INFLUENCE OF DISTRACTER ON PERCEIVED STIMULUS LENGTH AND ANGLE SIZE*

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This study describes experiments in which subjects adjusted the spatial positions of spots in three different kinds of basic stimuli in order to best perceive a required spatial property: 1) vernier alignment in a three-spot line arrangement, 2) orthogonality in a right-angled triangle constructed of three spots, or 3) length equality in a Brentano type figure. The magnitudes of the perceptual errors were measured as functions of the distance between the spots and flanking objects placed in close proximity to the spot stimuli. Quantitative characteristics of the strengths of the different illusions were obtained with the flanking objects placed at varying extents of spatial separation. The data were interpreted in terms of centroid biases caused by local integration processes. An appropriate analytical description of the experimental data was proposed, and a good correspondence between it and the data was obtained. The calculated spatial parameters of the local lateral integration showed a linear dependence on the stimulus size.

Key words: *illusions of alignment, right angle and linear extent, contextual flanks, local integration, centroid bias.*

Introduction

This paper deals with an experimental study of a small group of simple *geometrical-optical* illusions generated by stimuli composed of spots and short line segments. In the stimuli drawings (see Figure 1 a–c), a specific perceived metric property of the stimulus – 1) alignment, 2) orthogonality, or 3) linear extent – can be distorted by the presence of an additional flanking line or dot stimuli. These perceptual errors, which are induced by the presence of distracters in a close proximity to

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the constituent spot stimuli, are stable, reproducible and consistent across a number of observers.

We have measured the magnitudes of the three illusions as functions of the stimulus spatial parameters and, using these quantitative characteristics, we have considered the interrelations among them. We have explored the mechanisms of their generation in relation to the *center of gravity* concept, initially suggested by C. H. Judd (1905) & others (Festinger et al., 1968; Erlebacher & Seculer, 1969; Kaufman & Richards, 1969; Virsu, 1971; Coren & Hoening, 1972). This was subsequently the basis for the *centroid biases concept* (Morgan and Casco, 1990; Morgan et al., 1990). According to this idea, the visual system utilizes indirect position coding via centroids of the response of "eclectic" units with large aggregate receptive fields. Such a coarse coding yields misjudgment of the local position of an element within a cluster of elements. In order to examine positional coding via this concept of centroids, we have performed a psychophysical study of the distortions of perceived alignment, orthogonality and length matching by using the stimuli in which the basic spots and accompanying contextual objects may be considered as the clusters (Figure 1). We go on to suggest a model for experimental data based on calculations of centroid biases in these clusters.

Methods

Stimuli

Three types of illusory stimuli (Figure 1 A–C) which were composed of spots and short line segments (types 1 and 2) or combined of spots only (type 3) were used in the experiments. The first stimulus type comprised three spots arranged either vertically or horizontally, and the observers made judgments regarding the alignment of the spots in the presence of flanking line distracter stimuli (Figure 1A). In the second stimulus type the three spots were arranged in the form of a right-angled triangle. Observers were required to make judgments as to whether the 'right-angle' of the triangle was perceived as being either greater or smaller that 90° in the presence of line distracters oriented vertically, horizontally and at 45° (see

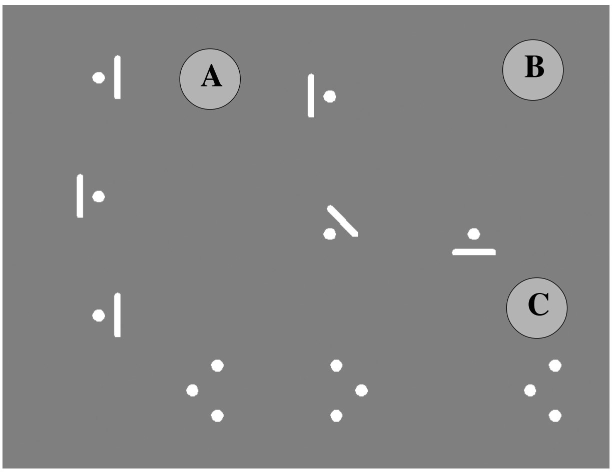

Figure 1. ***Facsimiles of the illusory three-spot stimuli used: imaginary line (type 1), right angle (type 2), and interpolated Brentano figure (type 3).***

Figure 1B). In the third kind of stimulus, observers were required to match the perceived linear extent of an interpolated Bretano type stimulus (Figure 1C).

