

Research Article

MODAL COMPLETION IN THE POGGENDORFF ILLUSION: Support for the Depth-Processing Theory

Branka Spehar and Barbara Gillam

The University of New South Wales, Sydney, Australia

Abstract—*The Poggendorff illusion is one of the most prominent geometrical-optical illusions and has attracted enduring interest for more than a hundred years. Most modern theories explain the illusion by postulating various kinds of distortion of the “test” component of the figure by the context or the inducing component. They make no reference to the importance of processes involved in three-dimensional scene perception for understanding the illusion. We measured the strength of the Poggendorff illusion in configurations containing solid inducing surfaces as opposed to the usual parallel lines. The surface, oblique-line, and background luminances were manipulated separately to create configurations consistent with modal completion of the obliques in front of the surface. The marked decrease in the size of the illusion in conditions favoring modal completion is consistent with claims that perceived spatial layout is a major determinant of the Poggendorff illusion.*

In a configuration consisting of an oblique line interrupted by an area defined by two vertical (or horizontal) parallel lines, the two separated but collinear oblique line segments appear strikingly non-collinear (Fig. 1a). This geometrical-optical illusion, known as the Poggendorff illusion, has intrigued researchers for more than a hundred years, but its underlying mechanisms remain as yet unclear. The proposed explanations postulate various kinds of distortions in the perception of the obliques caused by their spatial context and range from those devised to explain the Poggendorff illusion alone, often without much application outside the illusion domain, to those that argue that an understanding of geometrical-optical illusions requires consideration of their functional relationship to the processes involved in normal perception (for a review, see Gillam, 1998).

One such functional account was recently proposed by Morgan (1999), who argued that the Poggendorff illusion arises because of retinal and cortical processes involved in the processing of relative position, orientation, and the collinearity of spatially separated lines and objects in general. In his model, the observer tests for collinearity in the Poggendorff configuration by comparing the orientation of the visible oblique lines with that of the virtual line joining the points of their intersection with the verticals (dashed line in Fig. 1b). Although the orientation of the visible oblique lines can be encoded directly and with a high degree of accuracy (Morgan, 1999), the orientation of the virtual line can only be estimated from its endpoints. Several studies have shown that the slope of the virtual line joining the inner ends of the visible oblique lines is perceived as steeper than the obliques themselves (Pierce, 1901; Weintraub & Tong, 1974). According to Morgan (1999), endpoints of the virtual line are mislocated into the

acute angles of the figure as a consequence of spatial blurring by second-stage cortical filters, thus resulting in an illusory misalignment between the orientation of the virtual line and that of the visible obliques. Such an illusory misalignment can be eliminated by moving the lower oblique segment upward, consistent with the direction of the Poggendorff illusion. Morgan's model proposes a rectification stage prior to the coarse-scale isotropic filtering that shifts the maximum filter response into the acute angles of the figure. He stated that a rectification stage is required because the Poggendorff illusion still exists in configurations composed of luminance-balanced lines defined only by spatial contrast (Morgan, 1999).

Gillam (1971, 1980) proposed a very different functional account of the Poggendorff illusion, involving mechanisms related to the perception of depth and spatial layout, known as the depth-processing theory. Like other researchers (Gregory, 1963; Redding & Hawley, 1993; Warren & Bashford, 1977), she argued that geometrical illusions in general arise from the tendency of the perceptual system to process a two-dimensional figure as a representation of a three-dimensional scene and, consequently, that considering the processes involved in scene perception will lead to a better understanding of such illusions. However, although it has been typical to apply this analysis to illusions of size or extent, such as the Müller-Lyer and Ponzo illusions, the Poggendorff illusion, which is considered to be an illusion of alignment or orientation, has rarely been approached in this way. One notable exception is Green and Hoyle's (1963) “room geometry hypothesis,” which appeals to the processes of perceptual continuation within the implied “room geometry” interpretation of the standard Poggendorff display.

In regard to the Poggendorff illusion, Gillam's theory asserts that oblique lines are typically the perspective view of receding horizontal lines and, as such, automatically processed as if receding in horizontal planes of three-dimensional space. As shown in the left panel of Figure 1c, the orientations of segments *ab*, *bc*, and *cd* are identical, resulting in segments *ab* and *cd* being processed as collinear in a single receding plane of three-dimensional space. The height differences of such laterally displaced points are usually processed as depth differences. However, when the oblique lines are attached to the parallels from a Poggendorff figure, their laterally displaced endpoints are perceived as equidistant and attached to a fronto-parallel plane defined by the parallels (Fig. 1c, right panel). Consequently, the height difference between laterally displaced endpoints of the oblique lines in this case is not processed as a difference in depth in three-dimensional space but as a difference in height between the two receding lines. This theory also predicts that the implicit oblique between the parallels would be seen as steeper than the obliques themselves (Gillam, 1998).

Subsequent studies have demonstrated that the Poggendorff illusion diminishes as cues that indicate a degree of pictorial depth are added to the elements of the figure (Daniels & Gordon, 1993; Parks & Hui, 1989). However, the extent to which such findings can differentiate between different models of the illusion has been questioned. As

Address correspondence to Branka Spehar, School of Psychology, The University of New South Wales, Sydney NSW 2052, Australia; e-mail: b.spehar@unsw.edu.au.

