THE EFFECT OF THE STIMULATION OF ONE EYE UPON APPARENT DISPLACEMENT IN THE OTHER

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This study was designed to determine what effect the stimulation of one eye has on the apparent displacement perceived by the other. A stereoscope was used as an apparatus, and the apparent displacement was measured by the method of limits.

Three experiments were performed to examine the influence of spatial separations and sizes of stimuli on the displacement. The stimulus figures were parallel lines, whose separations were varied systematically.

The results of the experiments indicated that two lines independently exposed to the right and left eyes were almost always perceived to approach each other but that the degrees of displacement varied depending on the spatial separations and sizes of stimuli.

There have been many investigations concerning binocular interaction. Day (1961) examined the effect of geometrical optical illusion in one eye upon the other; Lau (1922, 1924) studied the depth effect produced by apparent binocular parallax; Werner (1937, 1938) investigated binocular depth contrast, and many other investigations concerning binocular fusion and binocular rivalry have shown the existence of binocular interaction in a broder sense.

Recently, fusion theory (Dodwell & Engel, 1963) and suppression theory (Asher, 1953) have been developed to explain the phenomena concerning binocular interaction, but its mechanism has not yet been fully confirmed. More data must be accumulated before the mechanism of these phenomena can be clarified.

The present author believes that such investigations on binocular interaction will offer useful facts, not only to help explain the mechanism for producing single vision, but also to clarify the fundamental processes in the production of depth perception by binocular fusion.

To clarify the effect of a stimulus object upon binocular depth perception of other objects, the author has previously studied how a stimulus object caused the apparent displacement of a small point presented in its surrounding visual space (Ichikawa, 1961, 1966). Those studies revealed that, firstly, such an effect occurs not only in the same frontal plane as the object but also in the third dimension of visual space and secondly, that the dispalcement is in the direction towards the object when it is presented close to the test point, whereas the object presented at a longer distance from the test point causes zero displacement or displacement away from the object. The studies also revealed that the maximum displacement occurred in an intermediate distance. Taken as a whole the results showed an inverted U shaped curve.

It is not clear whether these third dimensional displacement effects can be reduced to the frontal parallel displacements in two monocular fields. The apparent displacement in the frontal plane has been interpreted as "field induction effect" by Köhler (1940), Orbision (1939) and Yokose (1954, 1957) but the mechanism of the effect in the third dimension has not yet been confirmed. As the apparent displacement in the third

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dimension appeared through binocular vision, it is necessary to clarify the relationship between binocular fusion process and field induction effect.

The purpose of this study is also to confirm the existence of "field induction effect" in the visual field which combines both retinal images, and to clarify the relation of "field induction effect" to binocular fusion. It is difficult to test such a process directly because a pair of stimuli are fused into a single image for a small disparity. First, it is necessary to accumulate detailed quantitative data about binocular fusion and the "field induction effect" in the combined visual field.

From the above point of view, this study was designed to examine the displacement effect that the stimulation of one eye produces on the other.

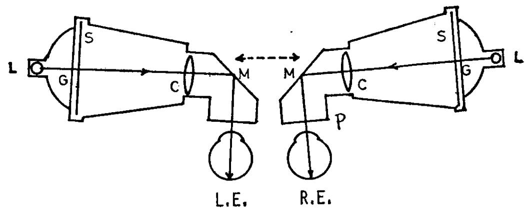

Fig. 1 The apparatus used in the study.
C: Convex lens M: Mirror
G: Diffusion glass S: Stimulus figure (Stereogram)
L: Light source P: Peep-hole

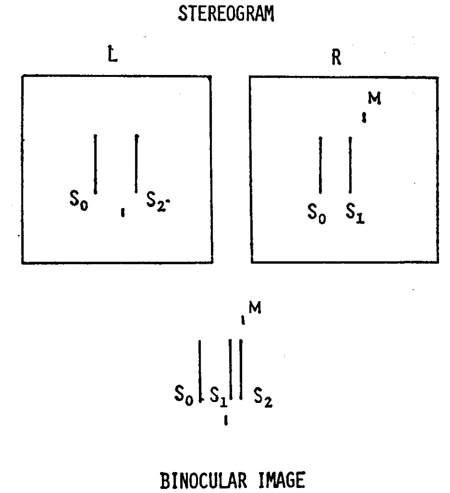

Fig. 2 Stimulus figures used in Exp. 1 and their binocular image.
S_0: Reference line S_1S_2: Interacting stimuli
M: Mark to measure the displacement of S_1 and S_2
The size of the square frame-work for the parallel lines is actually larger than in this figure.

