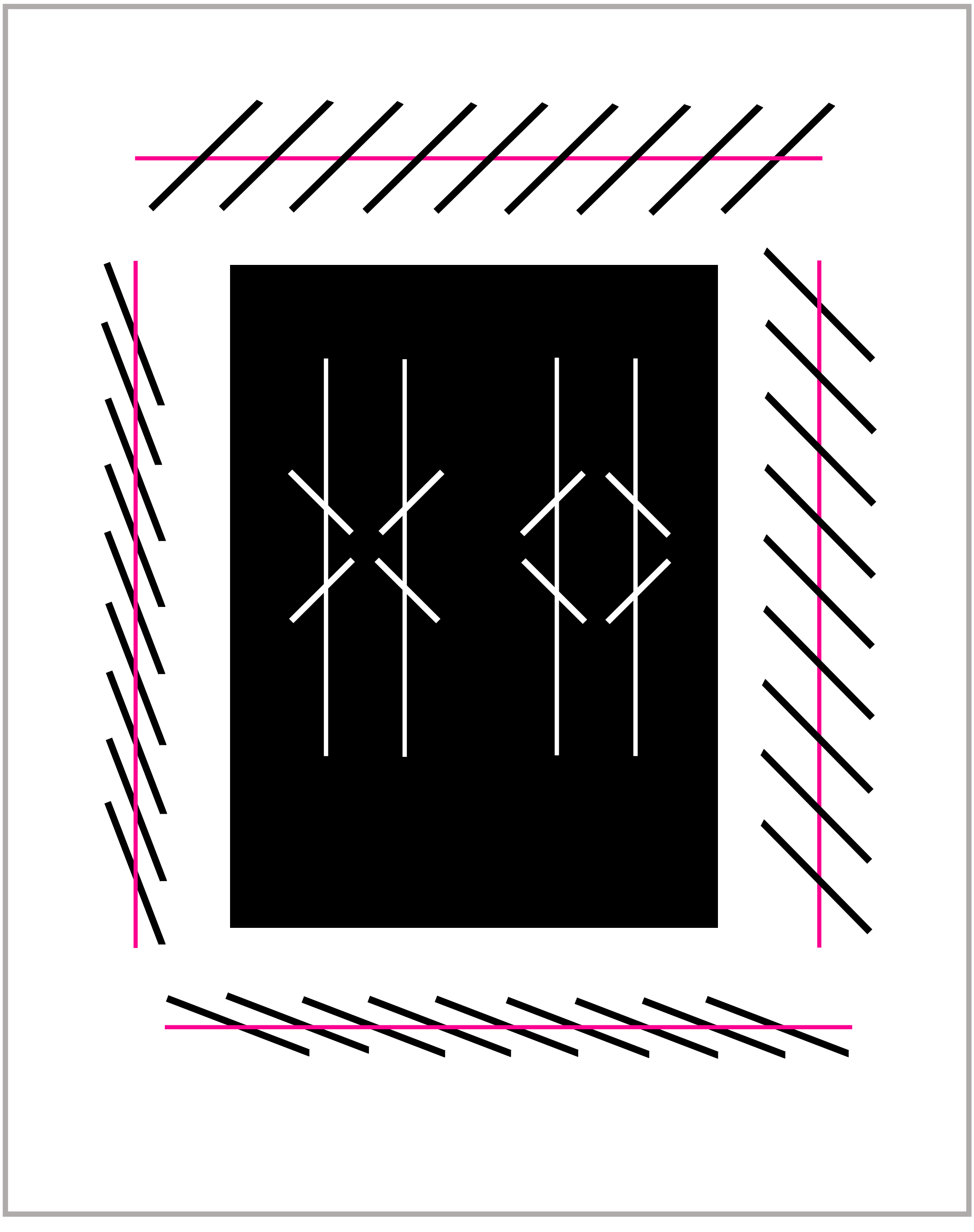

# Orientation Illusions and Crosstalk

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## 1. The Problem

In the original version of the Zöllner (1860) illusion [Fig 1, left], several parallel vertical lines are seen above mirrorlike alternating patterns of parallel strokes, crossing the lines at an angle of 45 degrees. The target lines appear inclined, in alternating sequence, to the right and to the left of the vertical. Towards the ends of the rows, the tilt appears to be slightly pronounced.

