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Contour displacements and tracking errors: Probing 'twixt Poggendorff parallels*

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Explanations of the Poggendorff effect were tested by varying the separation between outer parallels and by adding interior parallels. Error decreased with the addition of interior parallels, which can be explained by repulsion of parallels. A strong linear trend existed for judgmental error in millimeters plotted against separation between outer parallels. The nonzero intercept of a best-fit line and the slight nonlinearity of the data suggest a hypothesis of contour repulsion between parallels at moderate separations coupled with mistracking of the transversal across the region between parallels. Since the Poggendorff effect was independent of viewing distance, perceptual errors cannot be explained by purely peripheral mechanisms. A true intersection between transversal and parallel was the most critical feature of a display. Inverting a display increased the mean error.

The Poggendorff effect occurs when parallel lines interrupt a transversal. Three statements describing why the transversal segments do not appear to be collinear might serve as a focus for research: The parallels appear too close together. Or, transversal segments are misperceived in orientation. Or, a tracking error leads to misjudging the collinearity of the transversal segments. The purpose of the series of experiments to be reported is to examine in detail the role of the parallels and the space between in order to limit the range of admissible hypotheses.

The display employed was a modified version of the traditional Poggendorff display in which the upper right segment of the transversal was replaced by a dot lying on the right parallel line. The S's task was to set the dot so that it appeared to be collinear with the lower left transversal segment. The modified display is easier to construct, calibrate, and use in experiments employing the method of adjustment. It also precludes the complaints of some observers that the two transversal segments do not even appear to be parallel, and a collinearity setting is therefore impossible. The modified display produces large effects (Weintraub & Krantz, 1971) similar to those obtained with the traditional display.

If parallel lines appear perceptually as too close together, then the apparent collinearity of transversal segment and dot would be disturbed in a manner compatible with the Poggendorff effect of setting the dot too low (see Inset A in Fig. 5). Models of contour interaction based upon lateral inhibition normally predict a repulsion between contours that decreases with increasing separation between them (for example, Ganz, 1966). However, there is ample evidence that the contours of concentric circles appear closer together (for example, Weintraub, Wilson, Greene, & Palmquist, 1969). Therefore, a strong prediction is that if only neural interactions are involved, then the Poggendorff effect should eventually diminish with increasing separation between parallels.

Contour interactions may cause the orientation of the transversal segment to be misperceived. A Poggendorff effect will be obtained if the acute angle between transversal and parallel is overestimated (see Inset B of Fig. 5); there is positive psychophysical evidence (Blakemore, Carpenter, & Georgeson, 1970) and neurophysiological evidence (Burns & Pritchard, 1971) for presuming the overestimation of acute angles. Misperceived orientation of the transversal segment would produce a consistent tracking deviation between the parallels regardless of their separation. Displacing the dot along the right parallel until it appears collinear should give a displacement error in millimeters that is directly proportional to the separation between parallels.

If perceptual tracking beyond the transversal is disturbed by the presence of a parallel lying across the track, then the tracking error, as in the case of a misperceived transversal, should lead to a millimeter displacement that is directly proportional to the separation between parallels (Inset B of Fig. 5). The introduction of additional interior parallels should produce predictable additional deviations as the track is further disturbed.

In light of the foregoing, initial experiments were concerned with the separation between parallels and the introduction of lines into the interspace as a means of evaluating hypotheses.

EXPERIMENT I

Method

Subjects

A total of 80 Ss served, 40 from the unpaid S pool of the

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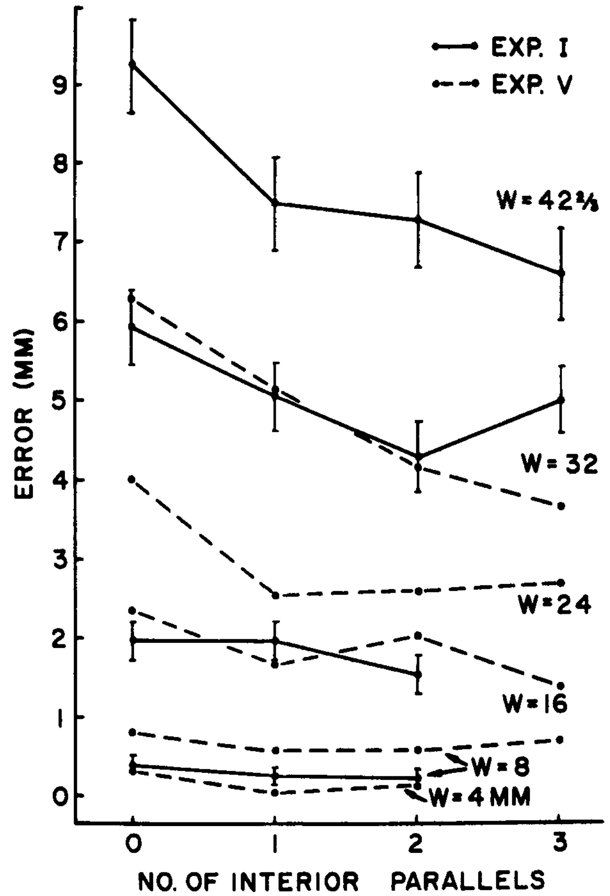

Fig. 1. Mean Poggendorff error as a function of width (w) between outer parallels and the number of interior parallels. (Vertical bars about a mean represent ±1 $SD_{\bar{X}}$.)

University of Michigan Psychology Department, 40 from the paid pool.

Stimuli and Apparatus

The stimuli were variations of the modified (single transversal segment) Poggendorff display described above. The black 1.5-mm dot replacing the right transversal was inscribed on the underside of a thin sheet of transparent matte-surface Mylar plastic, 22.8 x 48.3 cm (9 x 19 in.), constituting an overlay. The underlays were 22.8 x 30.5 cm (9 x 12 in.) sheets of white drafting paper (85% reflectance) containing .4-mm black lines ruled in India ink (3% reflectance). The transversal formed a 45-deg angle with the lower section of the left parallel, and the transversal extended to the left edge of the paper as viewed by S. The parallel lines, which extended the full length of the paper, were parallel to the long edges of it, and were vertical in S's visual field. Stimulus illumination was 430 lux.