Experiment I

Experiment I was performed to examine the mutual displacement effects of S_1 and S_2 in the binocular visual field. It was supposed that if there were any interaction between S_1 and S_2 presented to different eyes the effect would be mutual, and consequently, apparent displacement should occur.

Method

Subjects. Two female subjects were employed in this experiment. They all had visual acuities of more than 1.0 for both eyes and normal binocular fusion and depth perception.

Apparatus. A stereoscope of the reflex type (shown in Fig. 1) was used in the experments. With this apparatus it is possible to change the convergence of both eyes with the right and left arms, and to adjust the distance between the two circular peep-holes P to match the interpupilar distance in each subject. C is a convex lens to enlarge the visual image. The stimuli presented to both eyes are the figures drawn in the stereogram. Stereograms observed by the subjects are inserted into the positions S.

Stimuli: The stimulus figures shown in Fig. 2 were used. All three parallel lines S_0, S_1, and S_2 were 8° in length and 15′ in width. The spatial separation between S_0 and S_1 was 4° and that between S_0 and S_2 was 6°. The parallel lines were black and the background was a plane with a homogeneous luminance of approximately 7.5 cd/m². S_0 was presented in order to facilitate fusion of the right and left visual fields.

When two S_0 were projected on identical points of both retinae, the two S_0 fused completly. Since S_1 and S_2 were not projected on corresponding points, they appeared in different locations on the bincoular visual field. The binocular image in Fig. 2 shows its stimulus constellation.

Procedure. Preceding the experiment, all subjects were asked to fuse two small triangles drawn in a stereogram for practice. After this, the experiment was conducted. Part L of the stereogram was presented to the left eye and part R of the stereogram to the right eye. Parallel lines were seen in a single visual field when these figures were fused.

To examine the mutual influence of S_1 and S_2 on each other the amounts of the apparent displacements of S_1, S_2 were measured by the following procedure. Two short lines M were presented 2° in visual angle above and below the stimulus figures. The size of M was 1° in length and 15′ in width. The mesurement was performed by the method of limits. Each subject was asked the following question: on which side of the parallel lines S_1 or S_2 do you see the short lines M? If they are seen on the same line with S_1 or S_2, or can not be judged, the subject may answer "the same" or "uncertain". First, the mark M was presented in a position in which it appeared clearly on the left or the right side of S_1 or S_2. Then, it was moved horizontally in steps of 15′ from one side to the other. Each time M was varied, the subject was given the same question. M was prestented at 9 different positions in the direction to the right and left of S_1 or S_2.

Table 1 The apparent positions of S_1 ans S_2 in the binocular visual field. The values in the table indicate the points of subjective equality represented by the visual angle. The plus sign shows that both of S_1 and S_2 are perceived to approach each other.

Subjects \ Stimuli	S_1	S_2
Tg	+22′ 48″	+17′ 24″
Ha	+26′ 24″	+35′ 24″
Mean	+24′ 36″	+26′ 24″

Results

The values in table 1 indicate the apparent displacement of S_1 and S_2 from their physical positions projected onto the retina. They are represented by visual angle. Each value shows the mean of 10 repetitions. The result shows that both S_1 and S_2 were perceived to approach each other.

Experiment II

Experiment II was perfomed to examine the influence of the spatial separation between S_1 and S_2 upon the displacement.

Method

Subjects. Four female subjects were employed in this experiment.

Stimuli. The stereogram shown in Fig. 3A was used. In the stereogram, in addition to S_0 fixation points F were set to make the fusion of the right and left visual field more precise. When the subject fixated on the F marks, two S_0 were projected on identical points of both retinae.