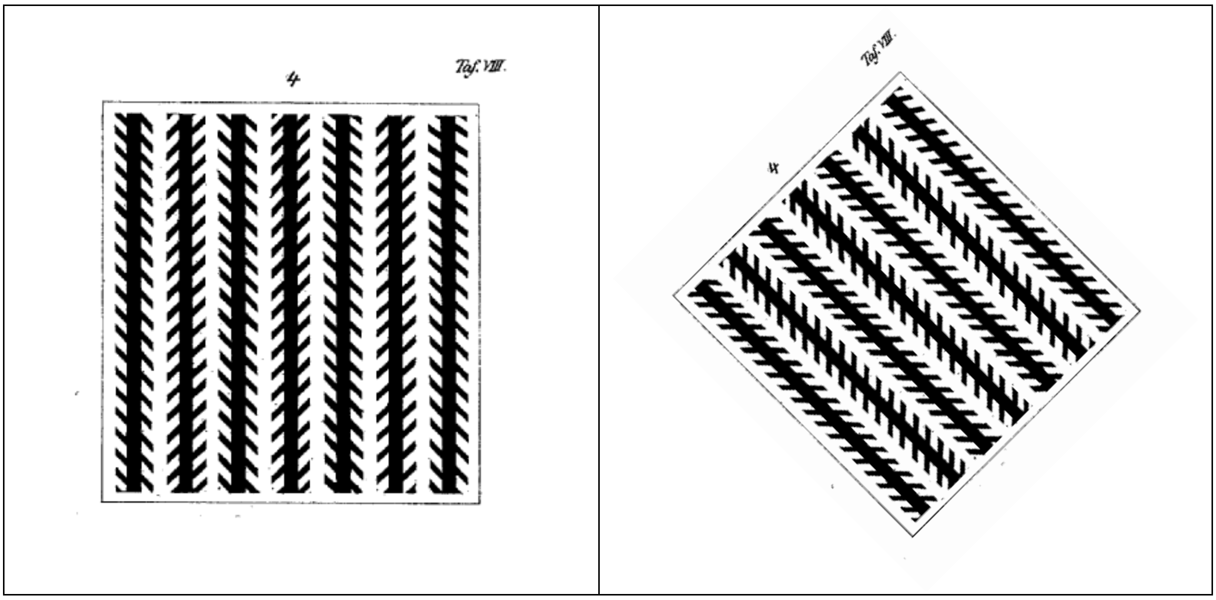


**Fig 1** The Zöllner illusion is observed, regardless of the orientation of the stimulus.

Rotating the whole pattern by $45^0$, or even $90^0$ or any other angle, doesn´t really change the intensity of the illusion. This has led to the explanation of the Zöllner illusion as due to an apparent acute angle enlargement [Predebon (1984)]. The effect is still observed when just two parallel lines are left above mirrorlike stroke patterns.

However, at a single vertical line above a stroke pattern of 45 degrees, an apparent tilt is hardly observable (title page, right), but an illusion is clearly seen when the crossing angle is reduced to about 20 degrees (title page, left). Is there more than one effect causing similar tilt illusions on straight lines?

In case of the Hering (1861) illusion, two parallel lines appear to be slightly bent when crossing other lines emerging radially from a center. Several of these crossings occur at a small angle.

There are illusions concerning the orientation of the thought extension of a line. As an example, in Fig 2, two lines are seen, a target line at 20 degrees with respect to the horizontal and, above, a red test line at 20 degrees off the vertical. It looks as if the thought extension of the latter hits the target somewhere left to its right end [Obonai and Koto-Gakko (1931)]. It is not quite clear whether the test line had been rotated apparently towards the vertical, or its thought extension only, or both. Things change when the whole arrangement is rotated such that the test line is oriented vertically. In this case its extension clearly hits the dip of the target, according to geometry. There is a similar problem with the Poggendorff illusion, Fig 3 [Zöllner, 1860).

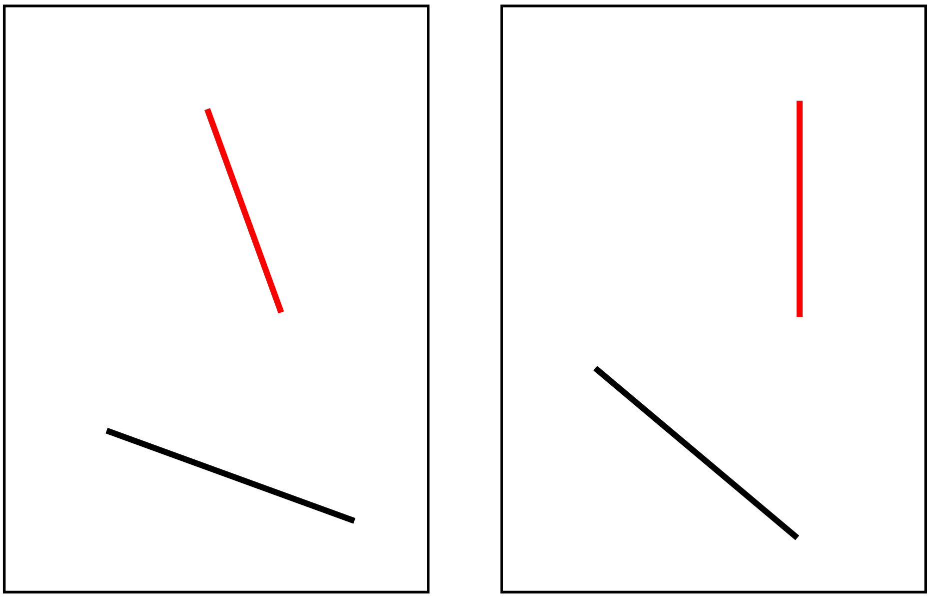


**Fig 2**

Left: The continuation of the red line appears to hit the black target line somewhere between its center and its lower end.

Right: Rotating the stimulus by $20^0$ gives an impression corresponding to the geometric situation.