The overlay and an underlay were positioned on a white board with their left edges resting against a raised straight edge. The underlay fit into a depression so that it was flush with the surface of the board. When S moved the overlay, keeping it in contact with the straight edge, the dot moved vertically along the right parallel of the underlay. Stimulus variables were: the width between the outermost parallels, 8, 16, 32, 42-2/3 mm; the number of interior parallels, 0, 1, 2, 3, with interior parallels always equally spaced in the space between outer parallels. (For 8- and 16-mm separations, displays with three interior parallels were omitted.) For the 32-mm width only (the *horizontal* separation between the tip of the transversal and the movable dot remained at 32 mm even when outer parallels were deleted), other display features were altered as illustrated in Fig. 2: In conjunction with equally spaced interior parallels, one or both exterior parallels were deleted. In addition, three interior parallels were positioned in either the left or right half of the space between exterior parallels (inset of Fig. 2). These altered displays were judged only by the 40 unpaid Ss; all Ss judged the other displays.

The board containing overlay and underlay lay on a table covered with white cloth. Fixed to a horizontal rod was a mask 53.3 cm above the stimuli containing eye slits restricting S's gaze to the perpendicular to the stimulus surface at its center and keeping the parallels of the Poggendorff display oriented top to bottom in his visual field.

Procedure

The S stood on one side of the table with E on the other. Viewing one of the set of randomly presented displays through the mask, the S was instructed to "move the overlay against the raised edge until the dot lies on an extension of this [E points to the transversal] line." Thus, S was asked to make a collinearity judgment. To start the trial, E randomly placed the dot either obviously too high or obviously too low for collinearity. No time limit was imposed on the judgment. Two identical display boards were located side by side, separated by a tall partition. After a judgment, S proceeded to the display in the next booth while E measured the response and set up a new display in the vacant booth.

An S's dot settings were measured by a plastic template laid on the display such that a scribed straight line on the template coincided with the transversal and extended it to intersect the right parallel. Vertical deviations along the right parallel of the dot setting in millimeters from this true intersection constituted errors. Errors in the Poggendorff direction (downward) are designated as positive.

Results and Discussion

For all widths between parallels, the addition of evenly spaced interior parallel lines led to a decrease in the Poggendorff effect (Fig. 1), i.e., S did not place the dot quite so low along the right parallel. Increasing the width between parallels increased the error in millimeters. A vertical bar about each mean in Fig. 1 indicates ± one standard error of the mean ($SD_{\bar{X}}$); note that variability in the data increased with increasing mean error.

These data are strong evidence against a parallels-attract hypothesis of the Poggendorff effect. Regardless of contour separation, which is represented in the distal stimulus as width between the parallels, additional interior parallels produced an anti-Poggendorff effect. The anti-Poggendorff effect could occur if interior parallels repel. It seems unlikely that the two parallel lines of the traditional Poggendorff display might attract one another, whereas there is mutual repulsion among more than two. Moreover, the errors did not diminish as contour separations increased in accordance with a contour-interaction hypothesis.

The displays illustrated in Fig. 2 are variations obtained by adding or removing parallels from a display with a 32-mm width between outer parallels. Compare these means with the means for W = 32 mm in Fig. 1. Removing only the left outer parallel reduced errors nearly to zero. When both outer parallels were deleted, adding interior parallels tended to increase the Poggendorff effect, in direct opposition to the data of Fig. 1. These outcomes can in fact be interpreted. Weintraub and Krantz (1971) have shown that the critical feature for a robust Poggendorff effect is an actual intersection between transversal and parallel. Removing the left parallel abolished the intersection and most of the error. In displays with both outer parallels missing, the addition of evenly spaced interior parallels closed the gap existing between the end of the transversal and the nearest parallel. A hypothesis to be tested in the second experiment is that the smaller the gap, the greater the Poggendorff effect, since a true intersection is a critical feature. Finally, Krantz and Weintraub (1973) have shown that removing the right parallel from any display containing a transversal reduces the Poggendorff effect. The data are consistent with that trend also.

Displays in the inset of Fig. 2, containing unevenly spaced interior parallels, evaluate a simple principle concerning mistracking: the earlier a track is misdirected, the greater the final error. Therefore, interior parallels will cause greater mistracking when inserted early in the track, that is, to the left. The mean errors were 5.34 mm for parallels left, and 5.14 mm for parallels right. The difference between means is small and not statistically significant.

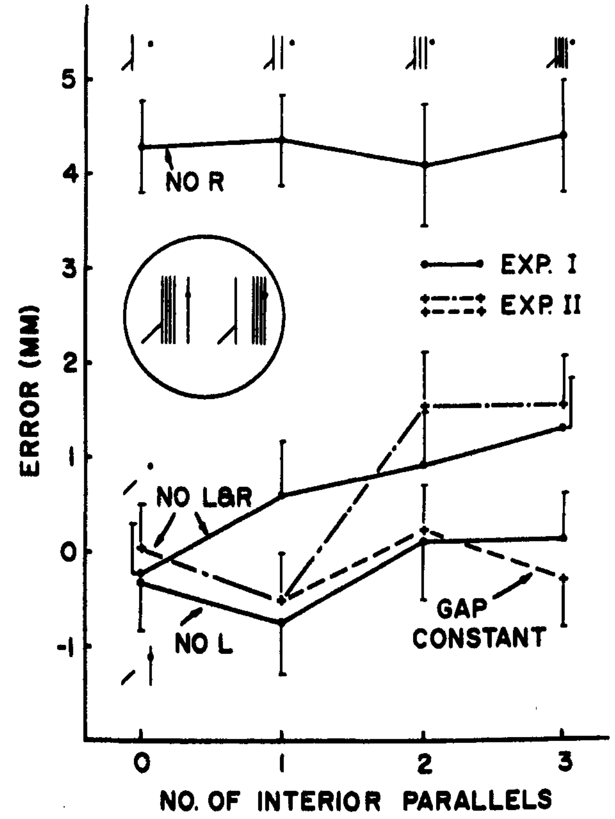

Fig. 2. Mean Poggendorff error as a function of the number of interior parallels and whether the right outer parallel (R), left outer parallel (L), or both (L&R) were deleted. In Experiment II, displays labeled "gap constant" are those without L or R, in which the distance between the tip of the transversal segment and the leftmost "interior" parallel remained constant. Inset: Displays in which three interior parallels were equally spaced in the left half or the right half of the region between outer parallels.

EXPERIMENT II

Method

A new group of 40 paid Ss served. The apparatus and procedure were the same as in Experiment I. Of the six displays used, four were those used in Experiment I. These were displays in which both outer parallels had been deleted, yet the Poggendorff error increased when interior parallels were added. In both new displays, the exterior parallels were deleted, and there was a center parallel plus either one or two additional parallels equally spaced to the right of the center parallel. The intention was to add parallels without concomitantly decreasing the gap between transversal and nearest parallel.