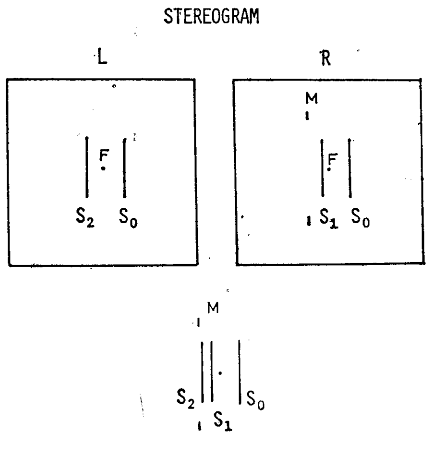

Fig. 3 A Stimulus figures used in Exp. II and their binocular image.
S_0: Reference line S_1: Inducing stimulus
S_2: Test stimulus F: Fixation point
M: Mark to match the apparent position of S_2
The size of the square frame-work for the parallel lines is actually greater than in this figure.

In the experiment, S_1 was considered to be an inducing stimulus and S_2 a test stimulus. S_0 S_1 and S_2 were all black parallel lines 6° in length and 15′ in width. Their background had a luminance of 50 cd/m². The spatial separations between S_0 and F and between S_1 and F were a constant 3° and 30′ repectively, but the spatial separation (binocular disparity) d between S_1 and S_2 was varied in five steps 1°30′, 2°, 2°30′ 3° and 3°30′.

Procedure. After the two fixation points F and the two lines S_0 were fused completely, the displacement of S_2 was measured. As S_0 and F were considered to be on corresponding points on the retinae, S_1 and S_2 were projected to non-corresponding points on each retina.

To measure the apparent displacement of S_2 more exactly, two short lines M were presented, one above and one below S_2. Two vertical positions of M were constantly 2° above and below S_2 but it was presented in 11 different horizontal positions. The presentation and measurement were all the same as in Exp. 1. The two M's were varied horizontally in steps of 15′ from

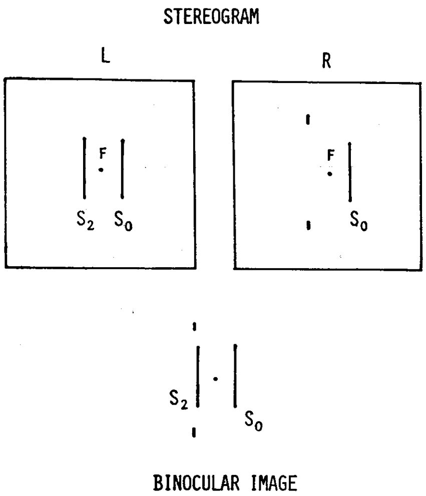

Fig. 3 B The stimulus figures used to measure the apparent positions of S_2 itself when S_1 is not presented. The values obtained with this stereogram form the zero point from which the displacement of S_2 is measured.

one side to the other according to the method of limits, and subjects were asked to indicate the positions of the paired M' s in relation to S_2 in three categosies: "right", "left" and "equal" (or "uncertain"). In addition to the above main measurement, a control measurement was performed, using the stereogram in Fig. 3B. This stereogram differs from that of Fig. 3A in that only the test stimulus S_2 was presented. The inducing stimulus S_1 was not presented. This was intended to eliminate experimental errors caused by individual differences, daily differences, time of repetition, measurement order, etc. In order to examine the influence of S_1 upon S_2, it is neccessary to find the difference between the apparent positions of S_2 in Fig. 3A and Fig. 3B. The values obtained in such a way are regarded as the amounts of displacement. As such a value is the basis of displacement, it was measured for the very same spatial separations (binocular disparities) d as that of Fig. 3A. The measurement of Fig. 3B was performed before or after that of Fig. 3 A. The other conditions and procedure were quite the same as the main measurement of Fig. 3A.

Results

The results from four female subjects are presented in Table 2. The table shows the apparent positions of S_2 from the physical positions projected onto the retina.

The displacement of S_2 caused by S_1 at various spatial separations is shown in Fig. 4A, B. The number of repetitions was from 10 to 14. The three curves in Fig. 4A show results of three of the four subjects, and the curve in Fig. 4B represents the mean value of those results. The reason for the omission of data for d at 1°30′in Fig. 4 is that in the subject Tu, it was not possible to measure the displacenent of S_2, because S_1 and S_2 were fused in this subject. In the table and two figures, the plus indicates the direction toward S_1 and the minus indicates the direction away from S_1.

