The Effects of Distractor Orientation on the Magnitude of Length Illusion

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Introduction. Previous psychophysical examination [1] of the Brentano figures with rotating contextual flanks has yielded cosine-like changes of the illusion magnitude, and thereby confirmed the crucial point of the "centroid" approach in explanation of illusions of extent. However, according to the basic equations of the model of automatic centroid extraction [2, 3], almost a pure cosine modulation of the illusion magnitude is valid only for the tilting of a small single-dot (or single-wing) contextual flank. In the case of rotation of relatively large distractors consisting of the Müller-Lyer wings with different orientations (Fig. 1), the model calculations offer a much more sophisticated functional dependency:

$$\delta\left(w,W,\alpha,\phi\right)\cong\frac{\mu\left(\cos\left(\phi+0.5\alpha\right)\frac{1-e^{-BW^{2}\left(1+\mu\cos^{2}\left(\phi+0.5\alpha\right)\right)}}{1+\mu\cos^{2}\left(\phi+0.5\alpha\right)}+\cos\left(\phi-0.5\alpha\right)\frac{1-e^{-Bw^{2}\left(1+\mu\cos^{2}\left(\phi-0.5\alpha\right)\right)}}{1+\mu\cos^{2}\left(\phi-0.5\alpha\right)}\right)}{\sqrt{\pi B}\left(erf\left(W\sqrt{B}\right)+erf\left(w\sqrt{B}\right)\right)} \qquad (1)$$

where w and W refer to the length of the short and long wing, respectively; α and φ refer to the internal and tilt angle of the distractor, respectively; $B=0.5\sigma^{-2}$, where σ is the standard deviation of the Gaussian function of the attentional pooling window; $\mu\approx1.5$ is the empirical coefficient.

Consequently, the dependence of the centroid bias, δ on the tilt angle, φ can be considered as a superposition of two cosine functions (symmetrically shifted by $\pm0.5\alpha$ relative to φ), whose amplitudes, in turn, depend nonlinearly on the tilt angle (Fig. 2). In order to check this prediction, the present psychophysical study was performed.

Methods. The stimuli used in the experiments consisted of three sets of the Müller-Lyer wings (either symmetric or asymmetric) arranged horizontally according to the Brentano pattern; apexes of the wings were considered as terminators specifying the ends of the left and right stimulus intervals (Fig. 1). The thickness of wing-lines was 1 minute of arc (minarc), and the length of the stimuli (the distance between the lateral terminators) was 200 minarc.

In experiments, the tilt angle, φ (the independent variable) of bisectors of the lateral flanks was altered in a random fashion from 0° to 360° (the tilt angle of the central flank varied as 180° + φ) with respect to the horizontal. In the first two series of experiments, the length of the symmetric Müller-Lyer wings was fixed at 8 minarc (in the first series, the internal angle of the wings, α was 30°, and in the second one, 120°). In the third (α=30°) and fourth (α=120°)

series, the wings length was set to 30 minarc. In the fifth (α=30°) and sixth (α=120°) series, the asymmetric wings were used (W=30, and w=8 minarc).

During the experiments, the subjects were asked to manipulate the keyboard buttons to move the central Müller-Lyer wings into a position that makes both stimulus intervals perceptually equal in length; the deviation of the position of the central terminator from the physical midpoint between the lateral terminators was considered as the value of the illusion magnitude. The initial length differences between the left and right stimulus intervals were randomized and distributed evenly within a range of ±10 minarc.

The experiments were carried out in a dark room. The stimuli were presented in the center of a Sony *SDM-HS95P* monitor calibrated and gamma corrected by a Cambridge Research Systems *OptiCAL* photometer. A chin rest, and forehead support were provided to limit the head movements. The 3 mm diameter artificial pupil was used to minimize the optical aberrations. The distance between the subject's eye and the screen was 300 cm. The subjects' eyes movements were not registered and observation time was not limited.

