The Poggendorff illusion.
Dots as context elements

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1. Introduction

A line, inclined at 45° to the horizontal, is crossing behind a vertical bar. To the observer, the protruding line segments appear to be offset vertically although they are perfectly aligned. Poggendorff (1870) is said to have discovered this phenomenon in a drawing of Zöllner (1860). Concerning the explanation, there are several hypotheses. Due to one of them one misjudges the angle formed by the intersecting line and the edges of the bar. It seems to be closer to a right angle than it really is (Hotopf, 1966). Fermüller and Malm (2003) explain this effect from an uncertainty in the visual process. Further, it is known that the perceived orientation of a line is tilted by up to a few degrees to the nearest horizontal or vertical (Obonai and Koto-Gakko, 1931; Gibson and Radner, 1937; Bouma and Andriessen, 1968; Ninio and O’Regan, 1999). Morgan and Melmoth (2011) investigated the saccadic eye movements and found a large bias in the same direction as the perceptual illusion. Another hypothesis claims that the width of the bar is underestimated, leading to an apparent vertical shift of the segments into opposite directions (Greist-Bousquet and Schiffman, 1981). The question arises whether additional geometrical elements would have an influence on the intensity of the Poggendorff illusion. We investigated the case where two dots are placed right on the edges of the occluding bar.

2. Experiment

2.1 Subjects. 18 Healthy volunteers took part, all of them elderly people above 60. Sight was corrected to normal.

2.2 Stimuli. In total, 28 transparencies were presented. They showed two black parallel vertical lines on white background which served as the occluding bar. They were 75 units long, one unit wide, and 16 units apart. On a DIN A4 print, one unit is equivalent to 1mm. The target line was inclined by 45°, running from the bottom left to the top right. The vertical separation of the merging points was 16 units. Exactly at the edges of the bars there were two black dots, in equivalent positions with respect to the centre of symmetry, as shown in Figs. 1a, b. An x-coordinate was chosen such that at x=0 both dots coincided with the left and the right merging points, respectively. The dots were shown in 27 different positions, ranging from x = -41 till x = +25 units, were a positive x-value means that the dot on the right edge is above the merging point and the dot on the left below, by the same amount. On two of the transparencies (x= -41 and -34 units) the protruding end at the left was shifted downwards by 2 units. One transparency gave the classic situation, without dots. For comparison, 9 standards were given below the target, showing pairs of oblique parallel lines shifted vertically from -2 till +13 units (the minus sign indicates that the offset is opposite to the illusion).
2.3 Procedure. The transparencies were projected with a beamer in random order. The linear magnification was 6 times. Average distance of observation was 4m. The transparencies were shown for seven seconds followed by a blank of two seconds. One of the transparencies (x= -8) was presented twice. The participants indicated the perceived mismatch by choosing one of the standard figures from below the target.

![Fig. 1a](image)

On the transparencies the dots are arranged in equivalent positions with respect to the centre of symmetry.

The coordinate system is chosen such that, for positive x-values, the dot on the right edge is above the merging point.

![Fig. 1b](image)

A negative x-value means that the dot on the right edge is below the merging point. The opposite holds for the dot on the left.

2.4 Results. Compared to the classic illusion, the intensity was enhanced or reduced, depending on the position of the dots (Fig. 2). The overall result is given in Figs. 3 to 5. With respect to the classic stimulus, negative x-values caused an enhancement of the illusion,
Fig. 2. The classic Poggendorff illusion (centre): The protruding ends of the crossing line appear to be offset vertically. Left: The intensity of the illusion is enhanced, when dots are positioned at the same height halfway between the merging points, but it is reduced, when the dots are above and below them (right). The apparent vertical shift is given in relation to the width of the bar.

![Graph showing the classic Poggendorff illusion with data points and algebraic function]

Algebraic function:

\[ y = \delta - A \cdot x \cdot \exp[-B \cdot |x|] \]

- \( \delta = 2.34(12) \)
- \( A = 0.52(12) \)
- \( B = 0.130(22) \)

\( \chi^2/\text{DoF} = 0.36293 \)

\( R^2 = 0.7767 \)

Fig. 3. Experimental results. The dashed line gives the classic Poggendorff illusion, i.e., the perceived mismatch of the protruding ends without dots. Dots at negative coordinates enhance the illusion and seem to have a slightly larger impact compared to dots at positive coordinates, which reduce it. The function fitted takes the structure effect into account (Equation 1).