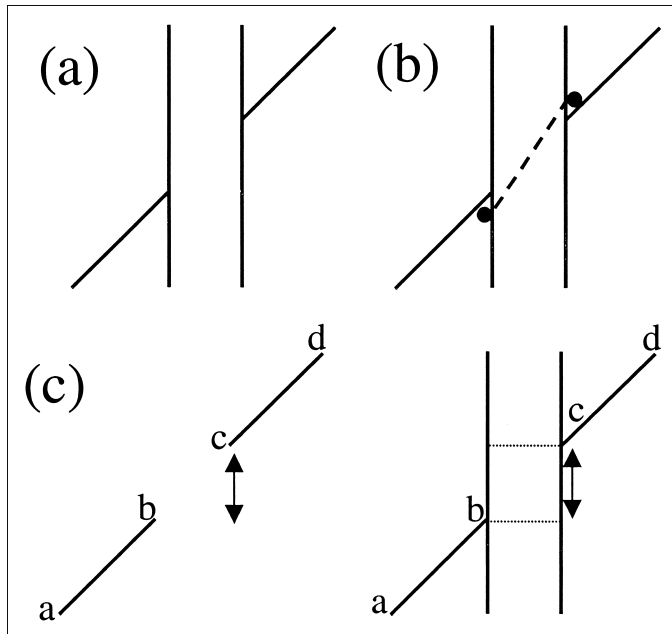


Fig. 1. The Poggendorff illusion. In the classical Poggendorff configuration (a), the two oblique line segments do not appear collinear. In Morgan's (1999) model of the Poggendorff illusion (b), the orientation of a virtual line derived from the misplaced inner ends of the obliques is steeper than their actual orientation. In Gillam's (1971) depth-processing account of the Poggendorff illusion, it is assumed that spatially separated but aligned line segments of equal orientation, such as *ab* and *cd* (c, left panel), are processed as collinear in a single receding plane of a three-dimensional space. The height differences between their laterally displaced endpoints are processed as depth differences. When the oblique lines are attached to parallels from a Poggendorff figure (c, right panel), their laterally displaced endpoints are perceived as points attached to the fronto-parallel plane defined by the parallels. The height difference between these laterally displaced endpoints cannot be processed as a difference in depth in three-dimensional space. Instead, their height difference is processed as a difference in height between the two receding lines.

Morgan (1999) pointed out, "understanding of the classical illusions has not been advanced by a tendency of authors to introduce amputated or altered versions of an illusion in order to bolster their own theories and refute rival ones: this style of research is pointless if it is not accompanied by proof that the different figures expose a common mechanism" (p. 2362).

THE PRESENT STUDY

In the work we report here, we explored further how two-dimensional cues to possible three-dimensional interpretations affect the strength of the Poggendorff illusion. The stimuli we used were neither amputated nor enriched with respect to the original classical configuration, thus ensuring that our experimental manipulations probed the same mechanisms as the ones exposed by the original configuration. We focused on occlusion-based depth cues provided by T-junctions in Poggendorff configurations with solid intraparallel extents.

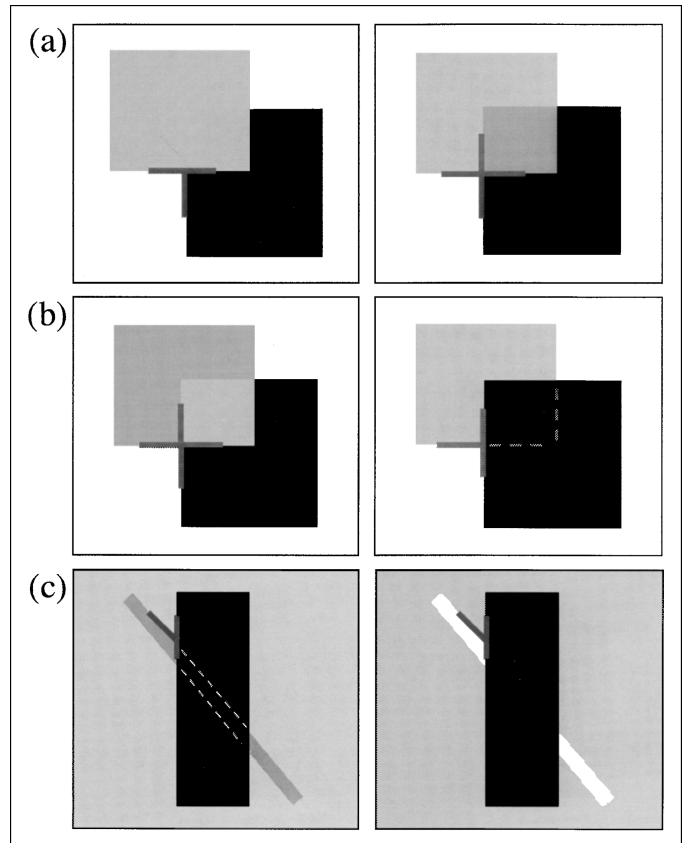


Fig. 2. Different kinds of junctions and the Poggendorff illusion. With changes in the illumination of the various regions, the opaque T-junction (a, left panel) and transparent X-junction (a, right panel) become a nontransparent X-junction (b, left panel) and an implicit X-junction (b, right panel). In an implicit X-junction, although the edges of the regions objectively form a T, modal completion of the area of intermediate luminance extends the stem of the T to form an illusory X (indicated here by dashed lines). In the case of the Poggendorff configuration (c), varying the luminance of the obliques relative to the parallels results in an implicit X-junction (left panel) or an opaque T-junction (right panel).