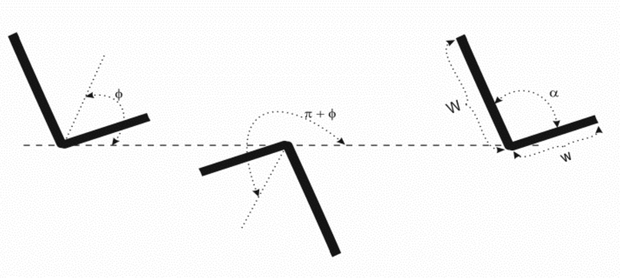

Fig. 1. Example of the stimulus used in experiments. Actual white figures (luminance 75 cd/m^2) were presented against a dark round-shaped background (5º in diameter and 0.4 cd/m^2 in luminance).

An experimental run comprised 60 stimulus presentations, i.e., 30 different values of the independent variable were taken (in a random order) twice. Ten trials went into each data point analysis, and in the data graphs, the error bars depict ± one standard error of the mean (SEM).

Two subjects were tested in the study (2 male: 35 and 52 years old). Subjects gave their informed consent before taking part in the experiments, which were performed in accordance with the ethical standards of the 1964 Helsinki Declaration.

Results and Discussion. As can be seen from the graphs (Fig. 3, upper row), for both the acute and obtuse internal angle of the short symmetric Müller-Lyer wings the experimental results showed curves rather similar to a cosine function. In the third (α=30°) and fourth (α=120°) series of experiments the length of the symmetric Müller-Lyer wings was enlarged to 30 minarc. As can be seen in Fig. 3 (middle row), for both the acute- and obtuse-angle wings the illusion magnitude diminishes to zero for vertically oriented distractors (i.e., the tilt angle approaching 90° or 270°). However, even a slight deviation from the vertical induces significant change of the illusion caused by the acute-angle wings, whereas for the obtuse-angle wings the slope of experimental curves remains close to zero for distractors inclinations within a range of about ±20°. On the contrary, the illusion magnitude varies relatively little for the near-horizontal orientation of the acute-angle distractors.

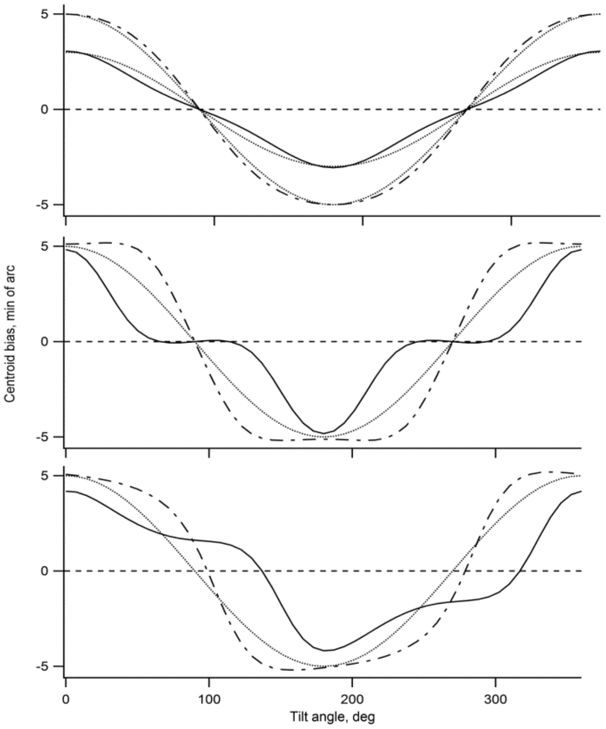

Fig. 2. Diagrams illustrating the model predictions. In calculations, the standard deviation, σ of the Gaussian function of the attentional window was equal to 10 minarc. In all graphs, dash-dot and solid curves represent the data for stimuli with the internal angle, α equal to 30° and 120°, respectively; dotted curves represent the cosine functions with appropriate amplitudes. The upper, middle, and lower graphs, tilting of the short symmetric (length 8 minarc), long symmetric (length 30 minarc), and the asymmetric Müller–Lyer wings (lengths 8 and 30 minarc), respectively.