![Graph showing experimental results with data points and fitting line]
Fig. 4 (Top) With the dots at equal height (x= -8), further enhancement of the illusion is observed. This is ascribed to the special arrangement of the dots which emphasize the horizontal orientation.

Fig. 5 (Bottom) Fit of the complete function. It is derived from a conceptual model, where two effects due to the influence of the dots at various positions are taken into account.

positive x reduced it. With the dots right at the merging points (x=0), the apparent vertical shift of the lines is nearly equivalent to the classic illusion. With the dots at x= +6, the effect (the apparent vertical shift of the ends) amounts to only 6% of the width of the bar, while
positioning the dots at the same height (x= -8) produced a considerable increase of the illusion up to about 25 %. Comparing the maximum value of the curve with its minimum (Figs. 3 and 5), one finds that the enhancement of the illusion seems to be slightly more efficient than its reduction. This is discussed in chapter 3.

3. Hypotheses

Following one of the protruding lines from its far end up to the merging point, the question arises, where exactly one expects the line to be continued across the bar. Obviously, there is a mismatch between the apparent and the geometrically correct continuation. This may be due to an effect called misangulation (Ninio and O’Regan, 1999), where the angle between the line and the edge of the bar appears larger than it really is (Fig 6a). The same authors discuss the possibility that the ends of the crossing line may suffer from a perceived vertical offset (6b). There may be other kinds of misperception in the sense that just the continuation of the protruding ends across the bar is expected to point into a direction not exactly collinear with the visible part of the crossing line (Fig. 6c). In this case the illusion would not relate to the visible parts of the target line, but to their imaginary continuations only. One may also consider the possibility that the bar is recognized as being narrower than it really is, because it is empty, providing no useful information concerning the target (Greist-Bousquet and Schiffman, 1981). Alternatively, one may assume that, at the merging point, perception jumps the gap on the shortest possible way, expecting continuation at approximately the same height across the occluding object. In an attempt to explain the observations, some more effects may be considered:

3.1 Right angle: There is a tendency of an acute angle to appear closer to a right angle than it actually is (Hotopf, 1966).

3.2 Coordinate system: It is observed that oblique lines are tilted slightly towards the nearest vertical or horizontal (Obonai and Koto-Gakko, 1931; Gibson and Radner, 1937; Bouma and Andriessen, 1968; Wallace and Crampin, 1969).

3.3 Context elements. Fig. 7: Starting from the classic illusion (vertical bar), an enhancement of the effect is observed, as soon as a horizontal element is added, e.g., two dots, placed at equal height in between the merging points (Fig. 7a), or a horizontal line (7b), replacing one of the oblique protruding ends. In this case the thought continuation of the remaining oblique segment appears to miss the intersection of the bar with the horizontal line by far. One may argue, that the elements added emphasize the orientation perpendicular to the occluding bar, causing the visual system to expect continuation just across the gap. This effect still holds when the stimulus is tilted (Fig. 7c, d).
Fig. 6. The ends of the oblique line crossing behind the bar don’t seem to match. This impression can be the result of a slant illusion, i.e. a perceived rotation of the protruding ends towards the horizontal (a), the result of a perceived vertical offset (b), or it may be triggered by an imaginary continuation across the bar which is not collinear to the visible ends of the crossing line (c). Second row: One may consider the possibility that the bar is recognized as being narrower than it really is, because it appears empty, therefore not providing any useful information about the target line. For a similar reason one may assume that perception, after having followed the line up to the merging point, jumps the gap on the shortest possible way, expecting continuation at approximately the same height across the bar.

3.5 Resolving fine structure. At small positive x-values (with the right and the left dot just above and below the merging points, respectively), size constancy (Lühr, 1898; Cornish, 1937; Kreiner, 2004; 2009; 2010) may be responsible for the observation that the effect is significantly smaller than without dots (Fig. 2, right).
Fig. 7 (a): Dots at half height, arranged horizontally, enhance the effect. A similar result is achieved when one of the protruding ends is replaced by a line perpendicular to the bar (b). The imaginary continuation of the oblique end seems to miss the merging point of the horizontal line by far. (c): Bar inclined by 45°. The effect is still pretty strong. In Fig. (d) the apparent match is an illusion.