Junctions are the points in the image where lines, different regions, or both meet. They are usually classified (e.g., as L-, T-, or X-junctions, to name a few) according to the number of lines (regions) meeting at a point and their geometrical configurations in the picture. Junctions can be employed in recovering three-dimensional configurations from two-dimensional images and have also been found to be useful in recovering shape from images (Barrow & Tennenbaum, 1981; Huffman, 1971; Kanade, 1980). For example, a T-junction typically indicates occlusion by an opaque surface (Fig. 2a, left panel), whereas an X-junction (Fig. 2a, right panel) usually indicates occlusion by a transparent region.

However, such interpretations are strongly affected by the distribution of constituent luminances. For example, X-junctions are not always associated with the transparency interpretation (Fig. 2b, left panel). Similarly, although the T-junction configuration depicted in the left panel of Figure 2a is consistent with an opaque occlusion only, a simple rearrangement of the constituent intensities can make such a

Modal Completion in the Poggendorff Illusion

junction consistent with a transparent occlusion (Fig. 2b, right panel). Specifically, when the luminance intensity on one side of the stem of a T-junction lies between the luminance intensities of the other two regions (the region on the top and on the other side of the stem), it is possible for the region of intermediate luminance to be perceived as a modally completed surface in front of the other two regions (Fig. 2b, right panel). Watanabe and Cavanagh (1993) labeled these junctions "implicit X-junctions."

In the Poggendorff configuration, when the luminance of the obliques lies between that of the background and that of the area defined by the parallels, or is equal to that of the area defined by the parallels, the intersections with the parallels represent implicit X-junctions (Fig. 2c, left panel). In such a configuration, it should be possible to perceive the obliques as modally completed in front of the area defined by the parallels. According to the depth-processing account of the

Poggendorff illusion, this should result in a decrease of the apparent misalignment between the obliques. Conversely, when the luminance of the obliques is not intermediate between the luminances of the background and the area defined by the parallels, the intersection with the parallels is consistent with a T-junction signaling an opaque occlusion by the area defined by the parallels (Fig. 2c, right panel). In such a configuration, the obliques cannot be completed modally in front of the area defined by the parallels. The apparent misalignment between obliques in this case is not expected to be different from that in the original Poggendorff configuration.

The stimuli used in our study are shown in Figures 3a through 3d. In each experimental condition, we varied the luminance of the obliques while keeping constant the luminance of the area defined by the parallels and the luminance of the background. The luminance relationship between the obliques and the area defined by the parallels

