the pause, then being within the required distance, or making physical contact with the model during the pause. Differences in following scores within groups were tested nonparametrically with the Wilcoxon two-tailed matched-pairs signed-ranks test; those between groups, with the Mann-Whitney *U*-test.

The results were clear-cut. Chicks of both experimental groups followed their respective training models at the initial exposure, with no significant differences in time scores; controls given the choice at the same age showed no preference (Table 1). During the subsequent test, however, both experimental groups preferred the striking model, while untrained controls of the same age showed no preference (Table 1). (Experimentals that did not follow during training, but merely sat watching the model, showed the same subsequent preference as initial "followers," although not as strongly.) These results are even more remarkable than our previous finding (*1*) that ducklings trained to a plain decoy showed no clear subsequent preference for their training model, while ducklings trained to the striking decoy did prefer theirs.

Chicks in control group 2, having had no training, failed to follow any model strongly, thus supporting the results of all previous investigators. Chicks in control group 1 probably did not follow as strongly as the experimentals because their presentation lacked sound stimuli.

These results cast doubt on the generality of conclusions derived from previous imprinting studies where the experimental variables were not applied to several groups of birds having various kinds of training models.

From our results, we deduce the following. (i) "Priming," or initiation of the following-response, requires an exposure to a (moving?) model, presumably during the critical period (*1*, *2*). (ii) Once primed, the following-response does not necessarily attach to the training model; other perceptual preferences may be of over-riding importance. (iii) Following during training appears not to be essential to the effectiveness of the training period, even though more initial followers than nonfollowers subsequently showed a clear preference for a particular model.

This evidence accords with our stated position (*1*) on the primacy of perceptual processes in imprinting and opposes the importance of motor responses as expressed in the "law of effort" (*6*). Stated differently, the generalization of the responses to, or the preference for, an object to which no prior exposure was made is greater than the preference for the training object.

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Depth Perception Loss with Local Monocular Suppression: A Problem in the Explanation of Stereopsis

Abstract. *Contours added to only one eye's view cause both suppression of the other view and loss of perceived depth. Since piecemeal contralateral suppression may be the general rule of binocular combination, the finding that suppressed views do not contribute to stereopsis raises basic questions about the nature of stereoscopic depth perception.*

Stereoscopic depth perception is caused by differences in the two eyes' views. In Fig. 1*A*, if both eyes fixate rod 1, its image falls on sets of corresponding points in the retinas of the two eyes, and we see only one rod. The image of rod 2 falls on noncorresponding or disparate points (Fig. 1*C*), and rod 2 looks doubled. If this disparity is small (less than 0.25 degree of visual angle), rod 2 looks single and nearer than rod 1. The disparity in retinal points stimulated by an object's images is often considered to be the basis of the object's apparent depth (*1*).

It now appears that a contour that stimulates the retina of one eye produces a field of contralateral suppression of about 0.25 degree, within which the view received by the other eye cannot be seen (*2*), so that, if a point is visible in the combined view, its counterpart in the other eye's image is not simultaneously visible. In fact, considerable evidence suggests that the combination of the two eyes' views always proceeds by piecemeal regional suppression of one view or the other (*3*). If one member of each pair of disparate points is always suppressed, how can the disparity effect our depth perceptions? The usual answer has been that the nervous system somehow registers the locus of the suppressed image, even though the image itself is not seen consciously. The observations reported here, however, suggest that this answer is wrong: the visual system does not use the information in the suppressed image while it is suppressed.

In Fig. 1*D*, *1*, view *L* is pink; view *R*, light green. If the black point, *x*, is fixated while the two views are in a stereoscope, the outer ring appears in the combined view, at *2*, as a single complete circle, changing in color from moment to moment and from one region to another (*4*). The small circle is clearly farther than the large one; if we keep our eyes carefully fixed on point *x*, the small circle is not a single ring, but fragments of both I_L and I_R, fragments that appear and disappear rapidly and unpredictably. Occasionally, only a pink circle (I_L) or a green one (I_R) is seen and, when that happens, stereodepth vanishes, and both large and small circle appear in the same plane. This is a difficult and dubious observation, since such moments of complete monocular dominance are rare and fleeting. The following experimental procedures increase the duration of the phenomenon.