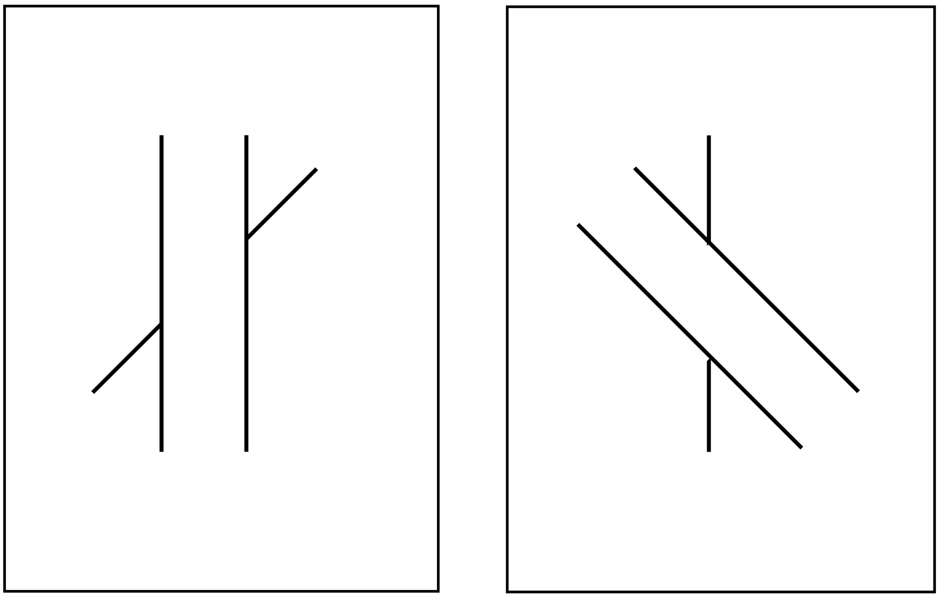


**Fig 3**

The Poggendorff illusion may be mainly due to an apparent rotation of the thought extension of the crossing line when it is oriented at 45 degrees to the main orientation axes.

## 2. Orientation illusions due to small angle patterns

One way to explain tilt illusions on straight target lines seen above a stroke pattern is to assume that the angle between the target and the strokes crossing it appears to be enlarged. Another possibility is that both, the straight target line and the pattern, are rotated simultaneously, but that the angle will be perceived correctly.

## 2.1 Target line oriented vertically or horizontally

A horizontal or vertical line appears slightly tilted when seen above a stroke pattern crossing the target at an angle of less than 30 degrees [Wallace and Crampin (1969)]. Maximum effect is observed at about 15 to 20 degrees. Concerning the small angle version of this stimulus

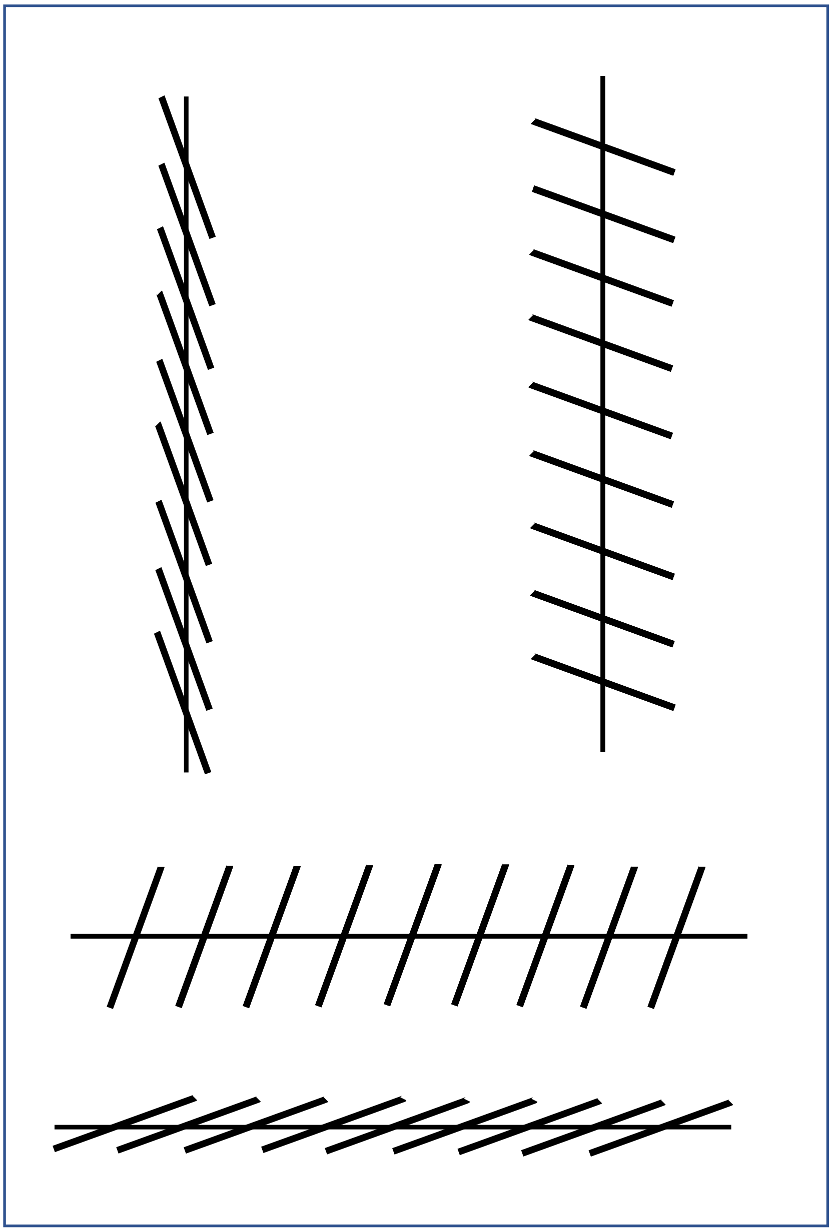


**Fig 4**

The strokes forming a pattern are aligned along the vertical or horizontal, respectively. They appear to be slightly tilted when they are at an angle of 20 degrees to the vertical or horizontal. Straight vertical or horizontal target lines above them seem to be rotated, too, (left and bottom). There is no rotation of the target lines observed when the relative angle is 70 degrees.

(left and bottom in Fig 4), it appears as if the pattern had been rotated towards the vertical or horizontal, respectively, and, simultaneously, had transferred its motion to the target line. This does not occur in case of larger crossing angles (right figure and second from bottom). Obviously, there is some interaction between the two elements of the stimulus, depending on the size of the angle. In the following, effects of this kind are referred to as crosstalk.

