

The vertical-horizontal illusion: Assessing the contributions of anisotropy, abutting, and crossing to the misperception of simple line stimuli

Kyriaki Mikellidou

Department of Translational Research on
New Technologies in Medicine and Surgery,
University of Pisa, Italy



Peter Thompson

Department of Psychology, University of York, York, UK



Mamassian and de Montalembert (2010) have proposed a simple model of the vertical-horizontal illusion. This model identified two components, an anisotropy which results in horizontal lines being perceived approximately 6% shorter than verticals and a bisection component which results in a bisected line being perceived approximately 16% shorter. We have shown that this bisection component confounds two effects: One when lines cross one another and a second effect when one line abuts another. We propose an extension to the Mamassian-de Montalembert model in which their bisection component is replaced by separate crossing and abutting components.

Introduction

One of the first visual illusions to be described in any detail was the Oppel-Kundt illusion (Oppel, 1855) in which a horizontal line with a series of vertical “ticks” along its length appears longer than a line of equal length without the ticks. Helmholtz (1925) saw this illusion as being an example of filled extents being perceived as larger than unfilled extents. He cited everyday examples of the illusions—that empty rooms look smaller than furnished rooms, walls covered with a paper pattern look larger than one painted in a uniform color, and (most controversially) that women wear horizontal stripes in order to look taller (see Thompson & Mikellidou, 2011). Although the optimal number of ticks has not been established with any rigor, there are reports to suggest that the effect increases as more ticks are introduced up to some number between 7 (Obonai, 1933) and 14 (Piaget & Osterrieth, 1953).

A second illusion of similar antiquity is the vertical-horizontal illusion, first reported by Frick (1851, as cited in Avery & Day, 1969). Usually shown as an inverted T figure with equal-length vertical and horizontal components, it is reported that the vertical appears significantly longer than the horizontal. This illusion has been the subject of much research, but the most thorough investigation was carried out by Mamassian and de Montalembert (2010) who have proposed a simple model to describe quantitatively the overestimation of the vertical segment compared to the horizontal in the vertical-horizontal illusion. They investigated the illusion in three configurations of a pair of vertical and horizontal lines: “T,” “L,” and “+.” They interpreted their results as showing two independent components, in agreement with previous studies (Charras & Lupianez, 2010; Künnapas, 1955): (a) an anisotropy bias causing a 6% overestimation of the vertical segment relative to the horizontal one and (b) a bisection bias of approximately 16%, causing an underestimation of the bisected line relative to the bisecting line.

The supposition that bisection is responsible for a large *underestimation* in perceived length does not sit easily with an interpretation of the Oppel-Kundt illusion being an illusion of filled extent; why should bisecting a line reduce its perceived length by 16% whereas introducing more lines increases its perceived length?

The aim of the present paper is to evaluate the two independent components of the vertical-horizontal illusion proposed by Mamassian and de Montalembert (2010), specifically “anisotropy” and “bisection” and to attempt to reconcile findings on the vertical-horizontal illusion with those on the Oppel-Kundt illusion. Several of our experiments have used exactly the same configurations as Mamassian and de Montalembert

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(2010) did in their study of the vertical-horizontal illusion, but whereas they compared the horizontal to the vertical component with each configuration, we have also compared the vertical or horizontal segment of one of our stimuli with another independent line of the same orientation. Based on results from two experiments, we propose a new model to describe quantitatively the overestimation of the vertical segment compared to the horizontal in the vertical-horizontal illusion.

Furthermore, we have investigated the bisection component as described by Mamassian and de Montalembert (2010) by which the horizontal segment of an inverted T configuration is underestimated by approximately 16% when compared to the vertical segment of the same configuration. Whereas they proposed that bisection results in the *underestimation* of the bisected line, we present evidence to suggest an *overestimation* of the bisecting line. Throughout this paper Mamassian and de Montalembert (2010) will be referred to as MdM.

Experiment 1

This experiment evaluates the “anisotropy component” as described by the MdM model in which the size of a vertical line is always overestimated when compared to a horizontal one of the same length.

Method

Subjects

Eleven naïve participants, six female (age range 18–27), participated in the experiment. Stimuli were viewed binocularly from a viewing distance of 57 cm.

Design

Stimuli were generated on the screen of a Clinton Monoray display with green phosphor. Two conditions were interleaved; in one condition a horizontal and a vertical line were positioned along the horizontal axis, one next to the other (see Figure 1A), and in the other condition the two lines were positioned along the vertical axis, one above the other (see Figure 1B). Both conditions were fully counterbalanced: in 50% of the trials the horizontal line was acting as the standard stimulus, and the remaining 50% of the trials the vertical line was the standard stimulus. The standard stimulus in each case was 6.1° long and was compared with one of seven orthogonal comparator stimuli, varying in size from slightly smaller to slightly longer than the standard. As in all subsequent experiments, the deviations from the standard length were -0.9° ,

-0.6° , -0.3° , 0° , 0.3° , 0.6° , 0.9° ; thus, the length of the comparator stimulus ranged between 5.2° and 7.0° . Ninety-five percent confidence intervals were calculated and displayed for each condition.