Results and Discussion

The mean data of Experiment II are shown in Fig. 2, connected by dotted lines. Replication of the increase in error with increasing interior parallels, as in Experiment I, was obtained, but only when gap size decreased. Thus, we conclude that gap size is the crucial variable, the smaller the gap, the greater the error. A problem left unresolved is that when only the left parallel was missing in Experiment I, the gap decreased with the addition of interior parallels, yet the amount of error did not increase.

EXPERIMENT III

If the critical feature of the Poggendorff display is, in fact, the actual intersection of the transversal tip and a parallel, then a strong maximum error should exist in that location when the lateral position of a single vertical line is systematically varied in relation to the transversal.

Method

A total of 48 naive paid Ss served. The experiment was patterned after one by Weintraub and Krantz (1971, Experiment IV), and the method is described there in detail. In brief, the fixed part of a figure was ruled in India ink on white paper (line thickness, .25 mm). A movable black dot (1.5 mm) was carried by a transparent acetate overlay. The configuration was viewed through a window shaped like a racetrack (flattened oval) with lines proceeding to the edge of the window. The S adjusted the vertical position of the dot to lie on the continuation of the transversal segment by turning a knob projecting from the box enclosing the display. The acute angle between transversal and vertical line was 24.2 deg (tan = .45).

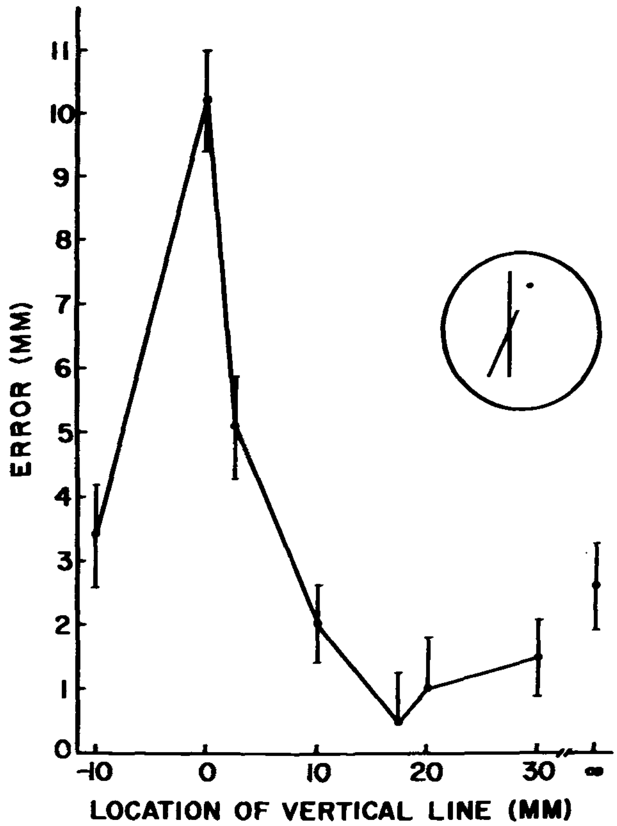

Fig. 3. Mean Poggendorff error in Experiment III as a function of the horizontal location (with respect to the top tip of the transversal segment) of a single vertical line. Depicted in the inset is −10 mm. Location 0 mm is at the transversal tip; 20 mm is at the dot; ∞ means that the vertical line was deleted.

Horizontal separation between transversal tip and movable dot was 20 mm. Displays consisted of a vertical line located at one of seven lateral positions with respect to the transversal plus one display with vertical line absent (see illustration in Fig. 3).

Results and Discussion

The mean data (Fig. 3) show that when the vertical line was not in close proximity to the tip of the transversal, there was only a small Poggendorff error, an error no greater than was produced by a transversal alone. Taken in the aggregate, the first three experiments support the contention that the crucial feature of a Poggendorff display is the actual intersection of transversal tip with a parallel. (Note that a small Poggendorff-type effect existed in the absence of any parallels.)

EXPERIMENT IV

The modest decrease in Poggendorff effect with the addition of interior parallels in Experiment I could be explained by a tracking hypothesis, a counterclockwise (leftward) and, therefore, anti-Poggendorff deviation of the track when crossing an interior parallel. No significant difference was obtained between grouping interior parallels near the beginning of the track (toward the left) and grouping near the end (toward the right), which is predicted by a tracking hypothesis. This study was conducted in order to reevaluate the hypothesis.

Method

A total of 40 naive students from the paid S pool served. The apparatus and procedure were the same as in Experiment I, and displays were variations of the basic display, having a horizontal separation between outer parallels of 32 mm. Interior parallels, 1, 2, or 3 in number, were positioned to the left, center, or right in the region between outer parallels. Among themselves, interior parallels were spaced 5-1/3 mm apart. In addition to these six displays plus a control display without interior parallels, Ss viewed a display identical to the five-line (width = 32 mm) display of Experiment I, that is, the two outer parallels with three evenly spaced interior parallels. However, this display was judged four times, with the vertically movable dot lying along each parallel except for the one intersecting the transversal.

Results and Discussion

The mean data are shown in Fig. 4. Not plotted is the point for the control display, two outer parallels with no interior parallels ($\bar{X}$ = 5.14, S.E.$_{\bar{X}}$ = .56), which is not

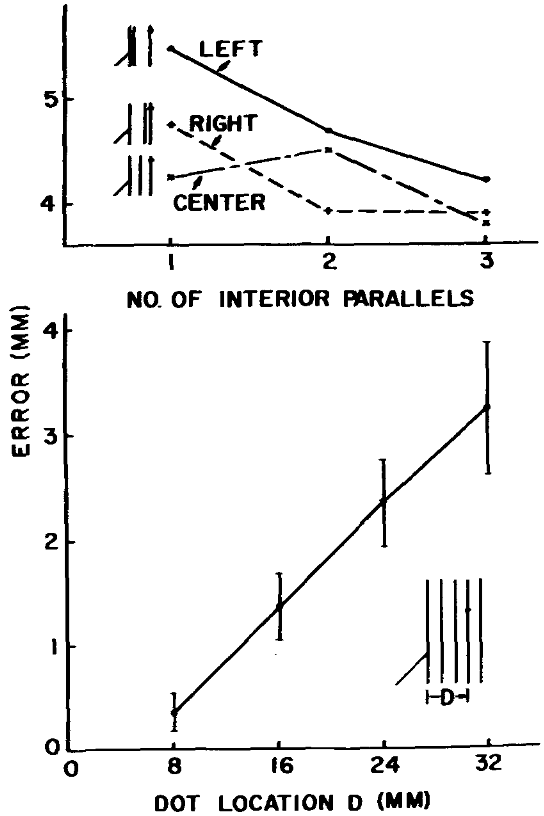

Fig. 4. The means of Experiment IV. Top: Error as a function of the number and location of interior parallels. Bottom: Error as a function of dot location on various parallels of a five-parallels display.

