Extraneous distractors in the Brentano illusion

A. Bulatov[1], L. Mickienė, N. Bulatova,
A. Gutauskas, J. Loginovič
Institute of Biological Systems and Genetics Research, Lithuanian University of Health Sciences, Lithuania
[1]E-mail: bulatov@vision.lsmuni.lt

Introduction. The results of a considerable number of studies of the Müller-Lyer and related illusions lead to a suggestion that the judgments of distance between visually distinguishable elements, which belong to separate clusters of elements, are strongly biased by the processes of neural computation of the centroids of the luminance distributions within the clusters. Recently, referring to the "centroid" hypothesis, we have developed a computational model of automatic centroid extraction [1 - 3] which was applied successfully to the illusory figures with contextual flanks comprising different structural elements: either the Müller-Lyer wings, or vertical stripes, or pairs of spots. It was shown that for modified Brentano figure made of separate spots, the model accurately predicted illusion magnitude alterations caused by manipulations with extraneous non-target spots positioned in close vicinity of the terminating stimulus elements [2]; however, for Brentano figures made of line segments, the question concerning the influence of manipulations with additional non-target elements remains open.

According to the model [1], the illusion magnitude for ordinary Brentano pattern (having no shaft line) comprising the Müller-Lyer wings made of line segments can be estimated by the formula:

$$I(w,\alpha) = C + A\frac{\cos(.5\alpha)\left[1 - e^{-Bw^2\left(1+\cos^2(.5\alpha)\right)}\right]}{\left[1+\cos^2(.5\alpha)\right]\sqrt{\pi B}\,erf(w\sqrt{B})}, \tag{1}$$

where w is the wing length, α is internal angle; $B = 0.5\sigma^{-2}$, where σ determines the width of the Gaussian profile of the attentional pooling window; C and A, are parameters representing the constant component and coefficient of proportionality (should be in the range, $1 \le A \le 4$), respectively.

For figure supplemented by additional wings (which vertices coincide with those of the wings of the basic figure) the illusion magnitude can be modeled as follows:

$$J(w,\alpha) = C + A\frac{\dfrac{\cos(.5\alpha)\left[1 - e^{-Bw^2\left(1+\cos^2(.5\alpha)\right)}\right]}{\left[1+\cos^2(.5\alpha)\right]} + \dfrac{\cos(.5\varphi)\left[1 - e^{-Bx^2\left(1+\cos^2(.5\varphi)\right)}\right]}{\left[1+\cos^2(.5\varphi)\right]}}{\sqrt{\pi B}\left[erf(w\sqrt{B}) + erf(x\sqrt{B})\right]}, \tag{2}$$

where x and φ are the length and internal angle of additional wings, respectively.

One can expect that manipulations with the spatial parameters (x and φ) of additional wings should affect in a systematic way the judgments of distances between the terminators (wings vertices) of the basic Brentano figure. In order to check these predictions, the present psychophysical study was performed.

Methods. Stimuli used in experiments consisted of three pairs of the Müller-Lyer wings (basic distractors) forming unchangeable illusory figure of the Brentano type (Fig. 1). The basic distractors (wings length, W = 15 min-of-arc and internal angle, α = 90° or 270°) were supplemented by additional wings (length x, and internal angle φ). Two series of experiments have been performed. In the first series, the length of additional wings, x was randomly varied from 0 to 30 min-of-arc; the internal angle, φ was fixed at 90°. In the second series of experiments, the internal angle, φ was randomly varied from 20° to 340°; wings length, x was fixed at 15 min-of-arc.

The stimuli were arranged horizontally and presented monocularly (the width of lines in the wings was 1 min-of-arc, their luminance was 75 cd/m^2) against a dark round-shaped background (4º in diameter and 0.4 cd/m^2 in luminance). The left part of the stimulus (spatial interval between the left and the central vertices of the wings) was considered to be the referential interval and the other, the test one. During the experimental runs, the subjects were asked to manipulate the keyboard buttons "←"and "→" to move the central cluster of the wings into a position that makes both stimulus intervals perceptually equal in length. The length of the figure (spatial interval between the left and the right vertices of the wings, L = 100 min-of-arc) remained unchanged.

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 400 cm. The right eye was always tested irrespective of whether or not it was the leading eye. The subjects' eyes movements were not registered and observation time was not limited.

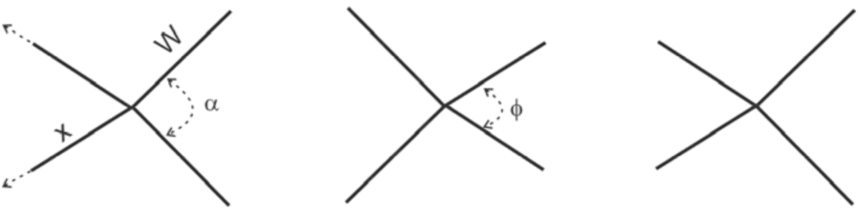

Fig. 1. Example of the Brentano stimuli composed of three clusters of basic/additional wings. W and α, the length and the internal angle of the basic wings, respectively; x and φ, the length and the internal angle of additional wings. Actual white figures (luminance 75 cd/m^2) were presented against a dark round-shaped background (4º in diameter and 0.4 cd/m^2 in luminance).