Each participant undertook 336 trials; eight pairs of stimuli each presented six times for seven comparator stimulus sizes. Participants were asked to indicate the longer line using a response box. Stimuli were presented simultaneously for 500ms. The lines of the stimuli were bright green on a black background.

Stimuli

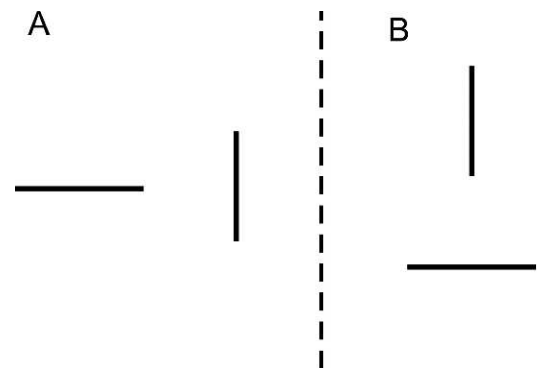


Figure 1. Stimuli used in Experiment 1. The two configurations shown in 1A and 1B were interleaved in the experiment.

Results

Psychometric functions (cumulative Gaussians) were fitted through the data for each subject by the method of least squares and the point of subjective equality (PSE) determined. Results for all participants are illustrated in Figure 2, showing that the mean PSE when a vertical was matched to a standard (6.1°) horizontal line was 5.67° ; and when a horizontal was matched to a standard vertical line, the mean PSE was 6.55° . A z test revealed that when a vertical line was compared to a horizontal line of the same size the length of the former was significantly overestimated by approximately 7%, ($p < 0.01$). Similarly, another z test revealed that the size of a horizontal line was found to be significantly underestimated by approximately 7% ($p < 0.01$). This result is in line with MdM’s figure of 6% for the anisotropy component of the vertical-horizontal illusion.

Experiment 2

The aim of this experiment was to investigate the bisection component of the vertical-horizontal illusion,

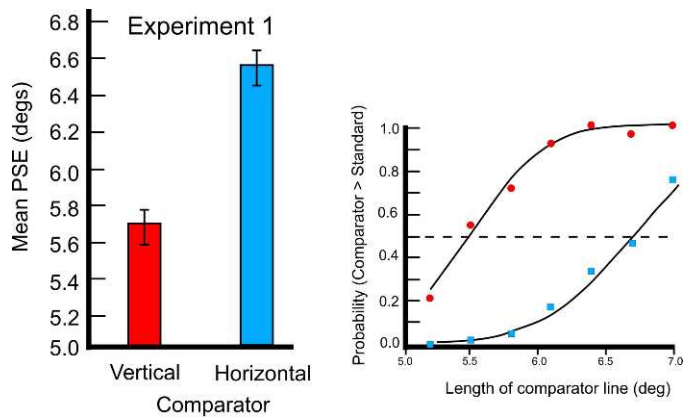


Figure 2. (Left) Results from Experiment 1. The dotted line indicates the true length of the standard line (6.1°). Vertical lines must be made shorter to match a horizontal, horizontals must be made longer to match a vertical. Error bars show 95% confidence intervals. (Right) Individual data from one subject. Red circles: Comparing vertical line to horizontal standard of 6.1° . Blue squares: Comparing horizontal line to vertical standard of 6.1° .

as described by the MdM model. In that model, bisection reduces the perceived length of the bisected line, whereas in the Oppel-Kundt illusion (Oppel, 1855), the presence of a number of dissecting ticks increases the perceived length of the line. Helmholtz (1925) describes this latter effect as an illusion of filled extent, in which filled extents look larger. The key condition here is shown in Figure 3B, the inverted T, in which the horizontal of the inverted T is compared to a horizontal. To extend the observation to stimuli closely related to the Oppel-Kundt illusion, we have also investigated conditions with five and nine vertical lines abutting the horizontal (Figure 3C and D).

Method

Subjects

Ten naïve participants, seven female (age range 18–27), participated in the experiment. Stimuli were viewed binocularly from a viewing distance of 57 cm.

Design

Four conditions were interleaved; in the control (no vertical lines) a standard horizontal line 6.1° long was compared with one of seven comparator stimuli composed of another horizontal line varying in size from slightly smaller to slightly longer than the standard. For the other three conditions, one, five, or nine vertical lines were positioned on the standard horizontal line in a regular manner, and their length was equal to that of the standard horizontal i.e., 6.1° . Figure 3 below illustrates the stimuli used in this experiment. Please note that as in all subsequent experiments, although all parts of the

stimuli used were the same color, the parts to be compared are shown in blue for the purpose of clarity.

Each participant undertook 1,400 trials; eight pairs of stimuli were each presented 25 times for seven variable stimulus sizes. Participants were asked to indicate the longer horizontal line using a response box, and the control condition was used to evaluate whether or not they were able to carry out the task. Stimuli were positioned one next to the other and presented simultaneously for 750 ms.