significantly different statistically (α = .05) from the equivalent display of Experiment I. In the top half of Fig. 4 is shown the expected decline in the Poggendorff effect with a greater number of interior lines [$F(2,78) = 6.75$, $p < .01$]. There was also a small, but significant, position effect [$F(2,78) = 4.45$, $p < .05$], such that, for any given number of interior lines, when they appeared at the left, the Poggendorff effect was greater than when they appeared at the right. Lines in the center did not consistently show an intermediate amount of error, but the interaction of number of interior parallels with their position was not statistically significant [$F(4,156) = 1.56$].

The position effect supports a mistracking hypothesis postulating a small clockwise (Poggendorff) deviation as the track crosses interior parallels. However, mistracking in a counterclockwise (anti-Poggendorff) direction is supported by the decline in mean error with the addition of interior parallels.

Results from the equally spaced five-line display are shown at the bottom of Fig. 4. The function is linear, but it does not have a zero intercept. The linear increase in error as S crossed additional interior parallels refutes a mistracking hypothesis. The prediction from any mistracking hypothesis is a nonlinear function as additional deflection increments accrue at each parallel crossed. The important characteristic of the displays under consideration is that they were identical except for dot location. No contours were added, so contour repulsion, if it exists, should be the same from display to display. Assuming that equally spaced parallels appear to be equally spaced (informal observation does not contradict the assumption), the function should be linear with zero intercept. The nonzero intercept is the only evidence against the repulsion hypothesis; all other evidence seems compatible.

How can the influence of the position of the interior parallels be explained if tracking is not deflected at each free-standing line? Assume that only free-standing parallels like the right outer parallel or the interior parallels are displaced perceptually by contour repulsion. It is quite reasonable to assume that the left parallel is anchored by the transversal. Therefore, interior parallels toward the right have a greater repulsion effect on the *right* parallel than do interior parallels toward the left. Greater repulsion means an increase in perceived separation between outer parallels and, as explained previously, a greater decrease in the Poggendorff error. The assumption that only a free-standing parallel can be displaced is useful in interpreting certain results from Experiments I and II. The top function in Fig. 2 shows data for displays with the right parallel deleted. The dot, not being attached to a free-standing parallel, was not affected by the addition of parallels. For the bottom function of Fig. 2, it was argued that when the left parallel was omitted, it destroyed the intersection of transversal and parallel, thereby eliminating the Poggendorff effect. Adding interior lines in the absence of a left parallel closed the gap between transversal tip and the leftmost parallel, leading to an increase in the judgmental error. However, such an increase was found only when both outer parallels were deleted. A reasonable explanation is that, with only the left parallel missing, the increase in the effect resulting from the closing gap between transversal and a parallel was counteracted by the decrease caused by contour repulsion of the right parallel.

The interaction among interior and outer parallels can be conceived of as the Oppel effect, where filled space is perceived as more extensive than unfilled space. Mistracking commencing at a true intersection is a separate phenomenon, which is of greater magnitude, and which acts in the opposite direction.

The Linearity Hypothesis

Two theories of the Poggendorff effect make predictions concerning the linearity of data. Misperceived transversal orientation predicts a judgmental error proportional to the separation between parallels, which approaches zero as the separation approaches zero. With respect to misdirected tracking in the region between parallels, if tracking were misdirected at the intersection between the transversal and the left parallel, then the display composed of two parallels should also provide data fitting a straight line of zero intercept.

The data of Experiment I are replotted in Fig. 5, with the abscissa representing the width between the parallels. Burmester (1896) and Weintraub and Krantz (1971) concluded that the amount of error in millimeters is equal to $kW/\tan A$, where k is a constant, W is the width between parallels, and A is the acute angle between transversal and parallels. With W varying and A fixed, the function predicts that the data will lie on a straight line of zero intercept (zero error when width equals zero). The data, for any given number of interior parallels, are not significantly different from a straight line. However, in every instance, there is a clear violation of the prediction of a zero intercept.

No more than casual observation of displays with separations close to zero is needed to convince oneself that the Poggendorff effect neither disappears nor reverses. Thus, linearity cannot hold throughout the entire range of separations. A reasonable expectation is that a function begins at the origin of Fig. 5, accelerating positively to meet the mean for an 8-mm separation. The aim of Experiment V was to determine Poggendorff errors as retinal separation between parallels approached zero. Viewing distance was increased, reducing retinal size without a concomitant reduction in the physical sizes of displays.

EXPERIMENT V

Method

The 40 naive Ss were drawn from the paid S pool. Viewing

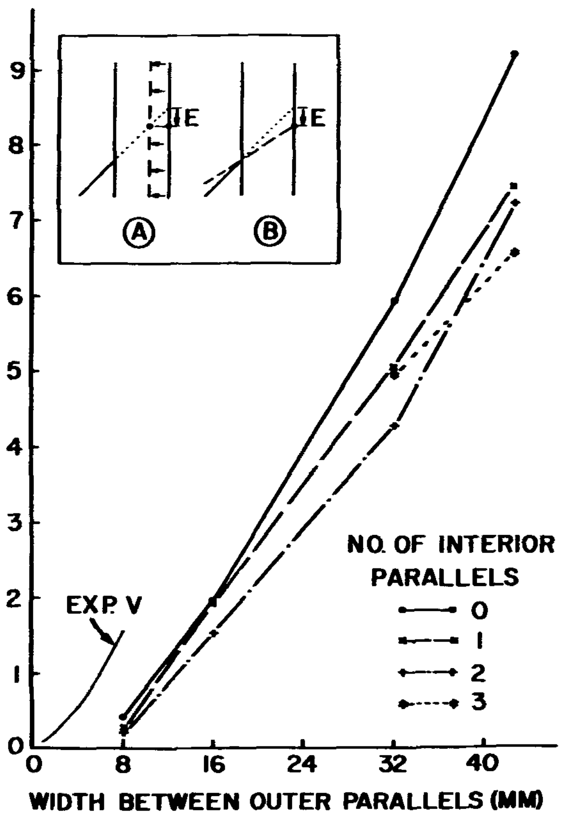

Fig. 5. Mean Poggendorff error in Experiment I. The data of Experiment V (for outer parallels without interior parallels) have been transformed to represent equivalent data at the standard viewing distance. Theories are depicted in the inset: (A) parallels attract; (b) mistracking or misperceived orientation of the transversal.