Stereograms *E*, *F*, and *G* were each viewed in a Zeiss stereoscope for eight trials each of 20 seconds duration, in counterbalanced order, by each of five observers (four of them naive as to the purpose of the experiment). Observers pressed a right-hand key when the small circle appeared farther than the large one, a left-hand key for the reverse, and neither when the figure looked flat. Median key-pressing times for each are shown in Fig. 1. For every observer, the following was true: *F* was predominantly flat, and significantly different from stereograms *E* and *G* ($p < .01$, by the *t*-test), both of which showed predominant stereodepth.

The grating in Fig. 1*F* was designed to suppress I_R; each grating line overlapped the contralateral suppressive fields produced by its neighbors (*5*).

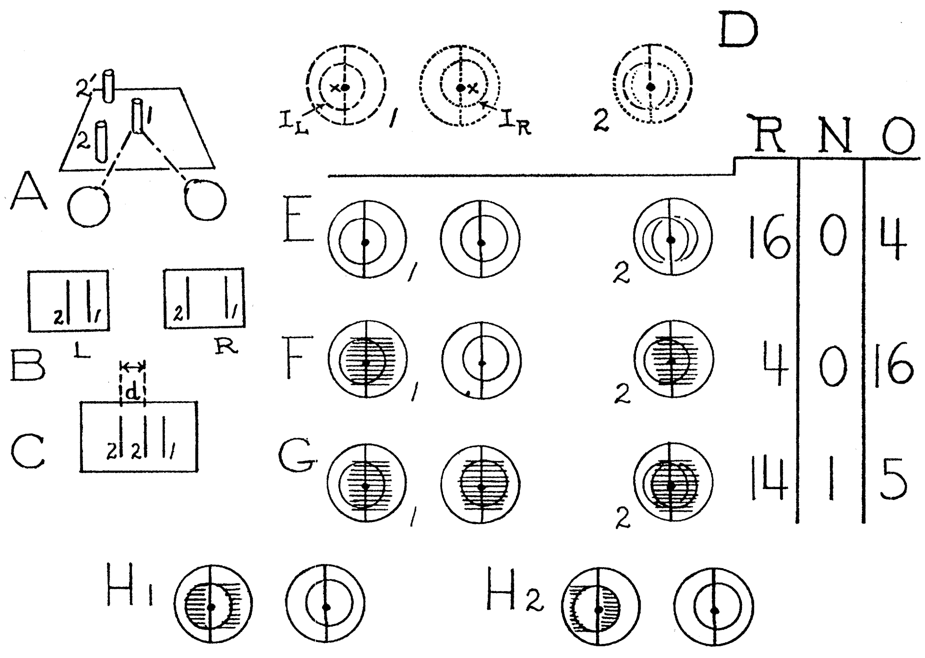

Fig. 1. *A*, Diagram of the two eyes fixating rod 1. *B*, The views of rods 1, 2 that confront each eye. *C*, The combined view, showing the disparity, *d*, between the two views of rod 2. *D*, At *1*, a stereogram of a tunnel, in which the left view is pink; the right, green. The smaller circles, I_L, I_R, are disparate, $d = 1$ degree of visual angle. The larger circle subtends 14 degrees; the smaller, 8 degrees. At *2*, the appearance of the combined view. *E*, *F*, *G*, At *1*, stereograms of the same dimensions as in *D*; the small circles are red in both views; all else is black. In *F*, grid lines and spaces are 5 minutes of visual angle in the left view; in *G*, identical grids are placed on corresponding regions of both views. At *2*, the predominant appearance of each combined view, and the median number of seconds in each 20-second observation period during which the small circle appeared to the rear (*R*) of the large circle, nearer (*N*), or in the same plane (*O*). *H*, At *1* and *2*, the stereograms used in the second experiment.

The resultant flat appearance was not due to the "confusion" of the combined view: in *G*, stereodepth was not reliably reduced, although an identical grating appears in the combined view. The loss of stereopsis in *F* must be attributed, therefore, to the unilateral presence of the grating. It may be thought that the difference in the two views of *F* is so great that they cannot be combined into a single perceived structure—that is, the views' dissimilarities may prevent stereopsis. The next experiment rejected this interpretation.

