces of letters) are used to obliterate the visual persistence of the stimulus (*3*), and noise fields may introduce complications of their own. Some of these problems are overcome by using reaction-time rather than detection methods to study visual search (*4*). However, the interpretation of reaction-time experiments is exceptionally difficult unless the probability of a correct response is very high, and this is a serious limitation. With the evolution of computer systems for generating sequential visual displays [and their employment in closely related contexts (*5*)], the study of detection in complicated stimulus sequences has become technically feasible. The sequential search procedure (*6*) is the logical outcome.

In the sequential search procedure, subjects view sequences of arrays. In our experiments, each array—except one critical array—is composed strictly of letters. A critical array, which contains a numeral in a randomly chosen location, is embedded somewhere in the middle of the sequence. The task of the subject is to state the location of the numeral. When the subject is not told