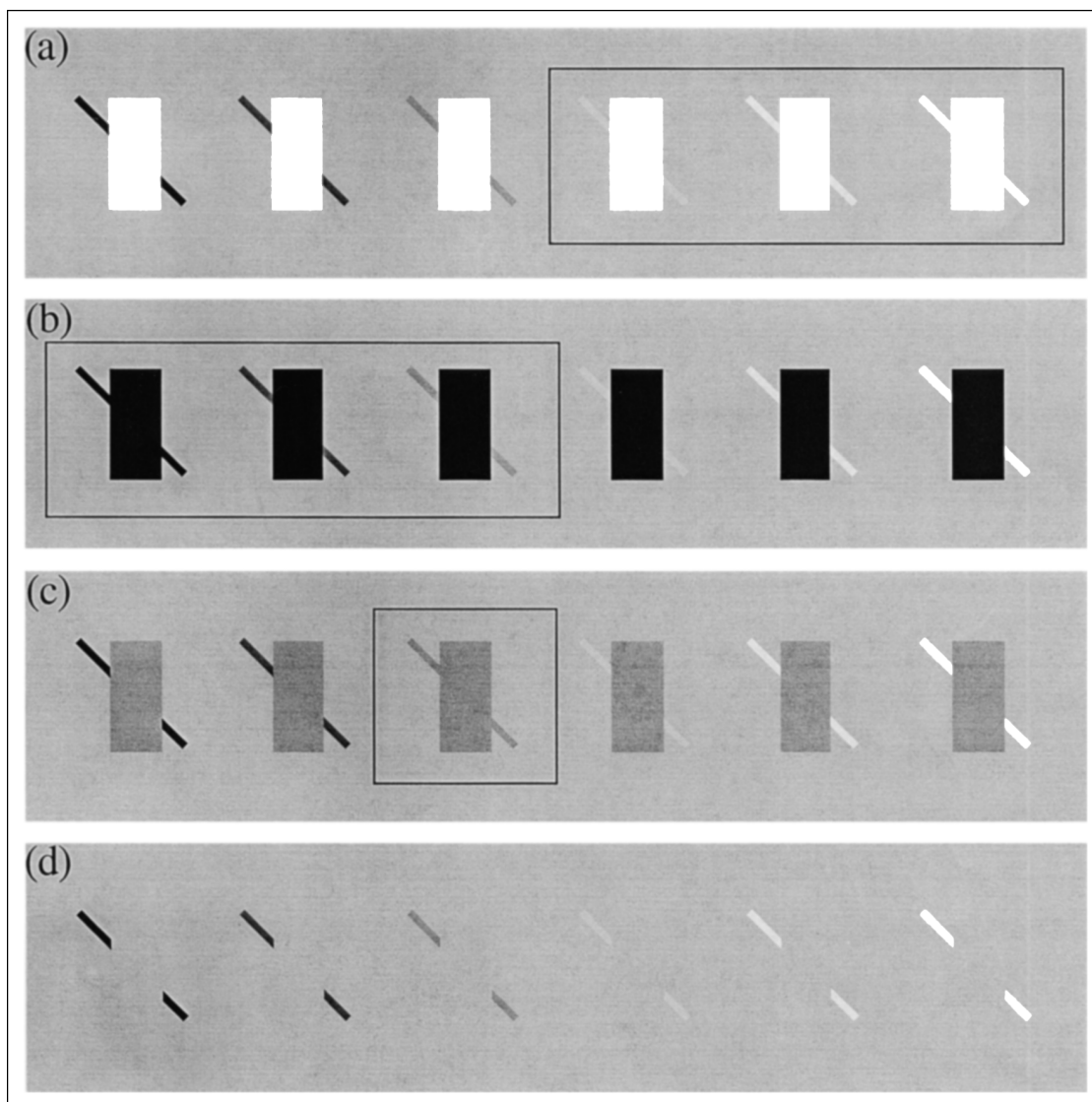


Fig. 3. Stimuli used in the main experiment. The outlined configurations are compatible with the modal completion of the obliques in front of a white inducing region (a), a black inducing region (b), and a gray inducing region (c). The stimuli in (d) were used in the control condition, in which there was no inducing region.

was manipulated in this way to provide stimulus support for perceptual completion of the oblique segments in front of the solid area defined by the inducing parallels (modal completion) in some configurations. Across experimental conditions, the luminance of the solid inducing area defined by the parallels was varied, too, so that combinations of luminances of the obliques and of the solid inducing area that afforded modal completion differed across experimental conditions (as indicated by the outlined configurations in Figs. 3a–3c). We did this to test the generality of the effect across different luminance conditions. A control condition in which there was no solid inducing area (Fig. 3d) was included to rule out the possibility that the observed effects were the result of variations in luminance contrast between the obliques and the background. We compared the apparent misalignment of the obliques for configurations that did support modal completion and those that did not.

Method

Participants

A total of 16 undergraduate psychology students at the University of New South Wales, Sydney, Australia, participated in three experimental conditions and one control condition in return for course credit. All had either normal or corrected-to-normal visual acuity and were naive in respect to the rationale of the study.

Apparatus

The experiment was conducted on a Power Macintosh 7600/132 computer with a 17-in. high-resolution color monitor (Apple AV1700). All aspects of stimulus presentation and data collection were computer controlled.

Stimuli

Stimuli appeared on the screen, which subtended $23^\circ \times 17^\circ$ with a luminance of 90 cd/m^2 . On every trial, two Poggendorff configurations were presented side by side in the center of the screen. Both configurations were presented against local backgrounds subtending $7.5^\circ \times 7.5^\circ$ with a luminance of 35 cd/m^2 . In each configuration, the dimensions of the solid inducing area were $1.5^\circ \times 3.5^\circ$. The luminances of the inducing area in the three experimental conditions were 90 cd/m^2 (white), 3 cd/m^2 (black), and 25 cd/m^2 (gray), respectively. Each of the two oblique, physically collinear, line segments was 1.5° long and oriented 45° relative to the vertical inducing area. In all the conditions, the luminance of the oblique segments varied in six steps: 3 cd/m^2 , 15 cd/m^2 , 25 cd/m^2 , 45 cd/m^2 , 70 cd/m^2 , and 90 cd/m^2 .

Procedure

Participants sat in a dimly lit room. No suggestions about the possibility of modal completion in stimulus configurations were given to observers during the course of the experiment. In a method of paired comparison, on each trial two Poggendorff configurations appeared on the screen. The observer's task was to select the configuration in which the obliques appeared more aligned. After the observer made the selection, by clicking the appropriate mouse button, the next stimulus pair appeared on the screen.