Stimuli

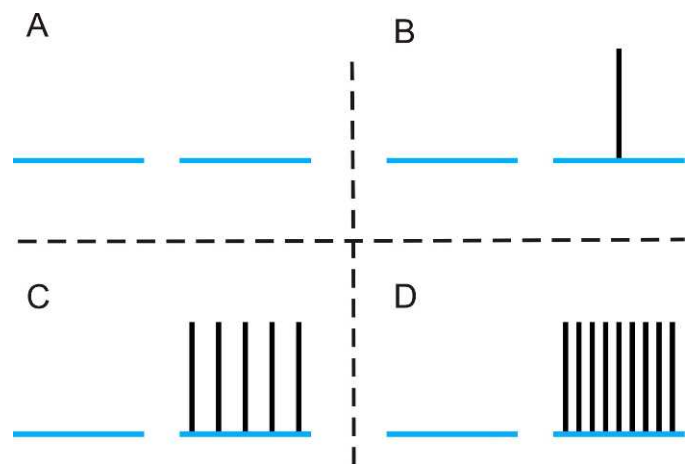


Figure 3. Stimuli used in Experiment 2. The variable stimulus was always a simple horizontal line. The control condition is shown in A. The configuration in B shows the inverted T, one of the figures investigated by MdM. The lines to be compared are shown in blue only for illustration.

Results

Results for all participants, illustrated in Figure 4, show that there is no significant decrease in the apparent size of a horizontal line when a single vertical abuts it at the midpoint. This is the standard version of the inverted T vertical horizontal illusion (Frick, 1851) and one of the configurations investigated by MdM. An absence of a significant difference in the perceived size of a horizontal line was also observed when five lines abutted it whereas a marginally significant increase of the perceived length of the horizontal line was evident when nine lines abutted it, the configuration that most closely approximates the Oppel-Kundt illusion.

Results show that the perceived size of the horizontal segment in our stimuli was significantly affected by the number of vertical lines abutting it, $V = 0.74$, $F(3, 27) = 4.04$, $p < 0.05$. A z test showed a significant increase in the perceived size of a horizontal line compared to the actual physical size of the stimulus when nine lines were present ($p < 0.05$).

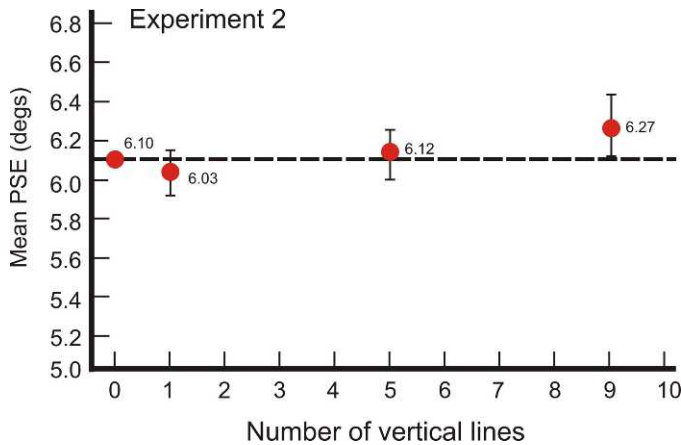


Figure 4. Results from Experiment 2, showing a significant overestimation of the perceived size of a horizontal line with nine vertical lines abutting it by approximately 2.7% ($N = 10$). Error bars show 95% confidence intervals. Error bars on the zero vertical line condition are smaller than symbol.

In the present experiment the general trend of the results suggests no significant differences in the apparent size of a horizontal line when one or five vertical lines of the same size abut it. More specifically, when a single vertical line, the same length as the horizontal one abutted the latter, we failed to observe any bisection component of the vertical-horizontal illusion as MdM would predict.

Experiment 3

Experiment 2 suggests that the horizontal component of the inverted T figure is not subject to any misperception when compared to an isolated horizontal line. This result would suggest that bisection, per se, does not affect perceived length. However, it should be remembered that in the MdM study the bisected horizontal was compared to the bisecting vertical. The aim of this experiment was to investigate further the bisection component of the vertical-horizontal illusion, as described by MdM. To this end, we have manipulated the size of an independent vertical line and asked participants to compare its length to the length of the vertical segment of one of three configurations; a horizontal T, a cross, and an inverted T.

Method

Subjects

Seven naïve participants, four female (age range 18–27), participated in the experiment. Stimuli were viewed binocularly from a viewing distance of 57 cm.

Design

Four conditions were interleaved; in the control, a standard vertical line was compared with one of seven comparator vertical lines, varying in size from slightly smaller to slightly longer than the standard. Stimuli were positioned along the vertical axis to prevent participants from carrying out size judgments by matching the position of their two ends. For the other three conditions, the standard stimulus was the vertical component of a horizontal T, a cross, and an inverted T which was compared against the comparator vertical stimulus. Figure 5 illustrates the stimuli used in this experiment. Other details are as in the previous experiments. Please note that although all parts of the stimuli used were the same color, the parts to be compared are shown in blue for the purpose of clarity.

Each participant undertook 336 trials; eight pairs of stimuli were each presented six times for seven comparator stimulus sizes. Participants were asked to indicate the longer vertical line using a response box, and the control condition was used to evaluate whether or not participants were able to carry out the task. Stimuli were presented simultaneously for 500 ms. All other methodological details were identical to those in Experiment 1.