### 2.2 Strokes aligned vertically or horizontally

Watching a single oblique target line (around $20^0$ to the vertical) one may ask whether it is perceived at its true orientation in space or whether it had been slightly rotated already. As an example, the case is discussed where the stroke pattern is oriented vertically, while the target line is inclined by 20 degrees (Fig 5c). The question is, of which kind the influence would be the line and the pattern would exert on each other.

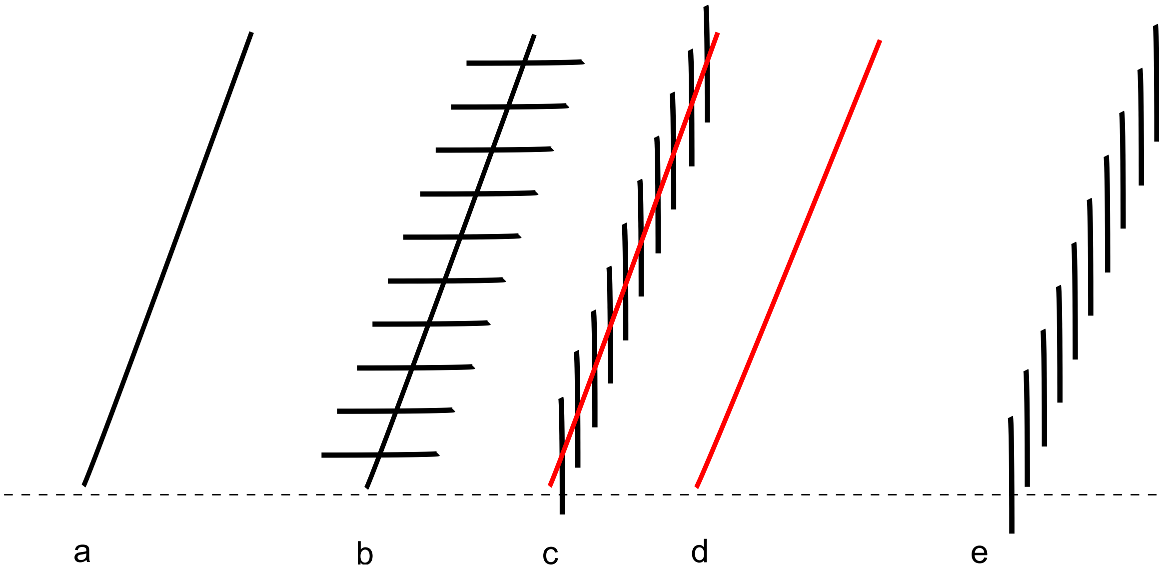



**Fig 5** Both red lines (c and d) appear to be parallel. In fact, they are not, while (a) and (c) are. The single red line had been rotated clockwise by 2 degrees to make it look parallel to (c). It appears as if in (c), the vertical stroke pattern had been rotated just to a minor extent and, simultaneously, had partly prevented rotation of the red target line. Single oblique lines are rotated counterclockwise (a and d). The horizontal pattern in Fig b does not interact with the target line, due to the large crossing angle.

A single line, as shown in Fig 5a, at an acute angle to the vertical, suffers from an apparent rotation (counterclockwise in this case). This can be checked in the following way: Comparing it with the red target line in (c), the two lines seem not to be parallel (although they are). Obviously, the target in (5c) has been rotated counterclockwise to a lesser extent than the single line (a). To estimate this discrepancy, another red line (d) is shown to the right of the stimulus. Both lines appear to be parallel. In fact, they are *not*. The single line (d) had been turned clockwise by 2 degrees just to make it look parallel. From these observations one can conclude that, in Fig 5c, the vertical strokes have at least partly prevented the stimulus (c) to be rotated counterclockwise. Comparing the strokes with the pattern of Fig 5e one may still notice a slight tilt to the left, due to some interaction with the red target line. The line in Fig 5b appears parallel to (a). Perceptively, it had been rotated counterclockwise, too. Due to the large crossing angle, no interaction with the horizontal pattern has taken place.

Briefly, several vertical lines forming a pattern seem to be fairly stable with respect to rotation when interacting with a straight inclined line at a small angle. However, in Section

2.1, a single vertical line had been rotated due to interaction with several inclined lines, forming a stroke pattern.

## 3 Crosstalk

Concerning the perceived orientation of a target line above a stroke pattern, an interaction seems to occur along the neural pathways, processing the information relating to the elements of the stimulus. In this context this interaction is referred to as crosstalk. Originally, in electronics, crosstalk is any phenomenon by which a signal transmitted on one channel of a transmission system creates an undesired effect in another channel (Wikipedia 1). A common example is hearing pieces of other people's conversations on a telephone. Biological crosstalk refers to instances in which one or more components of one signal transduction pathway (eg, cell-signalling pathway) affects another [Kunkel and Brooks (2002); Wikipedia 2)].

It is observed that a line, inclined at a small angle to a principal axis of alignment, suffers from a small rotation towards this axis. However, a single vertical line, not interacting with another element, stays vertical. From the observation that a pattern of inclined parallel strokes transfers its rotation to a vertical target line it seems likely that there is some interaction along the corresponding neural pathways processing the visual information.

In case the relative angle becomes considerably larger than about 30 degrees, the interaction discontinues: As shown, a vertical line will not be rotated perceptually when crossed by a pattern at an angle of $70^0$ off the vertical, but a horizontal target line will be (Fig 4). Even at an angle of 45 degrees hardly an interaction is noticed.