Six Poggendorff configurations in each experimental condition were paired with each other, and each of the configurations in a pair was presented both on the left and on the right side. In a randomized presentation, each of the 30 pair combinations was shown 5 times, resulting in a total of 150 trials. Each configuration was presented 25 times on the left side of the screen and 25 times on the right side of the

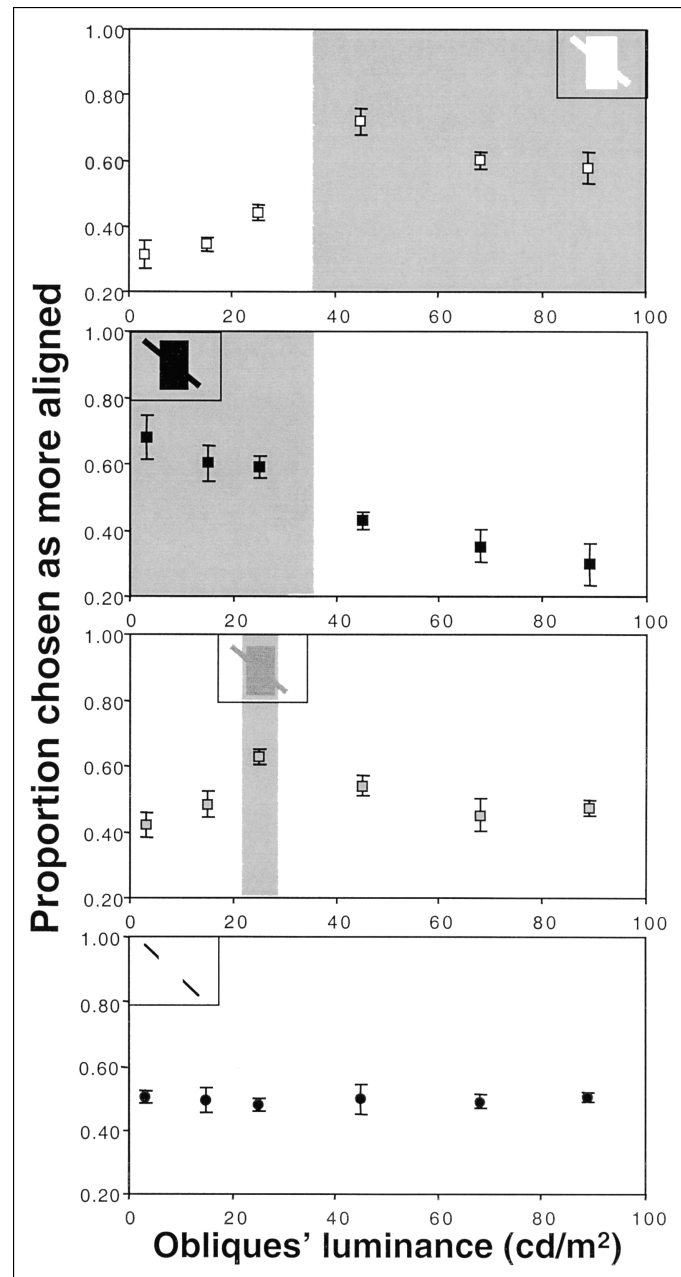


Fig. 4. Results from the four conditions in the main experiment. Each panel shows the proportion of trials on which a configuration was chosen as being more aligned than all the other configurations in that condition, as a function of the luminance of the obliques. The shaded region in each panel represents the region that afforded modal completion of the obliques. The inset in each panel shows the type of inducing region. The error bars represent the standard error of the mean.

Modal Completion in the Poggendorff Illusion

screen. The results for each configuration were expressed as the proportion of presentations on which it was selected as being more aligned out of the total of its 50 presentations.

Results

The results are shown in Figure 4. The four panels, one for each condition, show the proportion with which a configuration was chosen as being more aligned as a function of the luminance of the obliques. The shaded region in each panel represents the region in which the combination of the luminances of the obliques, the inducing solids, and the background afforded modal completion of the obliques in front of the inducing solid. Planned contrasts were performed on the average-proportion data in each experimental condition to test if the obliques were perceived as more aligned in configurations where modal completion was possible than in configurations that did not allow for modal completion. The analysis revealed a significant reduction in the apparent misalignment between the obliques when the luminance relationships between the obliques, the background, and the area defined by the parallels afforded modal completion of the obliques in front of the area defined by the parallels. The obtained $F(1, 15)$ values were 59.96 ($p = .0001$), 56.87 ($p = .0001$), and 11.99 ($p = .0007$) for the white, black, and gray vertical inducing areas, respectively. The perceived alignment of the obliques did not change as a function of their luminance in the control condition.

DISCUSSION

We varied the luminance of the oblique lines in Poggendorff configurations to create conditions in which the obliques could be modally completed in front of the area defined by the parallels. The apparent misalignment of the obliques was significantly reduced for configurations that supported modal completion compared with those that did not.

The data reported here are inconsistent with the model proposed by Morgan (1999), which tries to account for the Poggendorff illusion in terms of suspected neural mechanisms involved in the perception of

collinearity of spatially separated lines. The amount of apparent misalignment predicted by that model is equal for all the experimental configurations used here because of their identical geometrical layout. The model's inability to capture the variations in the strength of the Poggendorff illusion resulting from the luminance manipulations in our study is a necessary consequence of the proposed first-stage rectification of luminance signals. Additional evidence that calls into question the simple link between the Poggendorff illusion and mechanisms involved in the perception of collinearity between spatially separated lines has been provided by Westheimer and Wehrhahn (1997) and Westheimer, Brincat, and Wehrhahn (1999), who compared the contrast dependency of a simple alignment discrimination with that of the Poggendorff illusion. They found that whereas simple alignment-discrimination thresholds increased drastically with a reduction of luminance contrast (5- to 6-fold for abutting edges and 4- to 5-fold for spatially separated edges), the magnitude of the Poggendorff illusion changed very little. From these results, they concluded that substantially different mechanisms operate in the two tasks.

