POSITIONAL SHIFTS IN THE VISUAL ILLUSIONS OF EXTENT

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Abstract

The present communication addresses a possible role of the perceptual position shifts of the stimulus parts in Brentano's illusion and related illusions of extent. The results of the present psychophysical experiments with detached Müller–Lyer wings are discussed in relation to the findings of some recent studies of full versions of illusory figures. It is shown that the effects obtained strongly support the "centroid" explanation of illusions investigated.

According to explanation proposed by Morgan et al. (1990), the geometric illusions of extent of the Müller–Lyer type occur because the visual system fails to isolate the figure terminators (shaft end-points, or wings apexes) from the neighboring contextual flanks (wings themselves), and the judgments of the distances between the figure's terminators are biased toward the distances between the centroids of the adjacent flanks. Thus, the crucial point of the explanation is that it implies the perceptual positional shifts of the stimulus terminators in direction of centers-of-masses of the flanks. Recently, referring to the "centroid" hypothesis, a computational model of automatic centroid extraction has been developed and successfully applied (Bulatov et al., 2009, 2010) to account the data obtained in experiments with full versions of illusory figures of the Brentano type; however, the issue concerning the manifestation of positional shifts for a single wings set remains unclear.

In order to move forward in solving the problem and check the basic assumption of the "centroid" explanation of illusions of extent the present psychophysical study with detached Müller–Lyer wings was performed.

Method

Stimuli used in experiments (Fig.1) consisted of the Müller–Lyer wings with apex coinciding with the horizontal axis of an imaginary rectangle (width and height were fixed at 50 and 62.5 *min of arc*, respectively) formed by four reference circles (radius, 5 *min of arc*). During the experimental runs, the subjects were asked to manipulate the keyboard buttons "←"and "→" to displace simultaneously all the reference circles into a position that makes apex of the wings appeared at the rectangle center. Two series of experiments have been performed. In the first series, the internal angle of the wings (bisector orientation 0°; wing length, 8 *min of arc*) was randomly varied from 0° to 360° by the 9.2° steps. In the second series, the length of the wings (internal angle 90°) varied from -12.5 to 12.5 min of arc (negative value means 180° orientation of bisector of internal angle of wings).

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 were asked to stare at the wings apex; however, eye movements were not registered and observation time was not limited.

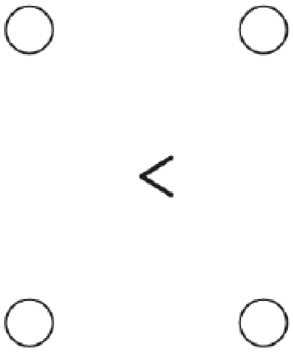

Fig. 1. Inverted version of the stimulus used in experiments. Actual white line drawings (luminance 75 cd/m^2) were presented against a dark round-shaped background (4° in diameter and 0.4 cd/m^2 in luminance).

Eighty stimulus presentations were included in a single experimental run, i.e., 40 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).

Two subjects (LE - normally sighted and NC - wearing usual optical corrections) were tested in the study. 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.

The experimental data were fitted with the function derived in our previous modeling of the procedure of centroid extraction (Bulatov et al., 2009):

$$\tau(w,\alpha) = A\cos(0.5\alpha)\frac{1-e^{-Bw^2[1+\cos(0.5\alpha)^2]}}{[1+\cos(0.5\alpha)^2]\sqrt{\pi B}\,\mathrm{erf}(w\sqrt{B})} + C \qquad (1)$$

where τ is the positional shift; w is the wing length; α, the internal angle of the wings; A, $B = 1/2\sigma^2$, and C are free parameters representing coefficient of proportionality, the width of the Gaussian profile of corresponding attentional pooling window (area of centroid extraction), and bias along ordinate axis, respectively. To fit the data, the method of least squares was used.

Results and Discussion

The magnitude of positional shift as function of the internal angle of the wings for both observers showed near symmetrical curves (similar to a cosine) with two parts comprising positive and negative values (Fig. 2, *left*). The dependencies gained their largest values for internal angles in ranges about 0° - 120° and 240° - 360°. When the internal angle approached 180°, the positional shifts decreased to zero.

Fitting the data with function (1) provides a good correspondence between the computational and experimental results (coefficient of determination R^2: 0.98 and 0.97 for subjects LE and NC, respectively). Thus, the computational model of centroid extraction appeared to be applicable to predict both the shape of experimental curves as an approximate cosine, and the deviations from the cosine law within a certain range of internal angles of the wings. The value of coefficient of proportionality *A* (0.97±0.47 and 0.94±0.43 for subjects LE and NC, respectively) demonstrates also that the calculated effect of centroid biases is powerful enough to account the perceptual positional shifts obtained experimentally.