There are other illusions exhibiting a similar mutual impact of the apparent properties of geometrical elements. Examples are the Müller-Lyer (1889) illusion [perceived length of the target line as a function of the distance of the wings´ centers of gravity (Kreiner (2012)], the effect of assimilation known from the Delboeuf (1893) illusion, the Baldwin (1895) illusion [apparent lengthening of the target line due to increasing size of the boxes, provided they are small [Wilson and Pressey (1988)]]. Contrast phenomena like Mach bands (Wikipedia 3) result from lateral inhibition among retinal neurons.

## 4 Apparent rotation of a single line

The question is why a single line is apparently rotated when oriented at a small angle to the vertical or horizontal and why this angle appears to be reduced. One may check whether this can be attributed to the distribution of orientation cells in the striate cortex.

### 4.1 Averaging

In the visual cortex, there is a large variety of simple cells and complex cells [Martinez and Alonso (2003)]. Complex receptive fields originate from the convergence of simple cells with similar orientation preference. In a simplified model the following assumptions are made:

a) The perceived orientation of some linear structure results from the average response of different types of cells with different orientation preferences.

b) The majority of cells exhibits a receptive field of at least 10 degrees.

c) There is a higher number of ganglions specific to vertical or horizontal structures, respectively, than to structures oriented at an angle in between.

In case the density of neurons varies as a function of the orientation of the stimulus they respond to, the apparent orientation will be shifted towards the higher population. The maximum shift is expected for orientations corresponding to the maximum of the first derivative of the neurons´ distribution function.

In Fig. 6, ganglions sensitive to certain orientations are arranged symbolically on a circle, shown together with their receptive fields. There is a higher density responding to the main orientation axes. In between, there is a drop off in density towards the 45 degrees orientation. The densities are chosen arbitrarily.

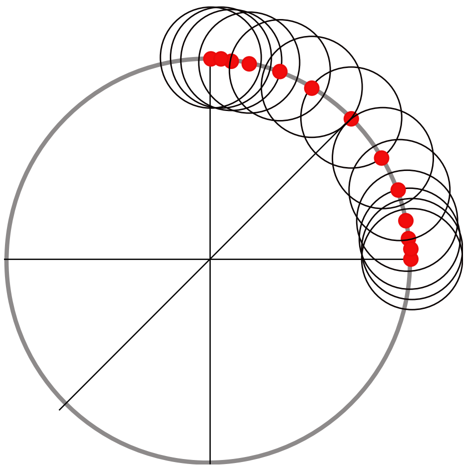


**Fig. 6** Density of cortical neurons responding to linear structures inclined by a certain angle (schematically). The circles indicate their receptive fields. There is a high density of neurons responding to vertical or horizontal lines. It drops off towards angles in between. The densities are chosen arbitrarily.

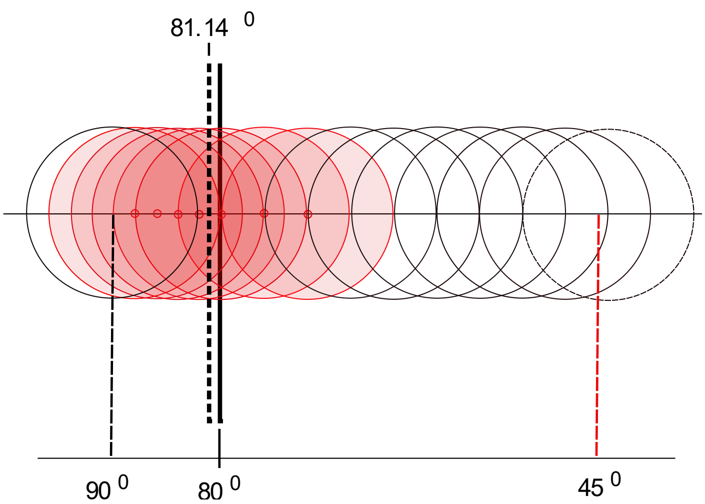



**Fig 7** Assuming an uneven distribution of the cortical orientation cells and averaging their signals leads to a slight apparent rotation of an oblique line towards the nearest axis of alignment.

In Fig 7, an attempt has been made to estimate the apparent shift of a line assuming a certain cell distribution. The orientation cells are plotted versus the angle they preferably respond to, together with their receptive fields. Their density drops from $90^0$ towards $45^0$, by an arbitrary rate: Between $90^0$ and $80^0$, there are cells responding preferably to certain angles every $2^0$, then, till $45^0$, only every $5^0$. A stroke oriented at $80^0$ is "seen" by several neurons (red circles). Its apparent direction is due to their average response. As the density of cells increases towards $90^0$, the average signal will be shifted slightly towards the vertical, by $1.14^0$ in this case.

### 4.2 The Experiment of Wallace and Crampin

Wallace and Crampin (1969) have performed an experiment which allows to estimate the extent of this apparent rotation. Two parallel horizontal lines had been drawn above adjacent mirrorlike stroke patterns. The strokes were rotated in steps from 4 degrees to 45 degrees. Depending on this angle, the lines appeared to be tilted with respect to each other. This tilt angle was measured (Fig 8). It has been found that the intensity of the illusion depends on the pattern density as well. It is assumed that the observed rotation of the target lines corresponds approximately to the apparent rotation performed by the stroke pattern. Due to the curve drawn in Fig 8, the apparent tilt of a line exhibits a maximum when the field is rotated by about 17 degrees with respect to the horizontal. Due to this experiment, a line, off from the horizontal by this value, will be rotated apparently by about 1.2 degrees arc. Concerning lines off the vertical axis by the same amount, results may be different.