Stimuli

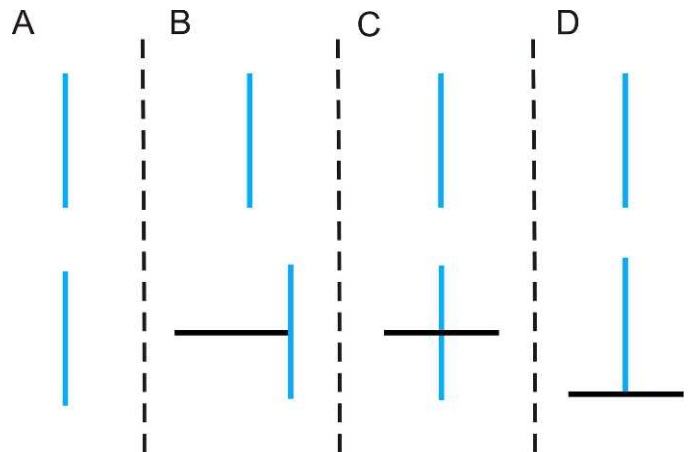


Figure 5. Stimuli used in Experiment 3. The comparator stimulus was always a vertical line located either above or below the standard stimulus. The control condition is illustrated in A. Lines to be compared are shown in blue only for illustration.

Results

Results for all participants are illustrated in Figure 6. The control condition shows that participants were able to match veridically the size of two simple vertical lines, generating a mean match of 6.09°. Moreover, when comparing the size of a simple vertical line to the vertical segment of a horizontal T, the mean PSE was

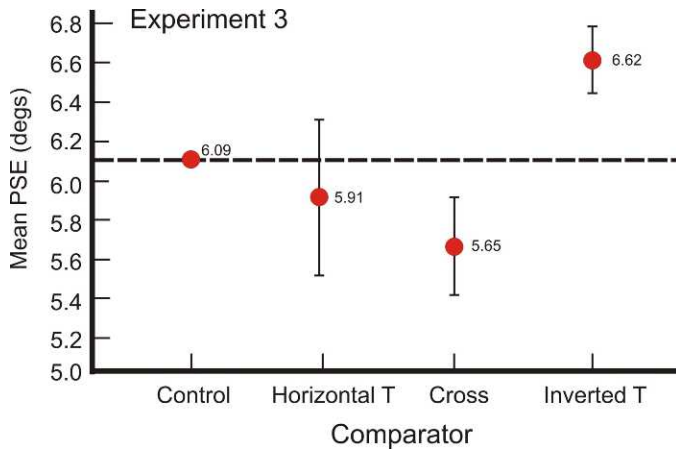


Figure 6. Results from Experiment 3, show a significant 7.1% underestimation of the perceived size of the vertical segment in a “+” and a significant 8.7% overestimation of the perceived size of the vertical segment in an inverted T ($N = 7$).

5.91° and a z test revealed no significant difference between the physical and perceived size of the latter ($p > 0.05$). However, for the vertical segment of the cross configuration to be perceived equal in size with the simple vertical line, the latter had to be approximately 7% shorter, generating a mean PSE of 5.65°. A z test revealed that this value was significantly different from 6.1° ($p < 0.01$) i.e., the actual physical size of the vertical segment in the cross configuration. Finally, for the vertical segment of the inverted T configuration to be perceived equal in size with the simple vertical line, the latter had to be approximately 9% longer, generating a mean PSE of 6.62°. A z test revealed that this value was significantly different from 6.1° ($p < 0.01$) i.e., the actual physical size of the vertical segment.

Results in Experiment 3 show that the perceived size of the vertical segment of the horizontal T condition is not significantly different from the control, thus challenging the definition of the bisection component as described in MdM’s simple model. In addition, the perceived size of the vertical segment in a cross configuration was found to be approximately 7% smaller than the standard. This result satisfied the qualitative nature of MdM’s bisection component as there is an observed reduction in the size of the vertical line. However, this prediction is not satisfied quantitatively as the reduction was only 7% and not 16% as they suggested. Finally, the perceived size of the vertical segment in an inverted T configuration was found to be significantly longer by 9% compared to its actual size. This result was not and could not have been predicted by their model as they do not predict any changes in the perceived size of a line which has its one end touching on another line. Importantly, the thickness of the “abuttee”

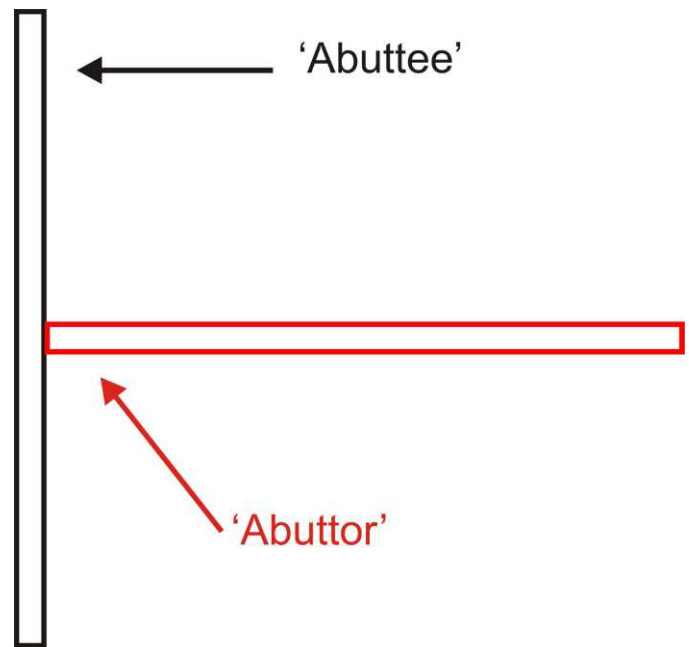


Figure 7. The abuttor has one of its ends simply touching another line: The abuttee.