From the results shown in Fig. 4A, it can be seen that S_2 is almost always perceived to approach S_1 except at the spatial separation of 3°30′ but the amount of displacement varies according to the spatial separation. Comparatively large displacements of S_2 were observed for small separations like 2° and 2°30′. On the contrary, for larger separations of 3° and 3°30′ small displacements toward S_1 or away from S_1 were obtained.

Table 2 The apparent positions of S_2 for various spatial separations (binocular disparities) d from S_1 in the binocular visual field.

Subjects \ d	1°30′	2°	2°30′	3°	3°30′
Na	+ 9′30″	+15′00″	+27′36″	+11′06″	+22′30″
Tg	+ 8′06″	+27′00″	+33′36″	+35′06″	+17′42″
Ha	−12′54″	0	+12′00″		
Tu		− 9′00″	0	−12′00″	−24′54″
Mean	+ 1′30″	+ 8′15″	+18′18″	+11′24″	+ 5′06″

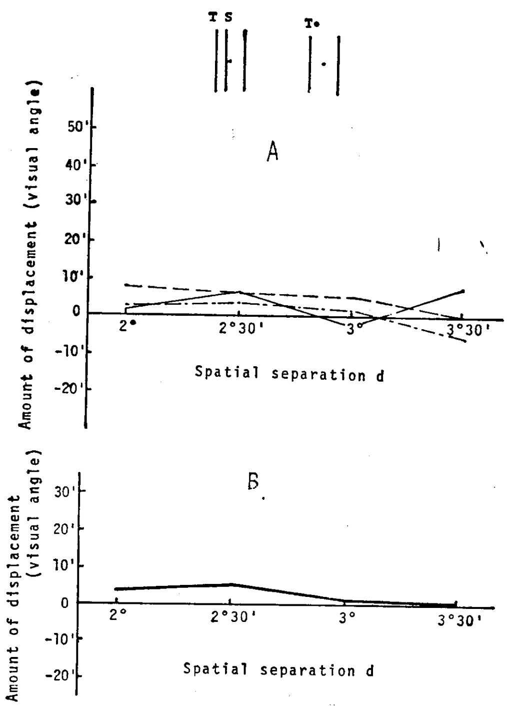

Fig. 4 A, B The relationship between the displacement of S_2 and the spatial separation of S_1 and S_2 (the results of Exp. II). Graph A shows the results of 3 subjects and graph B shows the mean value. The plus and minus signs indicate the approach and removal of S_2 from S_1.

All of the above mentioned trends are clearly represented in Fig. 4B. In this experiment, only the displacement of S_2 was measured, but it is assumed that the displacement of S_1 shows the same trend as that of S_2.

Experiment III

The aim of the experiment was to examine how stimulus S_1 affected S_2, when the test stimulus S_2 became very small. It was postulated that when S_2 became very small, the effect of S_1 would increase. The resuls of this experiment should show the displacement effect of stimulus upon the surrounding area in the binocular visual field.

Subjects. Five female subjects were employed in the experiment. Three of them were the same as in Exp. II.

Stimuli and Procedure. The stereogram shown in Fig. 5A was employed. In this experiment, S indicated an inducing stimulus and T was a test stimulus. T was a short black line 1° in length and 15′ in width. The luminance of the background was 50 cd/m². The spatial separations between S_0 and F and between S and F were 3° and 30′. T was presented at spatial sepa-

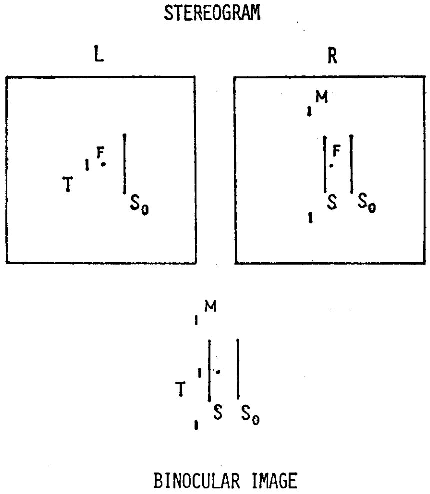

Fig. 5 A Stimulus figures used in Exp. III and the binocular image.
S_0: Reference line S: Influencing stimulus
T: Test stimulus F: Fixation point
M: Mark to match the apparent position of T
The size of the square frame-work for the parallel lines is actually greater than in this figure.

