Additivity effects in the visual illusions of extent

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Introduction. The results of a number of studies of the geometric illusions of extent (identical spatial intervals flanked by different contextual objects appear to be different in size) lead to a suggestion that the perceived distortions of length may be caused by the local positional shifts of the stimuli terminators (i.e., items designating the ends of spatial intervals). Applying the concept of centroid biases to the Müller-Lyer and similar illusions of extent, Morgan et al. [3] argued that due to the processes of spatial integration the visual system fails to isolate the figure terminators from the neighbouring contextual flanks (distracters), therefore, the judgments of the distances between the terminators are biased toward the distances between the centroids of the adjacent flanks. Recently, in order to account for the data obtained in experiments with different variants of illusory figures of the Müller-Lyer type, a quantitative model of centroid extraction has been developed [1, 2]. The crucial point of the model implies the summation of contributions from each contextual distractor, thus, the illusion magnitude for stimuli comprised three clusters of contextual flanks and terminators (full version of illusory figure) can be estimated by the formula:

\[
\Delta = (0.5T + \tau_R + \tau_C) - (0.5T - \tau_L - \tau_C) = \tau_L + \tau_R + 2\tau_C
\]

where \(\tau_L\), \(\tau_C\), and \(\tau_R\) are the perceptual positional shifts of the left, central, and right stimulus terminators, respectively; \(T\) is the stimulus length, i.e., the distance between the left and right terminators.

Consequently, it can be assumed that the results obtained for stimuli with reduced number of contextual flanks (either one or two) should commensurate, when summed, with the magnitude of the illusion derived from judgments of extent for full versions of the illusory figures. In order to check this assumption the present psychophysical study was performed.

Methods. Stimuli used in experiments consisted of three base spots (terminators) supplemented by contextual vertical stripes (distracters), thus, forming illusory figures of the Brentano type; in three different series of experiments either one stripe (left, central, or right; Fig. 1 A), pairs of stripes (left-central, right-central, or left-right; Fig. 1 B), or three stripes (Fig. 1 C) were presented.

Horizontally arranged stimuli were presented monocularly (spots were 2 min-of-arc in diameter and the stripes were 2 min-of-arc thick, luminance 75 cd/m²) against a dark round-shaped background (4º in diameter and 0.4 cd/m² in luminance). The left part of the stimulus (spatial interval between the left and the central spot) 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 right terminator (with adjacent stripe, if presented) into a position that makes both stimulus intervals perceptually equal in length. In experiments, the length of the referential interval (75 min-of-arc) and the stripe height (30 min-of-arc) remained unchanged. The independent variable, the gap between the spots and stripes, was randomly varied within a range of ± 30 min-of-arc.

![Fig. 1. Examples of stimuli. In different series of experiments one (A), two (B), or three (C) distracting stripes were used. Actual white figures (luminance 75 cd/m²) were presented against a dark round-shaped background (4° in diameter and 0.4 cd/m² in luminance).](image)

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.

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).

Four subjects were tested in the study (2 male: 21 and 50 years old; 2 female: 22 and 43 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 are shown in Fig. 2A. It can be seen that in all cases (i.e., for the left, central, or right stripe) the illusion magnitude slightly varied with the size of the gaps
between spots and distracting stripes. For the stripes positioned inside of the referential interval (negative values of the gap) its length was underestimated, whereas the outside stripes, conversely, induced an overestimation.

Fig. 2. Magnitude of illusion as a function of the gap size (averaged data for all four subjects). In A, illusion caused by a single stripe: the left (○), central (□), and right (Δ). In B, illusion caused by pairs of stripes: left-central (○), right-central (□), and left-right (Δ). In C, the data for the three-stripe figure (●), and the results of summation of curves taken from A (□), and from B (Δ). Vertical lines, SEM. In D, the results of Welch’s t-test comparison for the data taken from C: between the three- and single-stripe curves (○), and between the three- and double-stripe curves (□).
This common regularity is far more noticeable in Fig. 2 B, where the results of the second series of experiments are presented. In all cases (i.e., for the left-central, right-central, or left-right pairs of stripes), the magnitude of illusion showed curves with parts comprising positive and negative values. The absolute value of the illusion magnitude increased with growing of the gap up to about 8-10 min-of-arc, gained its maximum (approximately 2 - 3 min-of-arc) and monotonously diminished with further increase of the gap.

In order to compare whether the results obtained for stimuli with reduced number of contextual flanks are commensurate, when summed, with the magnitude of the illusion derived from judgments of extent for full version of the illusory figure, the data from the third series of experiments (Fig. 2 C, marker ●) are presented against the results of summation of curves taken from Fig. 2 A and from Fig. 2 B (Fig. 2 C, markers □ and Δ, respectively).

As can be seen in Fig. 2 D, Welch’s t-test at each point along the range of the independent variable revealed no significant differences (p-value >> 0.05) between the data obtained in experiments with the three-stripe figure (Fig. 2 C, marker ●) and the results of summation for single-stripe (Fig. 2 C, marker □) or double-stripe (Fig. 2 C, marker Δ) figures. Consequently, one can conclude that the results obtained are consistent with the “centroid” explanation of illusions of extent which implies additivity of contributions from each contextual distracter.

Conclusions. The data obtained in the present study support the suggestion that the side-effects of processes of centroid extraction can be considered as one of the main causes of the geometric illusions of extent.

References

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The present communication 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 illusory figures comprising reduced number of contextual flanks are commensurate, when summed, with illusion’s magnitude for full version of stimuli.