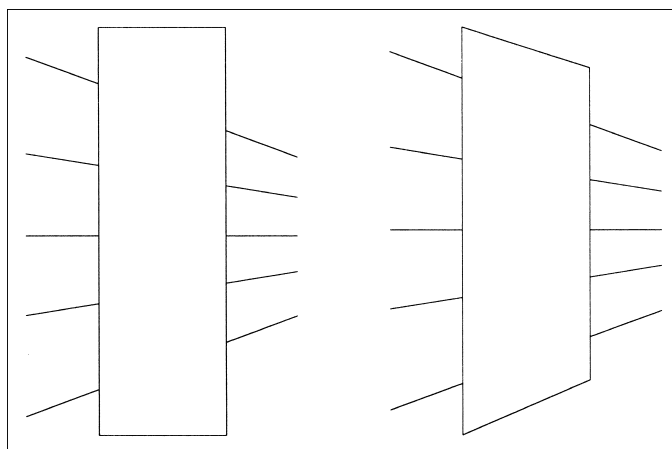


Fig. 5. The effect of continuity in three-dimensional space. The perceived misalignment of the obliques is larger in the configuration on the left than in the configuration on the right because in the configuration on the right the inducing region recedes in the same plane as the one defined by the obliques.

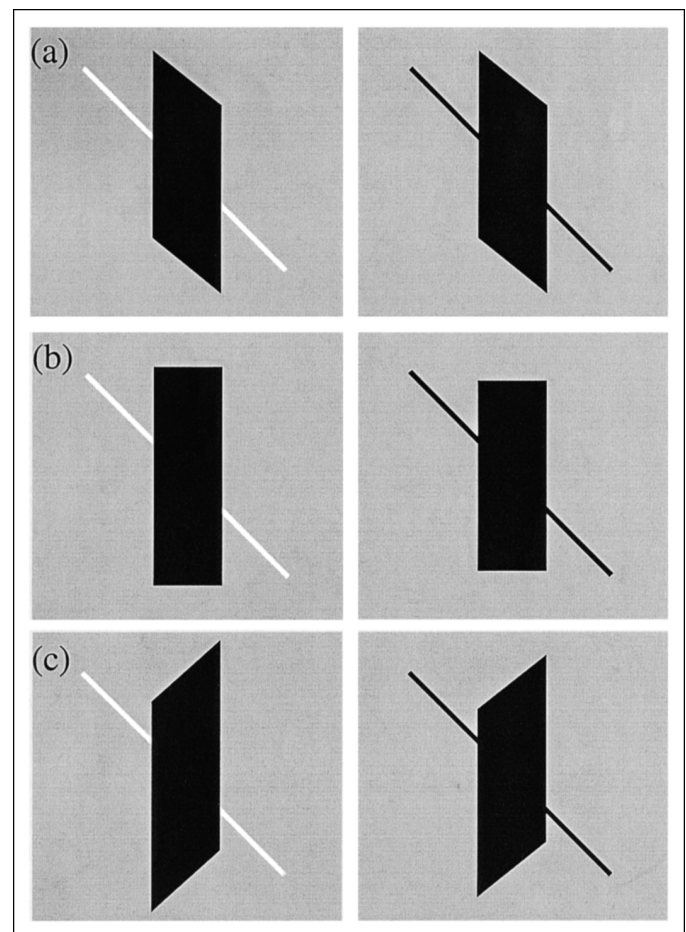


Fig. 6. Stimuli used to measure combined effects on the size of the Poggendorff illusion of two cues for three-dimensional interpretation: modal completion and continuity in three-dimensional space. The stimuli on the left do not allow modal completion of the obliques, and the stimuli on the right do. The interposed plane was either collinear with the obliques (a), an interrupting frontal plane (b), or perpendicular to the plane defined by the obliques (c).

The marked reduction in the size of the illusion under conditions favoring modal completion supports the claim that spatial layout cues are major determinants of the Poggendorff illusion. Modal completion allows the obliques to be perceived as passing in front of the parallels (and camouflaged by them). In addition, the modally completed transversal segments are not perceived as receding in depth, but appear to share the fronto-parallel plane of the inducing area defined by the parallels. Consistency in the perceived depth layout between obliques and the inducing area has been known to reduce the size of the perceived misalignment in the Poggendorff illusion (Daniels & Gordon, 1993; Gillam, 1971, 1980). As shown in Figure 5, such consistency can be created by manipulating the length and the height of the parallels according to a vanishing point shared by the obliques, resulting in a smaller perceived misalignment of the oblique lines (right panel) than when the parallels are not manipulated in this way (left panel). These observations, as well as the results of our study, suggest that the processes involved in three-dimensional scene interpretation are strong determinants of the Poggendorff illusion.