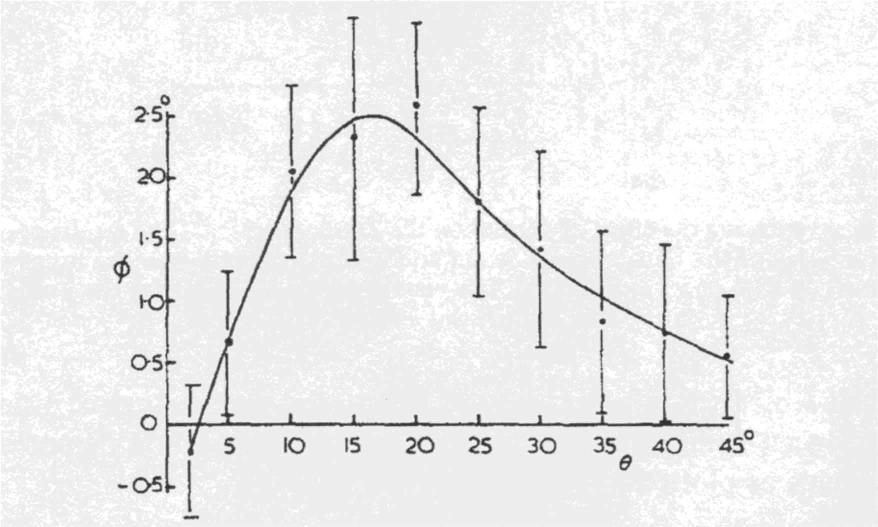



**Fig 8** Effect of a herringbone pattern on the Zöllner illusion. By Wallace and Crampin (1968). The vertical scale gives the angle measured between two lines apparently inclined with respect to each other due to the influence of two mirrorlike stroke patterns. One line appears to be inclined by half of this value

## 5 Herringbone Structures

When stroke patterns are arranged in a herringbone manner, the patterns appear to be inclined with respect to each other. In the example chosen in Fig 9, the illuson is mainly attributed to a small angle (SMOX)-effect, the angle formed by the strokes and the horizontal.

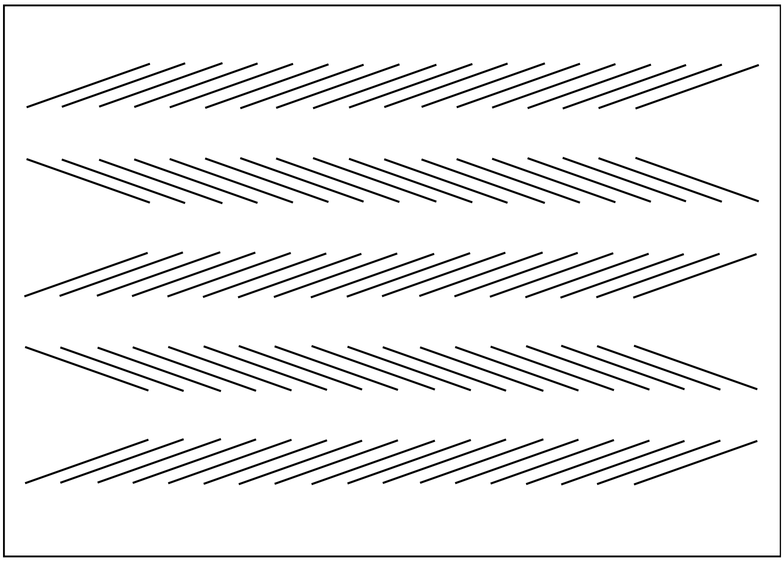


**Fig 9**

The strokes undergo an apparent rotation towards the horizontal. This rotation is transferred to the rows as a whole. Angle with respect to the horizonal is 20 degrees.

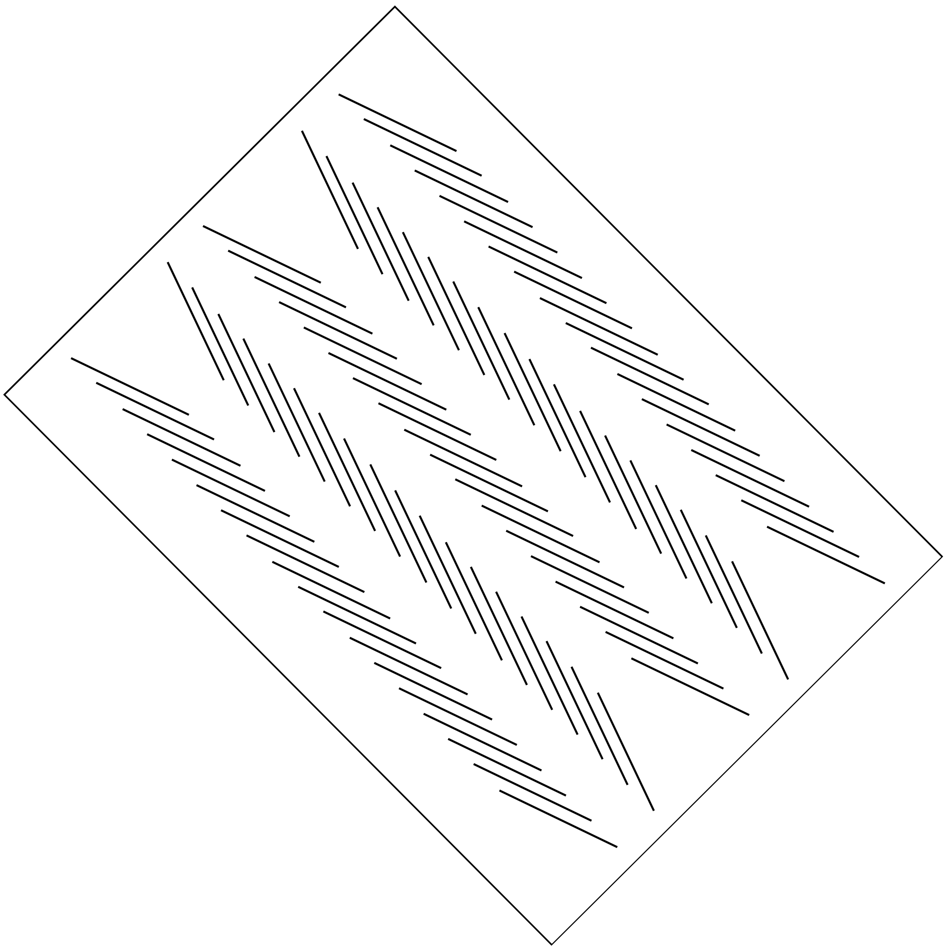


**Fig 10**

Rotation of the stimulus by 45 degrees reduces the intensity of the illusion.