distance between S and display was increased to four times that of previous experiments, a perpendicular distance of 213.2 cm from the surface of a stimulus display to the top of the eye mask. In the previous experiments, the standing S looked down at displays lying on a table. To maintain the same posture and line of regard, S was now required to mount a platform via a stepladder, thus the label, high-rise condition. Stimulus illumination was equated to the previous level (430 lux). The overlay, board, and suitable underlays from Experiment I were used. Additional underlays were drawn. Width between outer parallels was 4, 8, 16, 24, and 32 mm, with 0, 1, 2, or 3 interior parallels added (except for the 4-mm width, where the display with three interior parallels was omitted). At the high-rise viewing distance, the separations between the outer parallels provided stimuli equivalent in visual angle to 1-, 2-, 4-, 6-, and 8-mm stimuli at the standard viewing distance.

The E moved the overlay according to directions given by S, who viewed the display through the mask. The starting position of the dot was obviously too high or too low. The S was not permitted to watch the measuring of his error.

Results and Discussion

The high-rise data are shown in Fig. 1 connected by dashed lines. Presented are the means of untransformed errors, the errors in millimeters as measured on the displays. Note that the high-rise data map closely onto the standard data. Therefore, the hypothesis that physical size determines errors is not contradicted. The error data for the displays with no interior parallels were transformed by dividing the means by 4 and the separation between parallels by 4; they are plotted in Fig. 5. The transformation represents the data as if they had been gathered at the standard viewing distance, and assumes that visual angle (retinal size) is the only variable of concern. The high-rise data are not continuous with the standard-viewing-distance data to fill in smoothly the missing values for small separations between parallels. Thus, in Fig. 5, for data plotted at an 8-mm width between outer parallels, the *retinal* size of the display from Experiment V equals the *retinal* size of the display from Experiment I, yet the scaled-down errors for Experiment V are much too large. In summary, Poggendorff errors were not directly tied to separation between parallels of the proximal stimulus (retinal image).

EXPERIMENT VI

The increased viewing distance was not the only difference between Experiments I and V. Because the display was not within arm's length of S, E assumed the task of moving the dot. Also, the lines and dot of high-rise displays subtended a smaller visual angle. Experiment VI was designed to evaluate these differences.

With the modified Poggendorff display consisting of a single transversal segment and a dot like those employed here, Weintraub and Krantz (1971) noted that inverting the display increased the measured error. Weintraub and Virsu (1972) found that Ss consistently placed a dot too high in their visual field when estimating collinearity. Thus, if a transversal were tracked in an upward direction, then the so-called elevator effect would introduce an anti-Poggendorff increment to dot-setting errors. Inverting the display requires a downward tracking so that the elevator effect would add to the Poggendorff error. A possible explanation for the nonzero intercept of the linear functions is that the elevator effect was the cause of reduced mean errors at all separations between parallels.

Method

Another group of 40 naive Ss from the paid-S pool served. Two viewing distances were investigated, the standard distance of 53.3 cm and the high-rise distance of 213.2 cm. Only stimuli with the two outer parallels and no interior parallels were retained from Experiment V, with widths between parallels of 4, 8, 16, 24, and 32 mm. Inverted displays with the same five widths were drawn, with the transversal proceeding downward to intersect the left parallel at a 45-deg angle. The transversal remained on the left, but S now tracked *downward* toward the dot on the right parallel.

Only in the high-rise condition did Ss view upright displays constructed with contours made four times thicker, lines 1.6 mm thick and the dot 6.0 mm in diam. Width between these parallels, measured from the centers of the lines, was 8, 16, 24, and 32 mm, with the transversal forming the usual 45-deg angle with the lower part of the left parallel.

For the standard viewing distance, two additional judgments were made at both the 16- and 32-mm widths. The upright and the inverted display at each width were rotated 180 deg in the plane of the display in order to place the transversals at S's right (i.e., two sets of mirror-image displays were added). Left vs right asymmetries could be evaluated, since S was now required to track toward the left.

Half of the group of Ss judged the high-rise condition first, and half judged it second. For both standard and high-rise viewing distances, E moved the overlay in accordance with S's instructions. At the end of the series of judgments at the standard viewing distance, S was asked to move the dot himself on 10 displays (widths of 4, 8, 16, 24, and 32 mm, transversal on the left, upright, and inverted displays).

Results and Discussion

Mean data from Experiment VI are shown in Fig. 6. High-rise condition, thin-line, and thick-line displays are displaced on the graph upward by 3 mm to improve the clarity of the graph.

Unlike the two prior experiments with "upright" Poggendorff displays (those where tracking the transversal proceeds upward), the more-or-less linear data plotted as a function of width between parallels have an intercept sufficiently close to zero to be called zero. Data for the thick-line high-rise displays have been transformed to make them equivalent to data at the standard distance and are plotted in the lower left of Fig. 6. A slight difference in slope between high-rise and standard data led to the minor degree of discontinuity that is evident. The severe discontinuities in previous experiments were primarily the result of a nonzero intercept.

For data gathered at the standard viewing distance, there is a difference in slope depending upon whether E adjusted the dot or S adjusted it. The S-adjusted displays evinced a shallower slope. If such a slope difference is real, then the discontinuity in Fig. 5 between transformed high-rise data from Experiment V and data at the standard viewing distance from Experiment I would have been less pronounced had E adjusted the dot for both viewing conditions.

Differences in line thickness among upright high-rise displays produced moderate changes in the magnitude of errors. An analysis of variance on upright high-rise displays (with the smallest width for thin-line displays omitted) showed width between parallels to be a significant variable [$F(3,117) = 70.69$, $p < .01$]. The differences due to line thickness were also significant [$F(1,39) = 5.77$, $p < .05$], but in the wrong direction to explain the mismatching in Experiments I and V between standard and high-rise data. (The interaction was not significant.)