In a second experiment, three observers (two being naive as to purpose) viewed stereograms H_1 and H_2 for 16 trials each in counterbalanced order, following the procedures of the first experiment. The two eyes' views differ in both stereograms, but in H_1 the left eye's grating overlaps I_R in the combined view, and in H_2 it does not. Median durations of right-hand keypressings (during which the small circle appeared farther than the large one) were 14 seconds for H_2 and 3 seconds for H_1; left-hand responses were negligible for both figures. Thus, H_1 was predominantly flat and H_2 was predominantly tridimensional; the difference between H_1 and H_2 was significant for each observer ($p < .001$, by the *t*-test). It is not simply the views' differences that prevent stereopsis in Fig. 1, *F* and H_1: the loss of stereopsis occurs only when the unilateral presence of the grating is such as to cause the visible suppression of I_R also. The residual depth responses in *F* and H_1 may be explained by momentary partial breakdowns in the unity with which the gratings suppressed I_R, so that bits of both I_R and I_L appear occasionally in the combined view. It seems most likely, therefore, that conditions which would lead to complete suppression of one image would result in complete suppression of stereodepth as well.

But this raises two questions: (i) If one or the other of the pair of disparate points (Fig. 1*C*) is always suppressed, and if, as we have just seen, suppressed images do not produce stereopsis, how does binocular parallax produce depth perception? (ii) Unambiguous stereopsis depends, geometrically, on knowing which of the two images in the combined view was received by each eye; for example, in Fig. 1*C*, the same disparity, *d*, is produced in the combined view by rod 2′ as by rod 2. There is not, however, any purely visual sign or quality in the combined view by which we can detect and report which eye has received a monocular stimulus (*6*). If, as I have now suggested, the combined view at any moment consists of a mosaic of monocular fragments contributed by one eye or the other, if the suppressed fragments do not contribute to stereopsis, and if each monocular bit contains no sign of eye-of-origin, how is this essential information mediated? Why is stereoscopic depth not at all ambiguous?

In answer to both these questions, it might seem tempting to argue that stereoscopic depth is given not by momentary binocular disparity, *d*, but by the rivalry and successive alternation of the disparate monocular inputs, and by the changes in their disparity caused by convergent eye movements [since such movement-coupled changes in disparity are not geometrically ambiguous (*7*)]. Because correct binocular judgments have been obtained, however, when such disparity changes were precluded (*8*), this answer cannot adequately explain stereoscopic depth perception.

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4. We cannot tell from this experiment, of course, whether such alternation between the eyes' views always occurs and is only here made visible because different colors have been used as "tracers," or whether the alternation results from the difference in colors as an artifact of this method. Whatever else the use of different colors may do, it does permit us to identify the contribution by each eye to the combined view, in Fig. 1*D*, without destroying the stereodepth effect [which, it should be noted, is perfectly capable of surviving even more violent kinds of binocular rivalry, such as is obtained by using a photographic negative in one eye and a positive in the other; see von Helmholtz (*1*), p. 512, and A. Treisman, *Quart. J. Exptl. Psychol.* **14**, 23.
5. The distance between each pair of lines was approximately 5′ of visual angle, so that one

line's suppression of the other eye's view permitted its neighbor to be seen as well; unsystematic observations with various grid spacings suggest that overlapping suppressive fields summate in some fashion, although probably not linearly.

6. M. J. Pickersgill, *Quart. J. Exptl. Psychol.* **11**, 168 (1961); S. Smith, *J. Exptl. Psychol.* **35**, 1 (1945).
7. Thus, in Fig. 1*A*, if the eyes diverge slightly and the angle between them decreases, the disparity, *d*, increases for rod 2, but decreases for rod 2′.
8. For example, binocular views illuminated by flashes of light too brief to permit eye movements, and afterimages produced by such flashes (which are of necessity fixed in place on each retina, regardless of the changes in convergence angle between the two eyes, once the flash is over), have been reported to yield correct stereodepth judgments: H. A. Dove, *Ber. Preuss. Akad. Wiss.* **251** (1841), as cited by C. E. Osgood, *Method and Theory in Experimental Psychology* (Oxford Univ. Press, New York, 1953), p. 270; K. N. Ogle and L. Reiher, *Vision Res.* **2**, 439 (1962). Such experiments do not, of course, preclude the occurrence of fragmentary rivalry and alternation between the afterimages of the two eyes' views, and the potential information offered the observer by these phenomena occurring after stimulation should not be dismissed.
9. Supported by NSF grant GB 71.