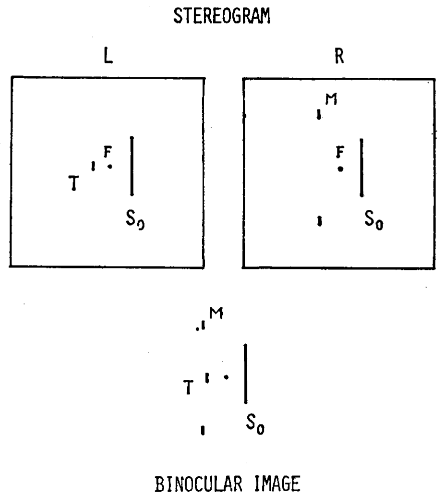

Fig. 5 B This stereogram is designed to measure the apparent positions of T when S is not presented. Such values form a basis for determining displacement of T.

Table 3 The apparent position of short line T for the spatial separations (binocular disparities) d from S in the binocular visual field.

Subjects \ d	1°30′	2°	2°30′	3°	3°30′
Na	+18′ 36″	+13′ 30″	+21′ 36″	+12′ 00″	+15′ 36″
Tg		+29′ 06″	+40′ 30″	+35′ 06″	+42′ 00″
Tu	−10′ 30″	−17′ 24″	−20′ 24″	−17′ 24″	−18′ 54″
In	+21′ 18″	+35′ 06″	+21′ 18″	+21′ 18″	+13′ 48″
Yo	+ 6′ 36″	− 5′ 42″	− 2′ 42″	−12′ 54″	− 5′ 42″
Mean	+ 9′ 00″	+10′ 55″	+12′ 04″	+ 7′ 37″	+ 9′ 22″

rations d of 1°30′, 2°, 2°30′, 3° and 3°30′ from S. Two short lines M above and below T were used to measure the displacement of T. The positions of M and measurement procedures were exactly the same as in Exp. II. The binocular stimulus constellation they viewed is presented below the stereogram in Fig. 5. After the right and left points F and lines S_0 were completely fused in each single image, the apparent displacement of T was measured. Before or after the measurement of Fig. 5A (main measurement), the measurement of Fig. 5B (control measurement) was performed. This stereogram used in the control measurement was the same as in Fig. 5A except that S was not presented in this case. In the control measurement (Fig. 5B), the test stimulus was represented as T_0. As in Exp. II, the value of T_0 for each spatial separation (binocular disparity) d was used as the basis for obtaining the displacement of T. The amounts and directions of displacement were obtained by subtracting the values of T_0 from T. All of the conditions and procedures for control measurement 5B were the same as in the main measurement 5A.

Results

The results of experiments with 5 subjects are presented in Table 3 and Fig. 6. Table 3 shows the apparent positions of T from the physical positions projected onto the retina. The curves in Fig. 6A shows the relationship between the displacement of T and the spatial separations d for each subject. Fig. 6B represents the group mean of all subjects. From the results in Fig. 6A, it can be seen that three of the subjects almost always perceived T to approach S except at a spatial separation of 3°30′. At a separation of 3°, the maximum displacement appeared clearly, and at a greater separation of 3°30′, either a small displacement towards S or a displacement away from S was perceived.

As shown by the curve in Fig. 6B, the results of Exp. Ⅲ are consistent with those of Exp. II in the following point. That is, the test stimulus displaces in the direction toward the inducing stimulus in the area close to it, but at a greater sepration the test stimulus displaces away from the inducing stimulus. As Fig. 6B clearly shows, an inverted U-shaped curve was obtained in Exp. III.