(i.e., the horizontal line), which is approximately 0.3°, is such that adding this to the length of the “abuttor” (i.e., vertical line) would lead to an insignificant increase in the latter’s length and cannot account for the 9% increase in its perceived size (see Figure 7).

The ABC model

Predictions

Following results from the previous two experiments, we propose an elaboration of the MdM model, consisting of three components: anisotropy (**A**), abutting (**B**), and crossing (**C**). *Anisotropy* represents the overestimation of the perceived length of a vertical line compared to a horizontal one, and is identical to the MdM model. *Abutting* refers to the overestimation of the perceived length of a line, either vertical or horizontal, that has one end simply touching or abutting a second line. Lastly, *crossing* refers to the underestimation of the perceived size of a line, either vertical or horizontal, which crosses another one orthogonal to it. Table 1 illustrates predictions for the perceived size of the vertical segment in accordance with MdM’s simple model, as well as predictions derived from the new **ABC** model we propose.

According to MdM, the perceived size of the vertical segment in the horizontal T condition would be








Predictions			
Type of stimulus			
MdM			Veridical
ABC model	Veridical		

Table 1. Predictions for perceived length of vertical segment within the horizontal T, cross, and inverted T figures when compared to a comparator vertical line.

reduced compared to its actual physical size by virtue of their bisection component. On the contrary, we hypothesize that size perception of the vertical segment in such a shape would be veridical as the horizontal does not *cross* the vertical nor has it one of its ends *abutting* another line. Both models agree that the perceived size of the vertical segment in the cross condition would be reduced compared to its actual physical size by virtue of bisection. Lastly, in an inverted T configuration, MdM would predict that the perceived size of the vertical segment should be veridical as it is not bisected. On the contrary the ABC model predicts that due to the fact that one end of it abuts a horizontal line, its perceived size should be increased. Following results from Experiment 3, we predict that abutting will increase the size of a line by approximately 9%, whereas crossing would decrease the size of a line by 7%.

Stimuli were viewed binocularly from a viewing distance of 57 cm.

Design

Three conditions were interleaved; in all cases the horizontal component of a cross, an inverted T, and an L-shape was compared with one of seven comparator vertical lines, varying in size from slightly smaller to slightly longer than the standard. Both the vertical and the horizontal segments of the standard stimuli were 6.1° long. Figure 8 below illustrates the stimuli used in this experiment. Other details as in previous experiments.

Each participant undertook 840 trials; six pairs of stimuli each presented 20 times for seven comparator stimulus sizes. Participants were asked to indicate the longer line using a response box. Stimuli were presented simultaneously for 750ms. The stimuli were presented as black lines on a bright green (20cd/m²) background.

Experiment 4

This experiment investigated whether predictions derived from the ABC model are upheld. Participants were asked to compare the apparent length of a vertical to a horizontal line. We manipulated the size of an independent vertical line (comparator) which was compared against the horizontal segment (standard) of each of the three standard stimuli: a cross, an inverted T, and an L-shape. Predictions are summarized in Table 2.

Method

Subjects

Eight naïve participants, seven female (age range 18–27), participated in Experiment 4 and Experiment 5.

Stimuli

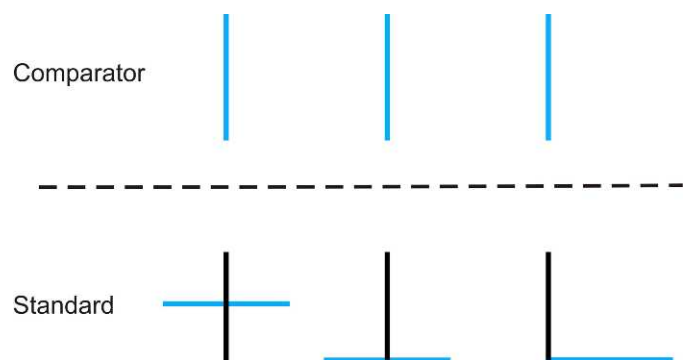


Figure 8. Stimuli used in Experiment 4. The comparator stimulus was always a vertical line located either above or below the standard stimulus.