In order to test this idea further, we measured the size of the Poggendorff illusion in configurations containing combinations of different cues for the three-dimensional interpretation. Figure 6 shows the configurations used. They allowed us to simultaneously examine the role of two factors: the presence or absence of luminance conditions that support modal completion in the Poggendorff configuration and continuity in three-dimensional space between the plane defined by the obliques and the inducing area defined by the parallels.

The configurations shown in the left panels in Figures 6a, 6b, and 6c do not support modal completion of the obliques in front of the inducing area defined by the parallels, whereas the configurations shown

in the panels on the right are consistent with such an interpretation. Continuity in three-dimensional space along the plane defined by the obliques was varied by an interposition of three types of planes: a collinear plane (Fig. 6a), an interrupting frontal plane (Fig. 6b), and an interrupting plane at a roughly perpendicular orientation to the plane defined by the obliques (Fig. 6c). Whereas an interrupting frontal plane is equivalent to the classical geometrical layout of the Poggendorff configuration, interrupting collinear and perpendicular planes are modifications motivated by observations that perceived geometrical layout affects the size of the illusion. It has been shown that the illusion is reduced by half in configurations where an interrupting plane is perceived to recede in the same (or similar) plane as the obliques (Gillam, 1971). Configurations with a perpendicular interrupting plane have not been empirically investigated before, but, given the difference in directions in which the obliques and the interrupting plane recede, the depth-processing-based account would not predict a reduction in the illusion's magnitude under these conditions.

The average results of 10 naive observers are summarized in Figure 7. The average proportion with which a configuration was chosen as being more aligned in a paired-comparison procedure is plotted as a function of the continuity in three-dimensional space between the plane defined by the obliques and the interrupting plane. The results show that the perceived alignment between the obliques decreased as a function of the orientation of the interposing plane, $F(1, 9) = 34.9$, $p < .001$. Consistent with the results observed in our main study, the illusory misalignment between the obliques was markedly reduced in configurations consistent with the modal completion of the obliques in the region of the interrupting plane, $F(1, 9) = 27.5$, $p < .001$.

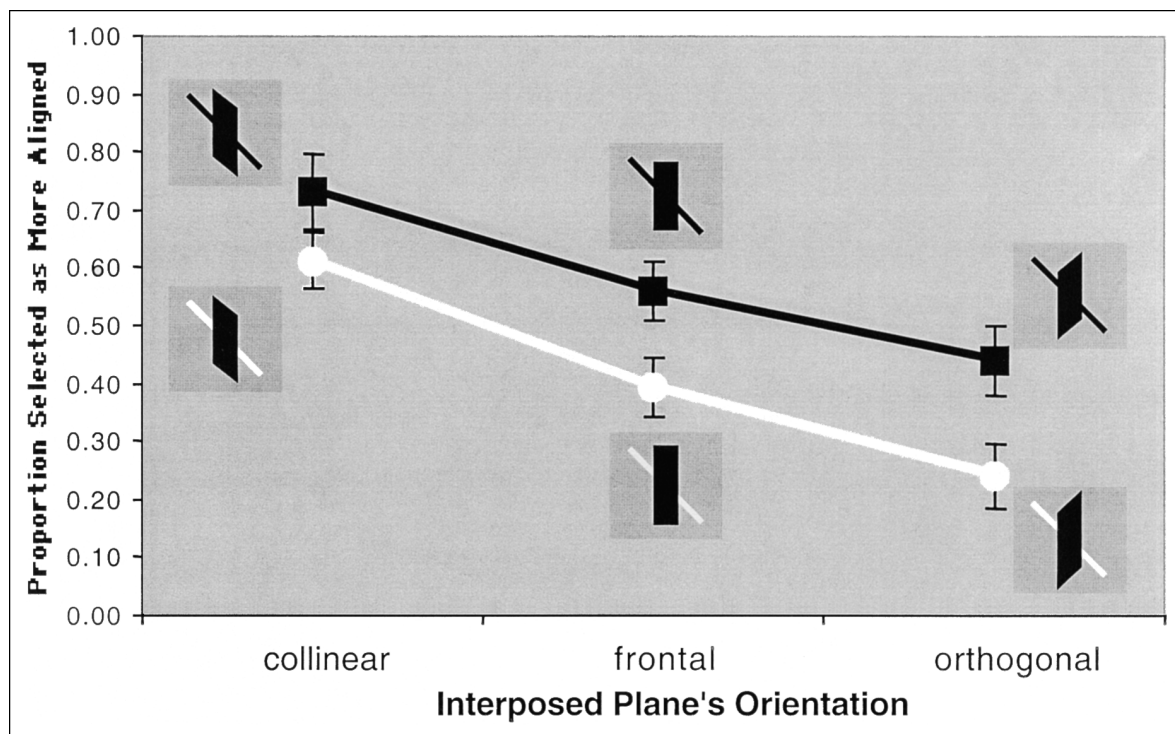


Fig. 7. Paired-comparison results for the configurations depicted in Figure 6. The graph shows the proportion of trials on which each configuration was chosen as being more aligned than its paired configuration. The error bars represent the standard error of the mean.