One hundred stimulus presentations were included in a single experimental run, i.e., 50 randomly distributed values of the independent variable were taken twice. A single experimental run usually lasted about half an hour. Each observer carried out at least five experimental runs on different days. Ten trials went into each data point analysis, and in the data graphs, the error bars depict ± one standard error of the mean (SEM).

Three subjects were tested in the study (1 male: 51 years old; 2 female: 21 and 44 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. The results of the first series of experiments showed significant alterations of illusion magnitude (Fig. 2. *upper*). Lengthening of additional wings within the range from 0 to about 15 min-of-arc caused gradual decreasing of absolute value of illusion magnitude. The illusion disappeared when the length of additional wings achieved that of the basic ones (15 min-of-arc), and the effects caused by two contexts counterbalanced each other. Further lengthening of additional wings caused the inversion of illusion and increasing of its magnitude to about 8 min-of-arc.

The results of the second series of experiments (Fig. 2. *lower*) also showed curves with parts comprising positive and negative values. Increasing of the internal angle of additional wings within the range from 20° to about 180° (i.e., when additional wings were situated on the same sides of the stimulus terminators compared with the basic wings) caused gradual decreasing of absolute value of the illusion magnitude. Further increasing of internal angle up to 340° caused, like in the first series of experiments, the resulting illusion corresponded to subtraction of effects caused by two contexts.

To test our model, we fitted (method of least squares) the experimental data with the function (2). Three free parameters (coefficients A, B, and C) were used for fitting. A good resemblance between the computational and experimental data was obtained (Fig. 2, *solid curves*); the values of coefficient of determination R^2 in all cases were higher than 0.9. It should be noted, that the calculated σ values are similar for both sets of independent variables used in experiments (15.8 ± 4.2 and 13.7 ± 2.6). Moreover, the values of the coefficient A are (1.7 ± 0.62 and 2.64 ± 0.71) in the range, $1 \leq A \leq 4$, predicted by the modeling. Thus, a success in fitting strongly supports the "centroid" concept, and we believe that the effects of centroid extraction are powerful enough to be considered as one of the main causes of the illusion investigated.

Conclusions. The model accurately predicted illusion magnitude alterations caused by manipulations with additional non-target stimulus elements, closely matching the data we collected in psychophysical experiments. Such a result is consistent with the suggestion on the local positional shifts of stimulus terminators as a reason of emergence of illusions of extent.

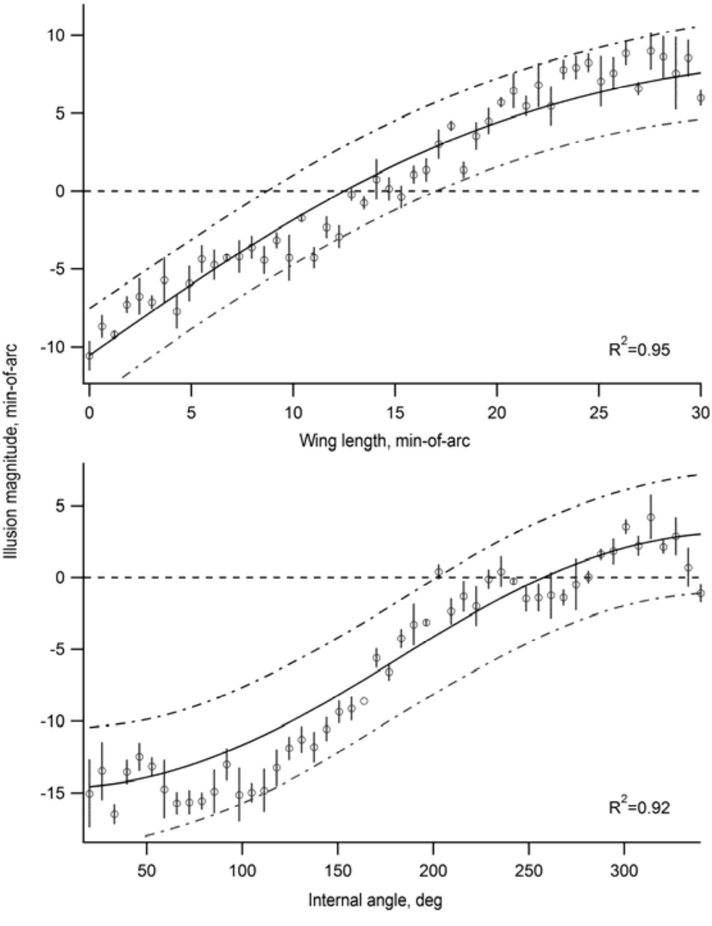

Fig. 2. Magnitude of illusion as a function of the length (*upper*) and the internal angle (*lower*) of additional wings. *Circles*, averaged experimental data for all three subjects; *error bars*, ± one standard error of the mean (SEM); *solid curves*, the least squares fitting by function (2); length of the stimulus, 100 min-of-arc; length and internal angle of the wings of the base figure, 15 min-of-arc and 90° (270°), respectively; *dashed-dotted curves*, confidence intervals (95%) of fitting.

References

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Institute of Biological Systems and Genetics Research, Lithuanian University of Health Sciences, Lithuania

The present study is concerned with a possible role of local positional shifts of the stimuli terminators in the occurrence of the illusions of extent. The data of the psychophysical experiments demonstrated that the results obtained for the Brentano figures supplemented by extraneous Müller-Lyer wings are compatible with predictions of our computational model of automatic centroid extraction.