The mirror-image displays (transversal on the right) led to errors that were not significantly different from the equivalent displays with transversal on the left. It can be concluded that if any such differences exist, then

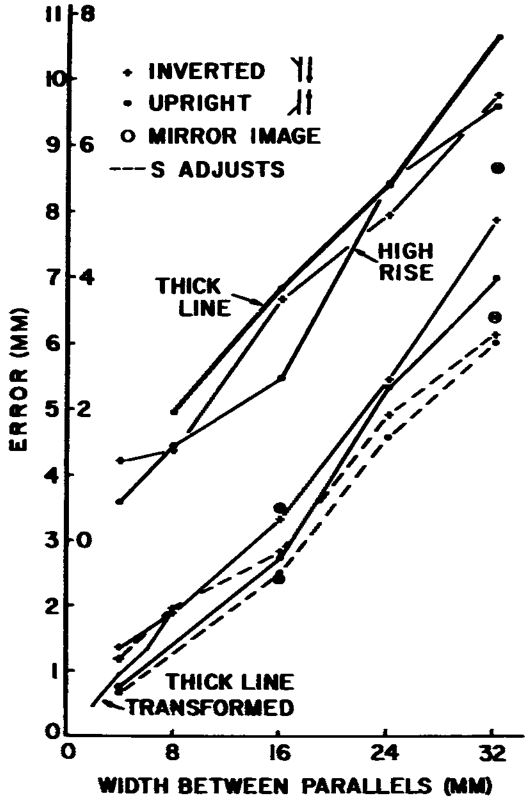

Fig. 6. Mean Poggendorff errors in Experiment VI. (For high-rise data, error scores have been displaced upward by 3 mm.)

they are relatively small. However, inverting a display by placing the transversal at the top consistently produced a rise in measured errors at the standard viewing distance. This elevator effect, which can be interpreted as a propensity for S to be satisfied with a dot setting too high in his visual field, occurred regardless of whether E or S actually moved the dot. (Weintraub & Virsu, 1972, also obtained an elevator effect with a constant-stimulus procedure in which the dot appeared too high or too low.) Averaged across separations between parallels, there was a small, but statistically nonsignificant, elevator effect for high-rise data (as well as a nonsignificant interaction between type of display, upright or inverted, and separation between parallels). The conclusion is that an elevator effect exists. The hope was that it might explain the negative y intercept found previously for upright displays. In other words, averaging out the elevator effect, i.e., combining the data for upright and inverted displays in Fig. 6 into one function might have yielded a linear function with a zero intercept. However, averaging out the elevator effect led to a positive y intercept.

With the upright Poggendorff display, two experiments had yielded negative y intercepts and one experiment an essentially zero intercept. Given the importance of the zero-intercept question and the rather

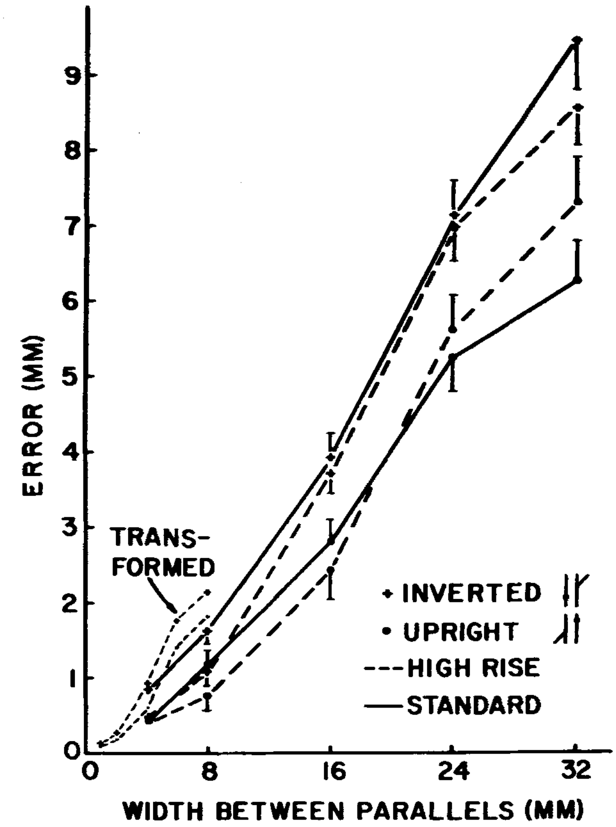

Fig. 7. Mean Poggendorff errors in Experiment VII.

small discrepancy from zero involved, a replication was deemed necessary.

EXPERIMENT VII

Method

Upright and inverted displays were presented at the two viewing distances, with a change in the method of drawing stimuli and modifications in the procedure used by E to measure S's dot settings. The aims of the alterations were a gain in precision, and, even more important, an attempt to determine if the previously used techniques might have introduced any unaccounted for bias into the results.

The Ss were 40 naive students from the paid-S pool. The apparatus was the same as that of Experiment VI. New displays were drawn in all cases. Lines forming a Poggendorff stimulus were scribed with a carbide point onto opaque white acetate constituting the underlay. India ink was poured into the scribe marks and the excess wiped away. Widths between parallels were 4, 8, 16, 24, and 32 mm, with the transversal forming a 45-deg angle with the lower part of the left transversal. A new Mylar overlay containing the 1.5-mm black dot was made. On each underlay, a short scribe mark indicated the vertical location of the intersection of the true transversal track and right parallel. A similar scribe mark on the transparent overlay indicated dot location. When the dot was placed at the true intersection, the scribe marks were superimposed. The distance in millimeters between scribe marks determined the Poggendorff error. A flap was added to the raised strip of the display boards to conceal the scribe marks from Ss. All displays were checked under 25-power magnification and were redrawn until dimensions were within 0.1 mm of their intended values. Acetate underlays are not much affected by changes in humidity and temperature compared to paper underlays.

The experiment was divided into two parts on the basis of viewing distance. Half of the group of Ss viewed the high-rise distance first. In each part, each display was viewed twice, once with the transversal at S's left pointing upwards and once with the display rotated 180 deg to an inverted position so that the transversal was on S's right pointing downward. The 10 trials in each part were randomized in a different order for each S; E moved the dot in accordance with S's instructions in both parts.