The results from the fifth series of experiments (Fig. 3, lower row, circles) demonstrate the illusion magnitude remained almost constant within a range of about ±30° with respect to the horizontal orientation of the distractor. In the case of the rotation of the obtuse-angle wings (the sixth series of experiments), the data (Fig. 3, lower row, squares) obtained exhibit a much more complicated asymmetric shape of the experimental curves, which, nevertheless, is in a rather good agreement with that predicted by the model (Fig. 2, lower, solid curve).

In order to check the model predictions quantitatively, we have fitted the experimental data presented in Fig. 3 with the following function:

$$I(w, W, \alpha, \phi) = C + AF(w, W, \alpha, \phi, B) \qquad (2)$$

where C refers to a constant shift along the ordinate axis, and A is a coefficient of proportionality; $F(w,W,\alpha,\varphi,B)$ represents function (1) with additional argument $B=0.5\sigma^{-2}$, where σ refers to the standard deviation of the circular Gaussian profile of the attentional pooling window.

A good resemblance between the computational and experimental results was obtained (Fig. 3, solid and dash-dot curves); the values of coefficient of determination R^2 in all the cases were higher than 0.8. A more careful examination of the goodness-of-fit by statistical analysis of the data with the Shapiro-Wilk (assessment of normality of residuals) and chi-square tests has also confirmed our assumption that the results obtained are consistent with the "centroid" explanation of illusions of extent.

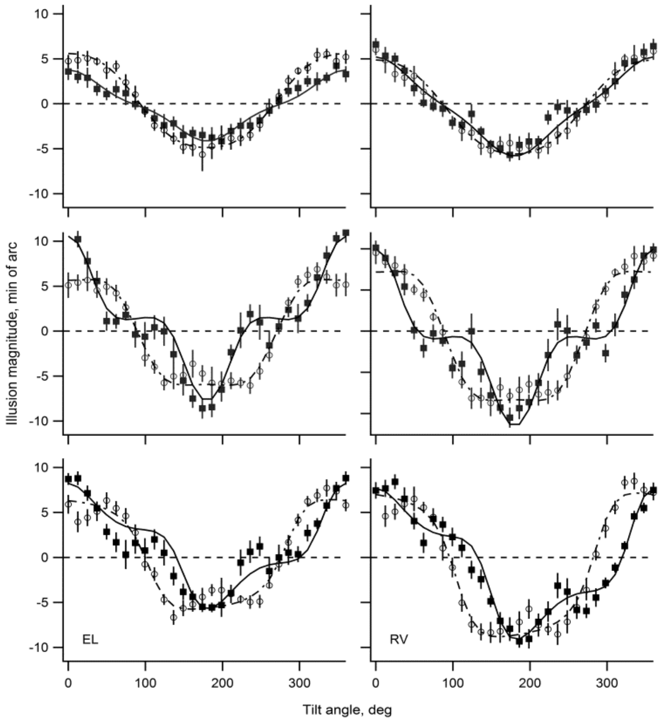

Fig. 3. The experimental results. The upper, middle, and lower rows, the data for the symmetric short, long, and the asymmetric flanks (circles, tilting of the acute- and, squares, obtuse-angle Müller–Lyer wings). Solid and dash-dot curves, the least squares fittings of Eq. 2 to the experimental data. Error bars, ± one SEM. Subjects: EL and RV.

Conclusions. A good correspondence between the experimental results and the predictions of our computational model strongly supports the suggestion that the effects of centroid extraction are powerful enough to be considered as one of the main causes of illusions of the Müller–Lyer type.

References

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The predictions of the model of automatic centroid extraction were tested in the psychophysical examinations of the Brentano figure comprising the symmetric or asymmetric Müller–Lyer wings. It was demonstrated that the model calculations properly account for all illusion magnitude variations induced by distractors' rotation. A good correspondence between the experimental and theoretical data supports the suggestion that local positional biases caused by the neural processes of automatic centroid extraction can be one of the main reasons of emergence of the Müller-Lyer and related illusions of extent.