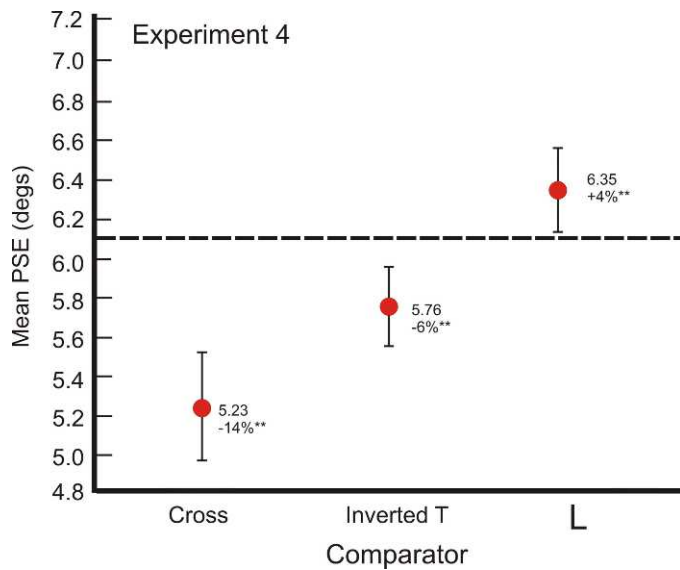


Figure 9. Results from Experiment 4 ($N = 8$), satisfying all three predictions derived from the ABC model.

Results

Results for all participants are illustrated in Figure 9. When comparing the size of a simple vertical line to the horizontal segment of a cross configuration, the mean PSE was 5.23° , and a z test revealed that this was significantly different from the actual physical size of the stimulus ($p < 0.01$). The size of this reduction was approximately 14%. For the horizontal segment of the inverted T configuration, the mean PSE was 5.76° , and a z test revealed that this was also significantly different from the actual physical size of the stimulus ($p < 0.01$). The size of this reduction was approximately 6%. Finally, the mean PSE for the horizontal segment of the L-shape was found to be 6.35° , and a z test confirmed that this was significantly different from the actual physical size of the stimulus ($p < 0.01$). The size of this increase was approximately 4%. In this experiment we looked only at the L configuration and not at both the L and its mirror image. We have previously looked at both configurations and found no significant difference between the conditions (Mikellidou & Thompson, 2011).

Experiment 5

Experiment 5 investigated the opposite conditions from Experiment 4: Participants were asked to compare the apparent length of a horizontal to a vertical component in the three figures. Predictions are summarized in Table 3.

Method

Design

Three conditions were interleaved; in all cases the vertical component of a cross, an inverted T, and an L-shape was compared with one of seven comparator horizontal lines, varying in size from slightly smaller to slightly longer than the standard and located either to the left or right of the standard. Each of nine naïve participants (seven female) were asked to indicate the longer line using a response box. All other experimental details are identical to those in Experiment 4. Figure 10 illustrates the stimuli used in this experiment.

Stimuli

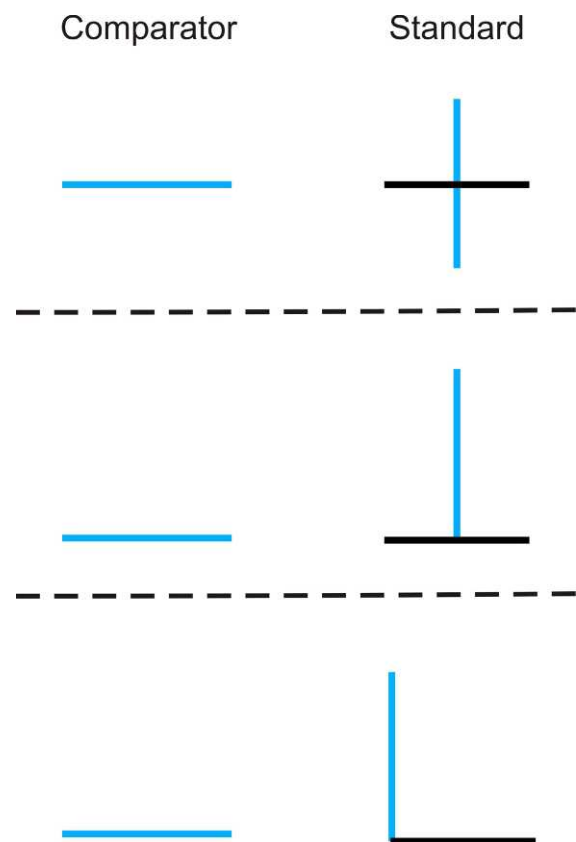


Figure 10. Stimuli used in Experiment 5. The comparator stimulus was always a horizontal line located on either the left or the right of the standard stimulus.

Results

Results for all participants are illustrated in Figure 11. When comparing the size of a simple horizontal line to the vertical segment of a cross configuration, the mean PSE was 5.98° , and a z test revealed that this result was not significantly different from the actual physical size of the stimulus ($p > .05$). The size of this reduction was approximately 2%. For the vertical







Predictions from the ABC model			
Comparator stimulus			
Standard stimulus			
Components	-A+C	-A	-A+B
Predicted size of illusion	-14%	-7%	2%

Table 2. Predictions for Experiment 4 derived from the ABC model.

segment of the inverted T configuration, the mean PSE was 6.52°, and a *z* test revealed that this increase was significantly different from the actual physical size of the stimulus ($p < 0.01$). The size of this increase was approximately 7%. Finally, the mean PSE for the vertical segment of the L-shape was found to be 6.99°, and a *z* test confirmed that this result was significantly different from the actual physical size of the stimulus ($p < 0.01$). The size of this increase was approximately 15%.