Results and Discussion

The mean data are shown in Fig. 7. In agreement with the previous outcomes, the magnitude of the standard deviation among errors was related to the magnitude of the mean. The product-moment correlation between standard deviation and mean for these 20 means is +.938 ($p < .001$). The elevator effect appeared consistently at both high-rise and standard distances, i.e., inverted displays always produced greater mean errors. In this experiment, inverted and upright displays were not different drawings, so virtually all nonrandom differences in data between the two can be attributed to Ss. The inverting of a display also changes the transversal from the left to the right side of the display as viewed by S. However, all available prior evidence points toward the up-down change as the critical one. As Fig. 7 shows, viewing distance was not an important variable. Functions are more or less linear, and, in conformity with all results save those from Experiment VI, the y intercepts for upright displays are negative. In addition, the y intercepts for inverted displays are also negative. Since each S judged all displays, 40 individual estimates of each y intercept were available. Each of the four mean intercepts was significantly different from zero in the negative direction ($p < .01$, two-tailed). The usual transformation of the high-rise data, dividing mean errors and separations between parallels by 4 to obtain values comparable to those of the standard viewing distance, is shown in the lower left of Fig. 7. A mismatch in functions is obtained. When transformed, the high-rise data at a 32-mm separation did not match the data for an 8-mm separation at the standard viewing distance.

Intercepts were too low to be zero. The elevator effect, although it surely exists, cannot account for nonzero intercepts. Since viewing distance was not a significant variable, the thickness and separation of retinal contours and the retinal location of the contours corresponding to the borders of a display must be of minor importance. In addition, experimental precision in order to fill the data gap at small separations between parallels cannot be gained merely by increasing the viewing distance. Results will not be commensurate with what would have been obtained at the original viewing distance.

OVERVIEW AND THEORY

The Oppel effect, that filled space appears more extensive than unfilled space, is a reasonable description of why the addition of interior parallels decreased the measured Poggendorff error. Contour repulsion among the neural representations of parallels is a likely hypothesis favored by the evidence. The additional postulate that only a free-standing parallel can be displaced when parallels repel can account for many otherwise puzzling findings. The data do not support the hypothesis of misdirected tracking caused by traversing free-standing interior parallels.

Although the parallels-attract hypothesis of the Poggendorff effect seems not to have received any serious attention in the literature, the hypothesis is a logical one deserving experimental attention. The hypothesis should be rejected, because it is strongly contradicted by the evidence. First, Poggendorff errors did not decrease toward zero as the separation between parallels increased, as any neural theory would predict on the basis of declining contour interactions with increasing distance. Second, a logical extension of the finding that the addition of any number of interior parallels produces a decrement in the Poggendorff effect interpretable as contour repulsion is that the two outer parallels alone, the only parallels in the traditional Poggendorff display, also repel.

The elevator effect exists, and is not dependent upon whether E or S adjusts the stimulus (Experiment VI). A similar outcome has been obtained with the method of constant stimuli (Weintraub & Virsu, 1972). An upright display gives a smaller total error than an inverted display, presumably because, with the former, the elevator and Poggendorff effects tend to cancel, whereas with the latter they reinforce one another. Weintraub and Virsu (1972) reported a correlation between the elevator effect and the standard deviation of data, such that the effect decreased as the standard deviation decreased. If the elevator effect acts equally on an inverted and an upright display, then, at each separation between parallels, half the difference between the pair of means is an estimate of the elevator effect at that separation. In Fig. 7, the best data for the purpose, the difference between the functions for inverted and upright displays shrank and the standard deviations of data shrank as the separation between parallels was reduced. The product-moment correlation between elevator effect and standard deviation of the data for these 10 pairs of means is +.833 ($p < .001$), supporting the Weintraub-Virsu (1972) finding. Therefore, the elevator effect must lead to a slope difference between the functions relating judgmental errors to separations between parallels. Since data variability shrinks toward zero as the distance between parallels narrows to zero, the elevator effect can be expected to disappear, leaving the y intercept unaffected, and the data of Fig. 7 are in agreement. Therefore, the elevator effect cannot explain the existence of a negative y intercept in upright displays. We have no hypothesis to offer concerning the cause of the elevator effect. Note that small "Poggendorff effects" with an "inverted" display may disappear or reverse sign when the display is rotated 180 deg to "upright." (See, for example, the displays in Figs. 1 and 2 of Pressey & Sweeney, 1972.)

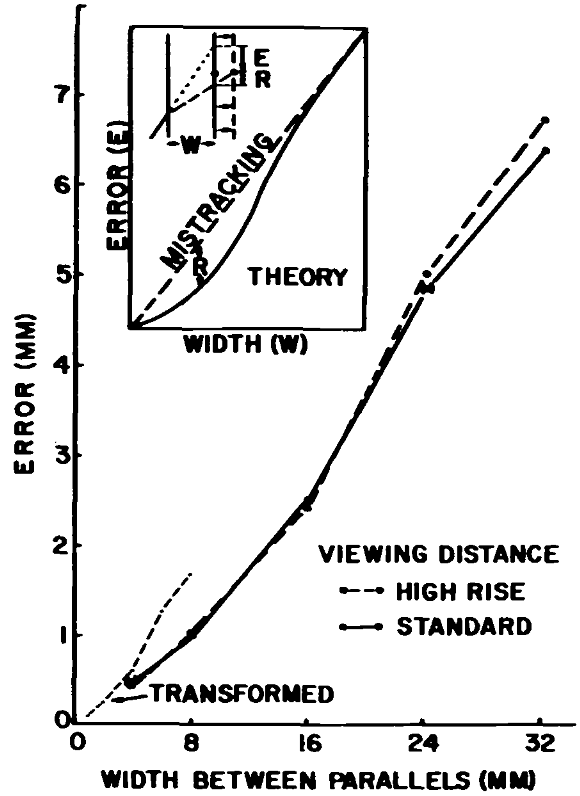

Fig. 8. Aggregate data based upon three experiments per plotted point. (For the two points in parentheses, linear interpolation between adjacent points was used to estimate missing data for Experiment I.)

Without question, the most salient feature of the function relating judgmental errors in millimeters to width between parallels is linearity. If the function is truly linear, then the best assumption from our data is that the line has a negative y intercept. For upright displays, Fig. 8 presents aggregate data from all relevant experiments, three experiments per plotted point (Experiments I, VI, and VII for standard-viewing-distance data, and Experiments V, VI, and VII for high-rise data). Two missing values in Experiment I were estimated via linear interpolation between adjacent points in Experiment I (assuming zero error at zero separation between parallels for the estimation of the 4-mm separation). Experiment I was not weighted twice as heavily, even though it had twice as many Ss. The aggregate data retain the small concave deviation from linearity and the nonzero intercept present in the data from most experiments. Viewing distance makes little difference. Transforming the high-rise data to be equivalent to data gathered at the standard viewing distance results in the discontinuous dotted segment near the origin of the graph.