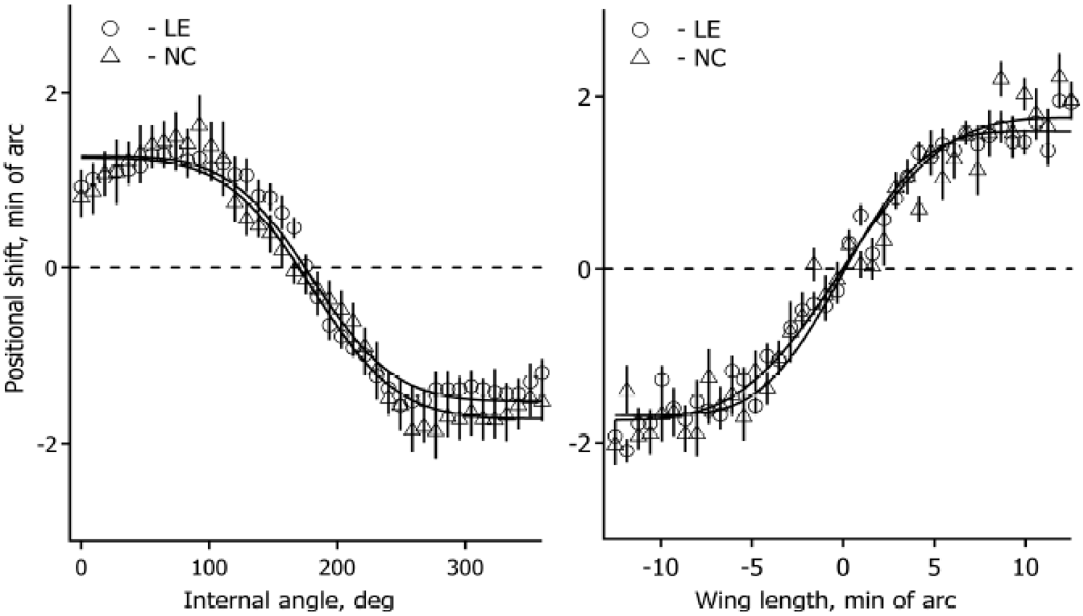

Fig. 2. The positional shift as functions of the internal angle (*left*) and length (*right*) of the wings for subjects LE (*circles*) and NC (*triangles*). *Solid curves* – fitting results.

The fitting parameters provide quantitative estimation of width of area of centroid extraction (3.54±0.97 and 3.85±1.23 for subjects LE and NC, respectively). Such the values are consistent with that (about 3 - 5 *min of arc*) estimated for the central part of *fovea* in experiments with full versions of illusory figures (Bulatov et al., 2009).

The dependencies obtained in the second series of experiments showed a monotonic growth of the positional shift magnitude with increase of the length of the wings from 0 to about ±5 *min of arc* (Fig. 2, *right*). For the larger lengths of the wings a certain tendency to saturation can be seen. Fitting the data with function (1), as well as in previous case demonstrates a good resemblance between the theoretical and experimental results (coefficient of determination R^2: 0.98 and 0.95 for subjects LE and NC, respectively). It should be noticed, also, that the evaluated widths of attentional windows (5.1±0.95 and 4.1±1.43 for subjects LE and NC, respectively) and the value of coefficient of proportionality *A* (0.9±0.12 and 1.06±0.25 for subjects LE and NC, respectively) do not differ dramatically from that obtained in fitting the data of the first series of experiments.

Interpretation of the experimental data for full versions of illusory figures (Bulatov et al., 2009, 2010, 2011) was associated with the inevitable uncertainty. The stimuli used in the study consisted of three contextual flanks located differently relative to *fovea* center, thus, the positional shift of each stimulus terminator could not be established separately and its contribution to overall illusion magnitude remained unknown. Therefore, for simplicity, the illusion magnitude was considered as a result of the weighted summation of individual effects induced by each contextual flank (an averaged individual effect multiplied by a certain coefficient of proportionality, *A*, that should not exceed 4). In the present study, to diminish uncertainty single distracter stimuli were used. The parameters obtained in fitting of present data are concordant with that established by regression analysis in previous studies of full versions of illusions of the Brentano type: the value of coefficient *A* is near to 1 (the calculated effect of centroid bias adequately accounts the positional shift evoked by a single wings set), and the width of area of centroid extraction is in a range from 3 to 5 *min of arc* (observers hold their gaze fixated on a distracter).

Neither previous experiments with full versions of the Brentano figures nor the present study with detached Müller–Lyer wings do not allow to determine certainly whether the same high-level neural mechanisms are involved in performance such the different visual tasks – comparison of stimulus parts lengths and assessment of positional displacement of a single wings set. It is possible also that in both these cases the mechanism of image symmetry evaluation could be used. However, the success in application of the same computational approach in explanation of different experimental data strongly supports suggestion that the observers misjudgments in both studies are determined by the same reason, namely by the distortion of the positional information (positional shifts) which occurs at relatively low levels of the visual processing. Although the positional shifts may occur due to various cues in objects' luminance profiles (e.g., the peaks, or points of inflexion, or zero crossings) which can be used by the visual system in determining the relative positions of the objects (McGraw et al., 2003; Morgan, 2010), the procedure of centroid extraction seems to be most biologically substantiated since it allows fast and reliable assessment of the location of the visual object as whole, irrespective of its size, the shape complexity and illumination conditions. Certainly, the procedure of centroid extraction is associated with integration (positional pooling) of neural activity evoked by the neighboring parts of images and, therefore, coarsens the spatial resolution. However, the advantages offered by such the mechanism considerably outweigh the losses in the positional acuity that manifest themselves in the form of illusions of extent. In other words, the illusion occurs as a side-effect due to necessarily low spatial resolution of the neural mechanism responsible for assessment of the relative location of objects in the visual field.

Conclusions

Good correspondences between the computational and experimental data obtained in the present study have provided evidence that the side-effects of indirect positional coding *via* centroids are powerful enough to be considered as one of the main causes for geometric illusions of the Brentano type.

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