Discussion

The aim of this series of experiments was to generate a more coherent explanation for the variations of

perceived size of simple lines, either vertical or horizontal within different configurations.

Experiment 1 investigated the anisotropy component of the MdM simple model by comparing the perceived size of horizontal and vertical lines to obtain an accurate measure of the effect. In accordance with their results, this experiment showed that the perceived size of a vertical line is approximately 7% longer when compared to a horizontal of the same size. Similarly, the perceived size of a horizontal line was found to be approximately 7% shorter when compared to a vertical of the same size. This difference was found to be significant and was attributed to the difference in orientation between the two lines.

In Experiment 2, we observed no reduction in the perceived size of the horizontal segment in an inverted T configuration, due to bisection as described by MdM.







Predictions from the ABC model			
Comparator stimulus			
Type of stimulus			
Components	A+C	A+B	A+B
Predicted size of illusion	0%	16%	16%

Table 3. Predictions for Experiment 5 derived from the ABC model.

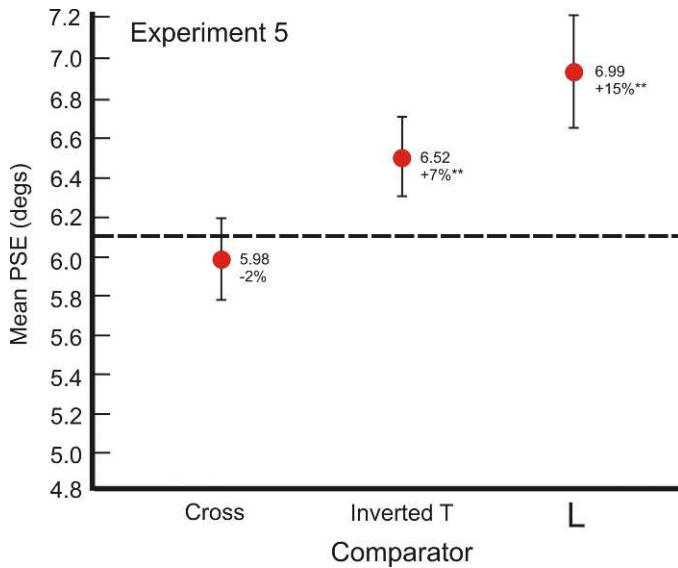


Figure 11. Results from Experiment 5, showing a significant overestimation of the perceived size of the vertical segment in an inverted T and an L-shape configuration compared to a simple vertical line by approximately 7% and 15% respectively ($N = 9$).

Subsequently, the aim of Experiment 3 was to inspect the bisection component of the vertical-horizontal illusion, as described by MdM, by comparing the vertical segment of a horizontal T, a cross, and an inverted T to an independent vertical line. It is important to remember that they considered both the horizontal segment of an inverted T as well as that of a cross configuration to be bisected by a vertical line.

Results from Experiments 2 and 3 have challenged predictions derived from the MdM model. Firstly, the definition of bisection was challenged as the perceived size of the vertical segment of the horizontal T condition was not found to be significantly different. In addition, the perceived size of the vertical segment in a cross configuration was found to be approximately 7% smaller, satisfying the qualitative nature of the MdM bisection component as there is an observed reduction in the size of the vertical line, but not doing so quantitatively as it was found to be only 7% and not 16% as expected. Finally, a significant 9% increase was observed in the perceived size of the vertical segment in an inverted T configuration. This increase could not have been accounted for by their model as they do not predict any changes in the perceived size of a line which has its one end abutting on another line.

Based on results from Experiments 1–3, we proposed an improved model to describe changes in the perceived size of lines within simple shapes. This **ABC** model consists of three components: anisotropy (**A**), abutting (**B**), and crossing (**C**). Anisotropy represents the overestimation of the perceived size of a vertical line

compared to a horizontal one by approximately 7%. Abutting refers to the overestimation of the perceived size of a line, either vertical or horizontal, that has its one end simply touching or abutting a second line by approximately 9%. Lastly, crossing describes the underestimation of the perceived size of a line, either vertical or horizontal, which crosses another one orthogonal to it by approximately 7%.

The next step was to confirm the validity of the **ABC** model by testing one or simultaneously two components in different configurations. Based on findings from previous experiments, we generated a series of predictions for each one of the three stimuli used and compared these to results from Experiments 4 and 5. In Experiment 4, the horizontal segment of a cross, an inverted T, and an L-shape was compared to an independent vertical line, and all three predictions made were confirmed by results. In Experiment 5, the vertical segment of a cross, an inverted T, and an L-shape was compared to an independent horizontal line; two out of three predictions made were confirmed qualitatively as well as quantitatively by results. These are displayed in Table 4.

Taking into account the fact that predictions involving the abutting component in an L-shape were confirmed, it is not clear why in Experiment 5 the size of the illusion in an inverted T configuration was only confirmed qualitatively and not quantitatively, failing to show an increase of approximately 16% in the perceived size of the vertical segment. It could be suggested that the size of the **B** could vary depending on the position of the vertical line relative to the horizontal. However, the size of the abutting component in Experiment 5 was estimated using an inverted T configuration.