Modal Completion in the Poggendorff Illusion

Taken together, our results are consistent with claims that processes determining spatial layout are major determinants of the Poggendorff illusion. The results were obtained without substantial modifications of the original configuration, making it unlikely that the observed effects could be explained in terms of variables extraneous to the basic mechanisms of the Poggendorff illusion (Wenderoth, 1981). Moreover, the differences in the amount of the apparent misalignment between conditions that were consistent or inconsistent with modal completion of the obliques cannot be captured by other models of the Poggendorff illusion based on angular distortions (Burns & Pritchard, 1971; Greene & Pavlov, 1989; Hering, 1861; Hotopf & Ollereanshaw, 1972) or underestimation of the intraparael extent (Day & Dickinson, 1976; Masini, Costa, Ferraro, & De Marco, 1995; Zanuttini, 1976) because the luminance manipulations used to create such conditions are inconsequential for the crucial mechanisms postulated by those models.

REFERENCES

- Barrow, H.G., & Tennenbaum, J.M. (1981). Interpreting line drawings as three-dimensional surfaces. *Artificial Intelligence*, 17, 75–116.
- Burns, B.D., & Pritchard, R. (1971). Geometrical illusions and the response of neurones in the cat's visual cortex to angle patterns. *Journal of Physiology*, 213, 599–616.
- Daniels, V., & Gordon, I.E. (1993). Occlusion and the distortion of alignment in three-dimensional space. *Perception*, 22, 1037–1044.
- Day, R.H., & Dickinson, R.G. (1976). The components of the Poggendorff illusion. *British Journal of Psychology*, 67, 537–552.
- Gillam, B. (1971). A depth processing theory of the Poggendorff illusion. *Perception & Psychophysics*, 10, 211–216.
- Gillam, B. (1980). Geometric illusions. *Scientific American*, 242, 102–111.
- Gillam, B. (1998). Illusions at century's end. In J. Hochberg (Ed.), *Perception and cognition at century's end* (pp. 95–136). San Diego: Academic Press.
- Green, R.T., & Hoyle, E.M. (1963). The Poggendorff illusion as a constancy phenomenon. *Nature*, 200, 611–612.
- Greene, E., & Pavlov, G. (1989). Angular induction as a function of contact and target orientation. *Perception*, 18, 143–154.
- Gregory, R.L. (1963). Distortions of visual space as inappropriate constancy scaling. *Nature*, 199, 678–680.
- Hering, E. (1861). *Beiträge zur Physiologie. I. Vom Ortssinne der Netzhaut*. Leipzig, Germany: Engelmann.
- Hotopf, W.H.N., & Ollereanshaw, C. (1972). The regression to right angles tendency and the Poggendorff illusion II. *British Journal of Psychology*, 63, 369–379.
- Huffman, D.A. (1971). Impossible objects as nonsense sentences. In B. Metzger & D. Michie (Eds.), *Machine intelligence 6* (pp. 295–323). Edinburgh, Scotland: Edinburgh University Press.
- Kanade, T. (1980). A theory of origami world. *Artificial Intelligence*, 13, 279–311.
- Masini, R., Costa, T., Ferraro, M., & De Marco, A. (1995). Modifications of the Poggendorff effect as a function of random dot textures between the verticals. *Perception & Psychophysics*, 55, 505–512.
- Morgan, M.J. (1999). The Poggendorff illusion: A bias in the estimation of the orientation of virtual lines by second-stage filters. *Vision Research*, 39, 2361–2380.
- Parks, T.E., & Hui, L. (1989). Pictorial depth and the Poggendorff illusion. *Perception & Psychophysics*, 46, 465–468.
- Pierce, A.H. (1901). *Studies in auditory and visual perception*. New York: Longmans Green.
- Redding, G.M., & Hawley, E. (1993). Length illusion in fractional Müller-Lyer stimuli: An object-perception approach. *Perception*, 22, 819–828.
- Warren, R.M., & Bashford, J.A. (1977). Müller-Lyer illusions: Their origin in processes facilitating object recognition. *Perception*, 6, 615–626.
- Watanabe, T., & Cavanagh, P. (1993). Transparent surfaces defined by implicit X junctions. *Vision Research*, 33, 2339–2346.
- Weintraub, D.J., & Tong, L. (1974). Assessing Poggendorff effects via collinearity, perpendicularity, parallelism and Oppel (distance) experiments. *Perception & Psychophysics*, 16, 213–221.
- Wenderoth, P. (1981). Bending the Poggendorff parallels and the rules of inference: A note on Brigell and Uhlarik (1980). *Perception & Psychophysics*, 29, 283–284.
- Westheimer, G., Brincat, S., & Wehrhahn, C. (1999). Contrast dependency of foveal spatial functions: Orientation, vernier, separation, blur and displacement discrimination and the tilt and Poggendorff illusions. *Vision Research*, 39, 1631–1639.
- Westheimer, G., & Wehrhahn, C. (1997). Real and virtual borders in the Poggendorff illusion. *Perception*, 26, 1495–1501.
- Zanuttini, L. (1976). A new explanation for the Poggendorff illusion. *Perception & Psychophysics*, 20, 29–32.

(RECEIVED 12/6/00; REVISION ACCEPTED 8/7/01)