The visual system can be taken as a data processing device. It extracts information preferably from a certain section of the retinal image (angle of attention, conspicuity range), and projects this section on to a kind of a visual memory screen of constant size (Fig. 9). This “screen” is just a pictorial way to express the fact that only a limited data processing capacity is available of which always full advantage is taken, irrespectively of the size of the angle of attention. Keeping in mind this limited capacity, the size of the conspicuity range has to be reduced in order to resolve fine details. This situation arises when the dots are approaching the merging points, where high resolution is required to separate the geometric features; this triggers the narrow angle mode which, in turn, leads to magnification (Fig. 10). As a result, the dot and the merging point appear to be pushed apart. For positive x-values,
In the narrow angle mode the visual system is able to resolve fine structure. Projection on to an internal screen leads to magnification, i.e., to an apparent size inversely proportional to the size of the attentional angle. The increase of the apparent distance between the dot and the merging point pushes the segment downwards and reduces the intensity of the illusion.

the lines appear to be shifted in a sense to reduce the illusion. However, for negative x-values this effect adds to the apparent shift. This is assumed to cause the asymmetry of the observed function relative to the classic illusion (Figs. 3 to 5).

4. Algebraic functions

The algebraic expression (eq. 1) fitted to the experimental values was derived in the following way: The intensity of the classic Poggendorff illusion is symbolized by the parameter del. Then, the influence of the dots, depending on their position x, is taken into account (structure effect, chapter 3.5): In case they are close to the merging points, the attentional angle of the visual system is narrowed down, resulting in magnification and better separation of the geometric elements. As a consequence, the perceived distance x(per) between the dot and the merging point exceeds its true distance x by some amount. This difference, [x(per) − x], causes the line segments to appear shifted which increases or reduces the illusion, depending on the sign of x. For small x-values, this shift is assumed to be in proportion to x [leading to the term A·x in eq (1)], but to reduce rapidly with increasing distance x (exponential function exp[-B·abs(x)]). Together, this gives

\[ y(x) = \text{del} + A \cdot x \cdot \exp[-B \cdot \text{abs}(x)] \]  

(1)

The fit to the experimental values is shown in Fig. 3. Finally, enhancement of the illusion is observed, when the dots are positioned around x= -8 (halfway between the merging points; Fig. 2, left). This is taken into account by the term exp[-C·abs(x+8)]. The final expression is
A fit of the complete function is given in Fig. 5. Note that the influence of the context elements fades away with the dots being at far distance from the merging points.

5. The Poggendorff illusion in paintings

As reported by Daneyko, Stucchi, and Zavagno (2011), in the Mausoleum of Galla Placidia in Ravenna, Italy, a mosaic from the first half of the 5th century shows the saint San Lorenzo, carrying a crucifix. One bar of the cross is geometrically misaligned in a way to compensate the Poggendorff illusion. A similar effect is to be seen in a painting on the rear side of an altar in the Ulmer Museum, the “Hagnauer Flügelaltar” from 1518, showing the “Bearing of the Cross of the emperor Heraclius” (Fig. 11 and note [1]).
6. Summary

The classic illusion is interpreted not as an apparent shift or tilt of the oblique segments, but as a perceived vertical shift of the thought continuations of the line segments across the bar. This shift is assumed to be mainly caused by a tendency of the visual system to ignore, at least partly, the occluding bar. The classic illusion is further enhanced by context elements extending perpendicularly to the orientation of the occluder (eg, a line merging at right angles to the bar). It has been shown experimentally that two dots placed at the edges of the occluding bar will, depending on their position, enhance or reduce significantly the intensity of the Poggendorff illusion. At least two effects seem to be involved. One is ascribed to an apparent magnification, when the dots are close to the merging points (structure induced enlargement), leading to a perceived shift (up or down) of the protruding ends of the target line. An additional enhancement of the illusion is induced by the dots arranged horizontally halfway between the merging points. An algebraic function is derived and fitted to the experimental values. The curve obtained approaches the classic illusion asymptotically, as soon as the dots are positioned at far distance from the merging points. There is no influence of the dots when they coincide with the merging points.

Citations


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