The data of Fig. 8 represent a best estimate of the influence of width between parallels. We believe that these aggregate findings are of diagnostic value, even though the deviations from a straight line of zero intercept are small. If these data were linear with zero intercept, then the hypothesis of a straight track across the space between the parallels would have been supported. If the track were straight, then the error, in degrees, would be a constant for all separations. Data from Pressey and Sweeney (1972) on an "inverted" Poggendorff display with one transversal segment omitted were plotted as errors in degrees in Fig. 4 of their article. The function is curvilinear rather than flat. The errors differ among themselves by less than 1.7 deg, which was reported as a statistically significant (.01 level) difference. Pressey supplied the raw data in millimeters (which he had kindly converted, judgment by judgment, from the original measures taken in degrees). The use of degrees vs millimeters makes a small difference. For example, converting the mean of errors in degrees to a millimeter equivalent gives a slightly larger value than taking the mean of errors in millimeters. Plotting the Pressey-Sweeney millimeter data produced a function whose shape was much like the ones for inverted displays here in Fig. 7. The slope was steeper because of a different angle between transversal and parallel. Like the data of Fig. 7, the Pressey-Sweeney data were reasonably linear; however, the best-fit line had a near-zero intercept. Whenever millimeter data deviate from a straight line of zero intercept, converting the data to errors in degrees will show different errors for different separations between parallels.

Hill (1971) published an interesting Poggendorff study comparing retardates with normals. An inverted Poggendorff display with a single transversal segment was used. Hill found no statistically significant differences between retardates and normals. More important for present purposes, he found no significant differences in errors as a function of viewing distance; the data are linear when plotted with respect to separation between parallels and they show a clearly negative y intercept. Other experiments (Velinsky, 1925; Weintraub & Krantz, 1971) have systematically investigated width between parallels employing the traditional Poggendorff display consisting of both transversal segments. For any angle between transversal and parallels, both studies obtained linear functions relating errors in millimeters to width between parallels. Intercepts were somewhat variable, but near zero.

What sort of Poggendorff theory *is* tenable? If the transversal were misperceived in orientation, or if mistracking were to occur when the track was interrupted by the intersection of the transversal and the left parallel, then the track across the space between parallels would produce errors proportional to the distance tracked, i.e., a linear function with zero intercept. Linearity, at least, is a salient aspect of the findings. Neurophysiological data and theory suggest misperceived orientation of the transversal (Blakemore, Carpenter, & Georgeson, 1970; Burns & Pritchard, 1971). On the other hand, data by Hotopf and Ollerearnshaw (1972a, b), who asked Ss to judge the orientation of the transveral, argue strongly against misperceived orientation as the major contributor to a Poggendorff effect. The evidence seems to us equivocal, but we tend to favor the hypothesis of mistracking commencing at the intersection of transversal and parallel. Mistracking does not imply mistracking by eye, since such errors still occur under stopped-image conditions in which the proximal stimulus is fixed with respect to the retina (Pritchard, 1958).

The prime requisite for the occurrence of a Poggendorff effect is the existence of an actual intersection between transversal and parallel. Previous data have also indicated that this intersection plays a dominant role, and errors will decline to the extent that this intersection is degraded or removed (Weintraub & Krantz, 1971; Krantz & Weintraub, 1973). The hypothesis is that the intersection produces cognitive (higher order) mistracking to the opposite side of the display. As shown by the straight-line function in the inset of Fig. 8, tracking across an actual intersection produces a Poggendorff error proportional to the width between the parallels. (Tracking across free-standing lines like interior parallels does not produce Poggendorff errors.) Pure mistracking errors are attenuated slightly at some separations by contour repulsion between the neural representations of the parallels (as shown in the sketch of a Poggendorff display in the inset of Fig. 8, where the right parallel is displaced to the right to depict repulsion). If the transversals are perceived as too far apart, then S will mistrack further than he ought, causing a slight reduction in the measured error. Contour repulsion conforms to the distance paradox (Weintraub, Wilson, Greene, & Palmquist, 1969): At zero contour separation, repulsion is zero. Repulsion then increases to a maximum at moderate separations and declines again to zero as contour separation becomes very large. In the inset, the repulsion effect is depicted as the vertical distance between functions. It acts to decrease the error and leads to a net Poggendorff effect, as shown by the curved function in the inset of Fig. 8. The net effect is, of course, the effect that should appear in the data. The influence of contour repulsion is taken to be small relative to the errors produced by mistracking.

An additional postulate is that the contour repulsion between parallels takes place centrally, at higher neural levels where size-distance constancy is represented. The errors of S are directly related, not to retinal size, but to perceived size. Perceived size corresponds reasonably well to physical size, because all distance cues are present. Therefore, viewing distance is an ineffective variable (corroborated by Hill, 1971), even though the retinal representations of line thickness, borders of a display, and width between parallels change radically with viewing distance. A transformation that adjusts errors and sizes to be proportional to retinal size fails to handle data adequately. Indirect support for such a postulate is available. For the Ponzo effect, Greene, Lawson, and Godek (1972) produced changes in apparent distance by means of binocular disparity, and concluded that contour interactions had a central locus. Attneave and Block (1973) investigated the time delay between a pair of blinking lights necessary for apparent movement. The timing necessary to produce apparent movement was a function of the phenomenal distance between lights, even under conditions where the retinal distance between lights was held constant.

For Poggendorff displays containing a single transversal segment, an elevator effect is postulated, with inverted displays leading to greater measured errors. An S acts as though he is placing the dot marking his collinearity judgment too high in his visual field. It is predicted that only the slope of functions relating errors to separation between parallels will be altered by the elevator effect. For the Poggendorff display, the effect has been documented for upright and inverted displays containing a 45-deg intersection.

In addition to these postulates, which explain results presented here, two postulates based on previous work (Weintraub & Krantz, 1971) must be included in a general theory. The first is that Poggendorff errors are maximized when any given display is oriented so that tracking proceeds obliquely in S's visual field, and are minimized to near zero when the transversal is horizontal or vertical (Appelle, 1972; Weintraub & Krantz, 1971, Experiment V). The second is that mistracking is deflected toward the horizontal or vertical axis of the visual field, whichever is closer in orientation to the transversal (Weintraub & Krantz, 1971, Experiment V).

A theory that partitions the Poggendorff error into components seems inevitable, given the nature of the evidence. The magnitude of the error contributed by any theoretical component is one guide to its importance. A fruitful point of experimental attack would be to gather data permitting a choice between the two hypotheses that predict the large linear tracking errors: misperceived transversal orientation vs cognitive mistracking at the intersection of the transversal and parallel. Eliminating one of these hypotheses would be a big step forward.

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