Rotating the stimulus by 45 degrees (Fig 10) reduces the intensity of the illusion because the small angle effect is less efficient when the strokes form larger angles with the horizontal and vertical, respectively.

### 5.1 The Zöllner Illusion

In contrast to the Herringbone structure, in the Zöllner (1860) illusion straight lines are added, making judgement of parallelism easier (Fig 12). In the original version the target lines are vertical and the strokes cross at 45 degrees.

Fig 11 shows two examples of two parallel lines each, with strokes crossing at an angle of 45 degrees. It will be noticed that the separation of the lines is slightly modified. The perceived distance of the strokes exerts an influence on the apparent separation of the lines: It gets wider, where the strokes approach each other, and vice versa.

Primarily, this is ascribed to a size constancy effect: From an experiment performed by Gilinsky (1955) it is known that, at a given distance of observation, smaller objects appear magnified in relation to larger objects. Their retinal images are processed not in accordance

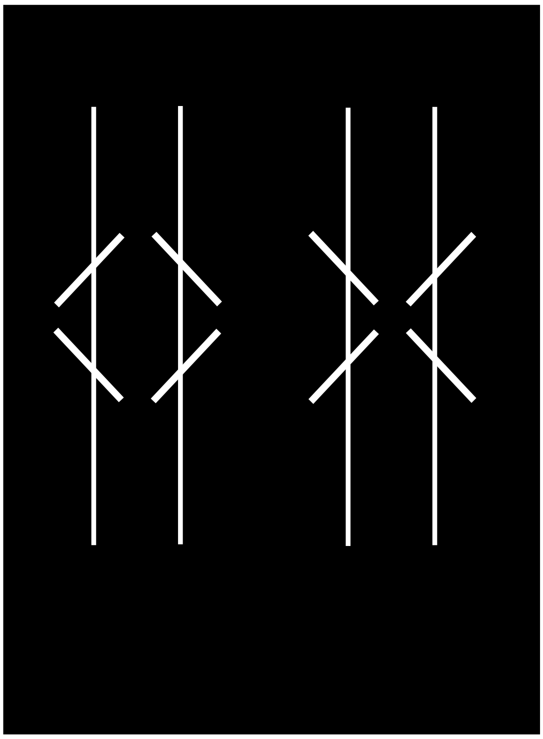


**Fig 11**

The distance between two parallel lines is slightly modified by strokes at an angle of 45 degrees. Around the centre of the stroke pattern, it is widened in the picture to the right, but reduced at the left.

with the laws of geometrical optics. In the example given here, it is not objects to appear larger or smaller, but gaps. A similar effect occurs with the mirrored triangle illusion [Kreiner (2015)].

In Fig 12, the patterns form an angle of 45 degrees with the vertical target lines. On the single target line, to the right, hardly any rotation can be recognized. At a crossing angle of 45 degrees no interaction between the pattern and the target line is expected and no rotation of the lines will occur.

However, the Zöllner illusion is to be observed on the four vertical lines to the left. Taking the first pair of patterns (from left), the distance between each two mirrorlike strokes decreases continuously when following them from bottom to top, but increases for the pair of patterns in the middle. As a result, the patterns as a whole move apart from each other on one end but approach each other at the opposite end. In short, the illusion is ascribed to the size constancy effect. And it appears to be more pronounced towards the ends.

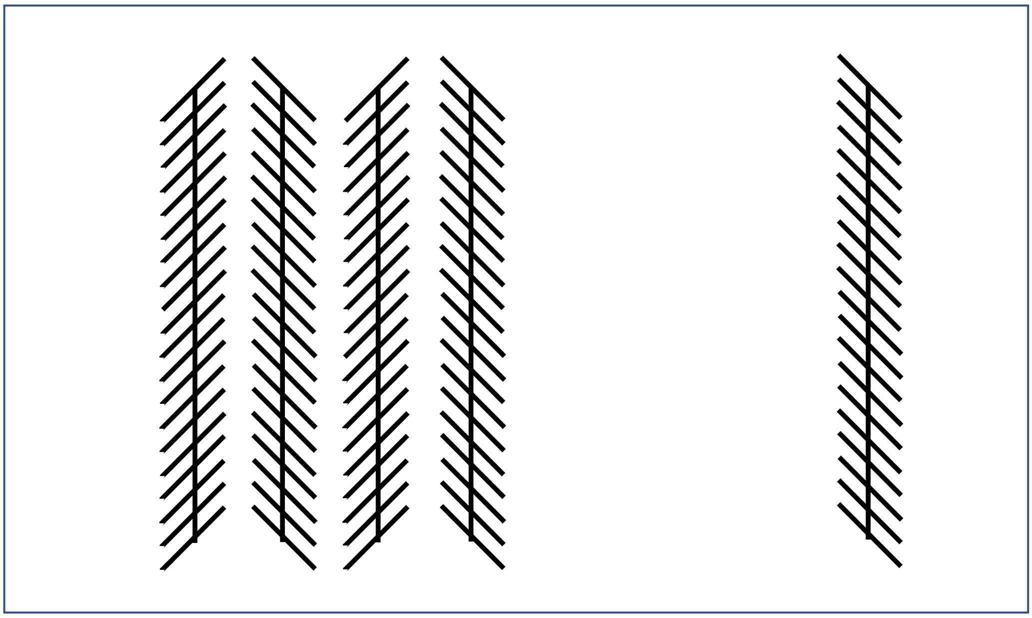
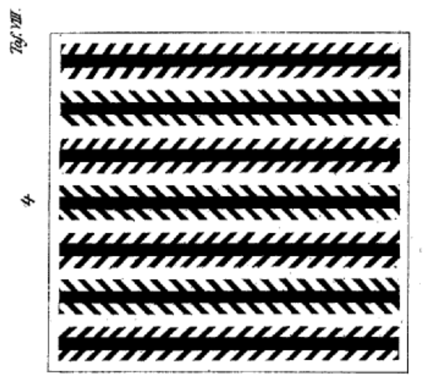