Compared to the model proposed by MdM, the **ABC** model has provided a better explanation for the variations in perceived size of lines. That a three-component model describes data better than a two-component model is of itself not surprising, but we believe we have demonstrated that their definition of bisection was imprecise as they considered both the horizontal segment of an inverted T and that of a cross configuration to be bisected. This imprecision led them to conclude that the bisection component was a shortening of the bisected line. Present results have shown that the size of a horizontal line in a horizontal T remains veridical (where the horizontal is the abuttee) and that *truly* bisected lines exist only in the cross configuration. It is necessary to introduce the notion of an overestimation of the length of abuttees to provide a coherent explanation of our results.

The **ABC** model presented here is only a “model” in the loosest sense of the word; it provides a description of the perceived length of lines that are crossed or abutted. However, we are well aware of its limitations.













Predictions from the ABC model						
Comparator stimulus						
Standard stimulus						
Components	-A+C	-A	-A+B	A+C	A+B	A+B
Predicted size of illusion	-14%	-7%	2%	0%	16%	16%
Results from Experiments 4 & 5	-14%**	-6%**	4%**	-2%	7%**	15%**

Table 4. Summary of predictions generated based on the **ABC** model and results from Experiments 4 and 5.

For example, in the seminal paper by Wolfe, Maloney, and Tam (2005) that examined inverted T and L configurations to test perspective theories of the vertical-horizontal illusion, two results were found that we have not considered here. Firstly, in the case of the inverted T figure, they found that the point along the horizontal at which the vertical abutted it affected the size of the illusion, with the symmetrical inverted T configuration (the one we have used) giving the largest illusion. Secondly, they investigated conditions in which lines abutted a horizontal obliquely. These are both manipulations that our experiments can shed no light on. As Wolfe et al. (2005) concluded, “It is evident that currently no model can account for how the human observer will interpret two arbitrarily joined line segments in the frontoparallel plane” (p. 978). This lack remains frustratingly true, but the experiments presented here take us a little closer to this goal.

Conclusion

To conclude, we believe that the **ABC** model, which can be regarded as an extension and refinement of MDM’s model, provides a more comprehensive explanation for the perceived size of line in various configurations. The effects of **anisotropy**, **abutting**, and **bisection** were found to affect the perceived size of lines by +7%, +9%, and -7%, respectively. The **ABC** model is able to provide a coherent qualitative explanation for the variations in perceived size of lines in various configurations.

Keywords: vertical-horizontal, illusion, anisotropy, crossing, bisection, abutting, model

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Corresponding author: Kyriaki Mikellidou.

Email: kyriaki.mikellidou@for.unipi.it.

Address: Department of Translational Research on New Technologies in Medicine and Surgery, University of Pisa, Italy.

References

- Avery, G. C., & Day, R.H. (1969). Basis of the horizontal vertical illusion. *Journal of Experimental Psychology*, *81*, 376–380.
- Charras, P., & Lupianez, J. (2010). Length perception of horizontal and vertical bisected lines. *Psychological Research*, *74*, 196–206.
- Helmholtz, H. von. (1925). The monocular field of vision. In J. P. C. Southhall (Ed.), *Helmholtz’s treatise on physiological optics: The perceptions of vision* (Vol. 3, pp. 154–242). Menasha, WI: The

- Optical Society of America. (Original work published 1867).
- Künnapas, T. M. (1955). An analysis of the “vertical-horizontal illusion.” *Vision Research*, *49*(2), 134–160.
- Mamassian, P., & de Montalembert, M. (2010). A simple model of the vertical-horizontal illusion. *Vision Research*, *50*(10), 956–962.
- Mikellidou, K., & Thompson, P. (2011). Bisection and dissection of horizontal lines: The long and the short of the Oppel-Kundt illusion. *Journal of Vision*, *11*(11): 1184. [Article]
- Obonai, T. (1933). Contributions to the study of psychophysical induction: III. Experiments on the illusions of filled space. *Japanese Journal of Psychology*, *8*, 699–720.
- Oppel, J. J. (1855). Über geometrisch-optische Tauschungen [Translation: About geometric-optical illusions]. *Jahresbericht des Frankfurter Vereins, 1854–1855*, 37–47.
- Piaget, J., & Osterrieth, P. A. (1953). Recherches sur le développement des perceptions: XVII. L'évolution de l'illusion d'Oppel-Kundt en fonction de l'âge [Translation: Research on the development of perceptions: XVIII The evolution of the Oppel-Kundt illusion as a function of age]. *Archives de Psychologie*, *34*, 1–38.
- Thompson, P., & Mikellidou, K. (2011). Applying the Helmholtz illusion to fashion: horizontal stripes won't make you look fatter. *i-Perception*, *2*(1), 69–76.
- Wolfe, U., Maloney, L. T., & Tam, M. (2005). Distortions of perceived length in the frontoparallel plane: Tests of perspective theories. *Perception & Psychophysics*, *67*, 969–979.