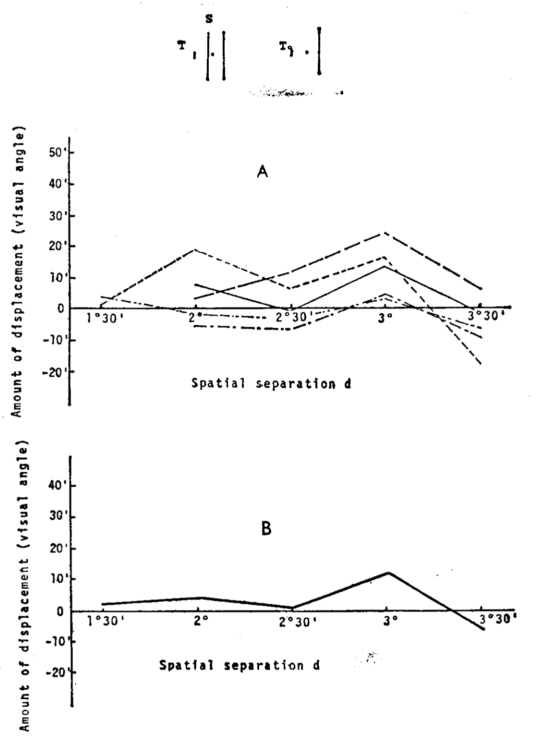

Fig. 6 A, B The curve showing the relationship between the amounts of displacement of T and the spatial separations of T and S (The results of Exp. Ⅲ). Graph A shows the results of 5 observers (subjects) and graph B shows the mean value. The plus and minus signs indicate the approach and removal of T from S.

The difference between the results of Exp. II and III is that a fairly large displacement of T appeared at a certain distance from the inducing stimulus in Exp. III, whereas in Exp. II the amounts of displacement are usually small and the maximum displacement did not appear clearly. Moreover, the maximum displacement in Exp. III appeared more distant than those in Exp. II. Such a difference shows that as a test stimulus becomes smaller the effect of an inducing stimulus on the former increases.

Discussion

The results of this study demonstrated that a pair of stimulus figures with binocular disparity have mutual effects and produce apparent displacements in the fused binocular field.

It has been considered that these displacements depend upon binocular fusion. However, the features of the displacements measured in this study are quite similar to those in "field induction effect" in the monocular field, and vary with the stimulus constellation. From these phenomena, the apparent displacements can be regarded as the field induction effect, not as any special effect of binocular fusion.

According to the theory of Dodwell & Engel (1963), binocular fusion can be considered as the operation to match two retinal images. Julesz's studies (1964, 1971) using random dot sterograms suggested that binocular depth perception can be produced by binocular disparity alone without contour recognition. It is postulated that the apparent displacement in the depth is caused by both binocular fusion and field induction effect. In other words, when a pair of stimuli having binocular disparity are fused stereoscopically, the field effect must operate to alter the disparity. As a result, the depth effect will vary with this altered disparity, and will produce apparent displacement in the depth.

An earlier study by the author was considered with the displacement effect in stereoscopic vision (Ichikawa, 1956). When a pair of small points and a pair of circular figures were presented with different horizontal disparity and fused stereoscopically, the apparent three-dimensional displacement of a small point occurred, and its direction and magnitude were varied with its position produced by fusion in the third dimension. This fact indirectly proves the above hypothesis.

The psychophysiological basis for the apparent displacement in the visual field is interpreted as follows. According to the psychophysiological model by Obonai (1959) and the informational-engineering model based on neurophysiology by Fujii & Morita (1971), the location in which contour is perceived corresonds to the retinal or cortical position in which neural activity are the most eminent. The induction field represents the distribution of nerual activities. The two monocular induction fields formed by stimulation to each retina interact with each other, and after this interaction, the two altered monocular fields form a binocular combind field. As the result of the interaction (interocular induction), the position of the maximum neural activity in the binocular combined field differs from the one caused by the stimulation to each eye separately. It is assumed that such interaction process is the psychophysiological basis for the occurrence of apparent displacement by field induction effect.

Recently, neruophysiological investigations of binocular depth discrimination and binocular interaction were conducted by Barlow, et al. (1967), Bishop, et al. (1968), and Joshua & Bishop (1970) on the basis of Hubel and Wiesel's 1962 study. From their studies, it was confirmed that optimum facilitatory responses occur only at the separated position most suitable to yield fusion in area 17 of the cortex of a cat. That is, the neurons analysing disparity reside in area 17. These new findings might facilitate investigations into the process in which binocular interaction occurs.

From the results of the three experiments presented here, it is concluded that two stimuli projected onto different positions of the right and left retinae produce mutual interaction in the binocular field and that the interaction causes apparent displacement in the direction of mutual attraction when two stimuli are close to each other in the binocular field. The amount of displacement does not increase in a simple proportion to the spatial separation d; maximum displacement appears at an intermediate separation, while at greater separations the displacement is slight or in the opposite direction.

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