21 July 1964

Quantasome as a Photosynthetic Unit

Park and Biggins [*Science* **144**, 1009 (1964)] report new structural details of chloroplast lamellar fragments. They explain that they have named these fragments quantasomes because these structures may be the morphological expression of the physiological photosynthetic unit PSU. The idea of PSU-quantasome equivalence is a useful hypothesis [Z. Bay and R. M. Pearlstein, *Proc. Natl. Acad. Sci. U.S.* **50**, 1071 (1963)]. This equivalence is complicated, however, by the existence of two pigment systems in green plant photosynthesis [R. M. Pearlstein, *ibid.*, in press]. It is, therefore, premature to accept this identification of PSU and quantasome as established fact. For this reason, I question your labeling the cover photograph of quantasomes as photosynthetic units.

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11 June 1964

Doppler Shifts of Quasars

James Terrell ("Quasi-stellar diameters and intensity fluctuations," 28 Aug., p. 918) has made the interesting suggestion that quasars may be far less distant than is currently believed, having been produced by an explosion or explosions within our galaxy. The large red shifts of their spectra must then be interpreted as first-order Doppler shifts caused by extremely high velocities of recession resulting from the explosion.

If an explosion occurred near the center of our galaxy, some of the fragments would move towards the earth; but according to the figures proposed by Terrell they would long since have passed well beyond the earth by a distance of a few galactic diameters. Therefore by now all fragments would be receding from us and all would exhibit Doppler red shifts.

Two possibilities need to be considered in this connection. The first is that a much more recent explosion of the type contemplated by Terrell may have occurred in our galaxy and that some of the fragments from it are still coming toward us. If this were so, these fragments would exhibit large violet shifts, the magnitudes of these shifts depending on the speed and direction of motion of the fragments relative to us. The second possibility is that if explosions of the type described by Terrell have occurred in our galaxy, they may well be assumed to have taken place occasionally in other galaxies too. If so, then some of the fragments could be coming toward us. If they were coming directly toward us they would probably be difficult to detect against the background of the galaxy in which they originated. But if they had also a significant transverse velocity, they could, according to Terrell's figures for a similar event in our own galaxy, move so as to appear a galactic diameter or so away from their parent galaxy and yet still have a component of velocity toward us that would yield a violet shift of the same order of magnitude as that of red shifts actually observed in quasars.

This being so, it might be desirable to search in the neighborhoods of our own and of nearby galaxies for stellar objects having large violet shifts. The lessened brightness due to the greater distance of object associated with nearby galaxies compared with the distances of those associated with our own galaxy would be partly offset by the fact that an object approaching with a speed corresponding to $d\lambda/\lambda = 0.5$ would appear several magnitudes brighter than a similar one receding at the same speed. With the more distant galaxies the main problem would be lack of brightness rather than the Hubble effect.

That no such "violet-shifted" objects seem yet to have been observed may not prove very much since (i) it is doubtful that anyone has seriously looked for them, and they would probably not be easily noticed unless one were specifically seeking them; and (ii) there is always the possibility (as Terrell has pointed out to me in correspondence) that the explosions are extremely rare events.

If any such violet-shifted objects were detected, their existence would go far toward proving the validity of Terrell's theory. If, however, after considerable search no such objects were found, that fact would tend to weigh against his theory.

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27 July 1964

Bone Mineral

In "Radiocarbon dating of bone and shell from their organic components" [*Science* **144**, 999 (1964)] the authors described bone as having the inorganic composition $[Ca_3(PO_4)_2]_3 \cdot Ca(OH)_2$. They relegate the carbonate component to the "mortar," along with citrate and other ions.

It has been demonstrated that most, if not all, of the carbonate (a few percent) is incorporated within the crystal structure of the apatite mineral and that the CO_3 groups substitute for PO_4 groups. The nature and extent of carbonate-ion substitution in phosphates, silicates, and sulfates is discussed in the *Journal of Chemical Education* [**40**, 512 (1963)]. Furthermore, it has been shown also that the unit-cell dimension *a* for the carbonate fluorapatite (francolite) is consistently smaller than for fluorapatite, which proves that the carbonate ions affect this fundamental periodicity of the lattice.

A brief but documented description of the nature of the bone mineral appeared in *Science* **136**, 241 (1962). A more extensive statement, "The crystal structure of bone," can be found in *Clinical Orthopaedics* [**23**, 253 (1962)].

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