**Fig 12** Within adjacent patterns, each two mirrorlike strokes, approaching each other, lead to a perceived widening of the gap between the targets. Where the strokes are farther apart, the gap appears to become smaller. As a consequence, the parallel target lines appear inclined or even bent. On the single line to the right no apparent rotation is observed



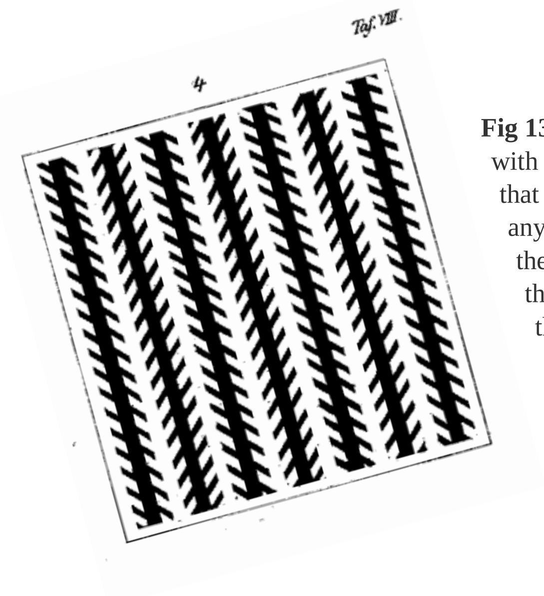




**Fig 13** Comparison with Fig 1 shows that there is hardly any influence of the orientaton of the stimulus on the intensity of the illusion

As the effect of size constancy is not as sensitive to orientation as the small angle illusion, the intensity of the Zöllner illusion hardly depends on the orientation of the stimulus.

## 6 The Hering illusion

Two parallel lines appear to be bent when seen above a pattern of radially divergent rays [Hering (1861)]. This illuson is attributed to the small angle effect, as well as to size constancy.

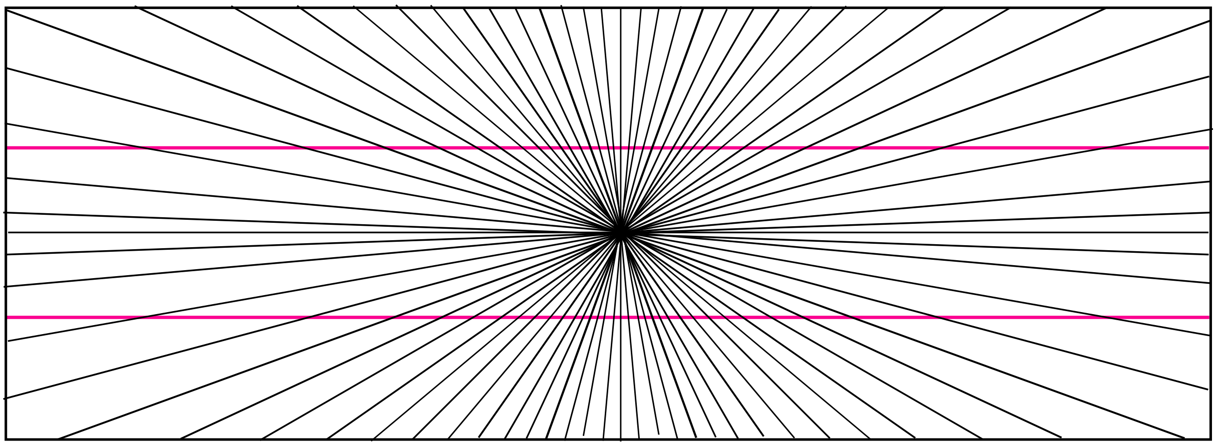



**Fig 14** The Hering illusion. The two horizontal lines are straight and parallel. The apparent curvature is attributed to two effects: Around the center, where the lines cross at larger angles, size constancy appears to be the main cause while farther outside the small angle effect seems to gain importance.

## 7 Conclusion

Two causes of some orientation illusions are discussed. One is the rotation of a line forming a small angle (around 20 degrees arc) with the vertical or horizontal. The line appears to be rotated towards the nearest axis of orientation and, simultaneously, may transfer its rotation to other elements of the stimulus. This interaction is attributed to crosstalk. Examples are different versions of herringbone patterns.

Rotation itself is explained hypothetically from an uneven distribution of the orientation cells in the visual cortex as a function of the angle they respond to.

Tilt illusions observed at target lines on stroke patterns crossing at angles above 30 degrees are interpreted as due to a consequence of size constancy. One example is the classic Zöllner illusion. The Hering illusion appears to rely on both effects.

**Citations**

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