All visual stimuli were presented on a Sony SDM-HS95P monitor placed at a distance of 400 cm from the observers. The stimuli were presented monocularly and centrally on a circular background 4° in diameter. Background luminance was 0.4 cd/m^2 and the spot and stripe stimuli had a luminance of 75 cd/m^2. Spot diameter and stripe width were set at 1.5 min of arc. The monitor was calibrated and gamma corrected using a Cambridge Research Systems OptiCAL photometer.

The observer's head movements were limited by a chin holder, and an artificial pupil with a diameter of 3 mm was used to minimize the optical deformations. The experiments were conducted under control of computer software of the authors' design. The program arranged the order of the stimuli, presented them on the monitor, introduced alterations according to the subject's command, and recorded the subject's responses. For stimuli drawings, the Microsoft GDI+ antialiasing technique was applied.

Procedure

The method of adjustment was used to establish the functional dependence of the illusion strength on the spatial parameters of the stimuli. Biases of the judgment criteria – an inherent characteristic of the method – were reduced by randomizing stimuli with different parameters in the presentation sequence.

The experiments were carried out in a darkened room, and the subjects were asked to adjust one or two basic spots of the stimulus into positions that enabled them to perceive the required spatial property of the interpolated pattern: alignment, 90° angle, or length equality. The subjects manipulated the keyboard buttons varying one or two spot positions in the required directions one pixel at a time (1 pixel = 0.25 min of arc). The initial positions of the spots were randomized and distributed evenly within a range of ± 5 min of arc. While the spot position was manipulated, the flanking objects' shape, size, and distance did not vary. The subjects were given no instructions concerning their eye fixations in Experiments 1 and 2. However, in Experiment 3 the subjects were asked to stare at a fixation spot (diameter = 3 min of arc, luminance = 75 cd/m^2) placed 25 min of arc above the central spot of the stimulus. Observation time was effectively unlimited. The errors made by the observers were considered as the values of the illusion strength. For each set of an independent variable, they carried out at least 10 experimental runs on different days, i.e. 10 trials were included in each data point analysis.

Subjects

A total of 27 observers, recruited from local university teachers and students, took part in the study. All the participants were normally sighted or were wearing their usual optical corrections. Twenty-two of the subjects were naive with respect to the goals of the study, and all gave their informed consent before taking part in the experiments which were performed in accordance with the ethical standards of the 1964 Helsinki Declaration.

Experiment 1

Method

The objective of Experiment 1 was to measure the strength of the perceived distortions in alignment as a function of the distance between the stimulus spots and the distracting stripes (stimulus type 1). The subjects adjusted the middle spot into a position which made all three spots to form an imaginary line. The stimulus orientation was 0° or 90°; its half length, 60 min of arc; the stripe length, 3 min of arc. The six subjects who participated in the experiments gave qualitatively similar results.

Results

Participants of this experiment reported a misalignment of the three-spot stimulus when the positions of spots physically form of a straight line and the accompanying stripes were displayed at some distance apart. The data are shown in Figure 2 and indicate that the illusion is not present when the positions of the stripes coincide with those of the spots. The illusion is present irrespective of the stripe flanking side and reaches its maximum at about 5 to 8 min of arc of the gap size, beyond which it gradually decreases to zero. Similar, symmetrical results were obtained for the horizontal and vertical stimulus orientations, and the data demonstrate the limits of the distance of the perceptual action of the distracting stripes.

Discussion

The quantitative characteristics of the misalignment illusion (Figure 2) reveal the presence of the local processes of lateral interactions within proximal surroundings of the stimulus terminator spots. The surroundings may be defined as patches of perceptual influence, which could be referred to the large aggregate receptive fields. We assume that a weighted spatial pooling is performed over each patch of influence. We interpret the pooling as a multiplication of the neural excitations evoked by a single stimulus spot and its flank by the weighting profile of the patch. Afterwards, a convolution procedure enables to define the position of the pooling centroid (see General Discussion for a formal treatment of this approach). Since the position of the centroid is identified with the

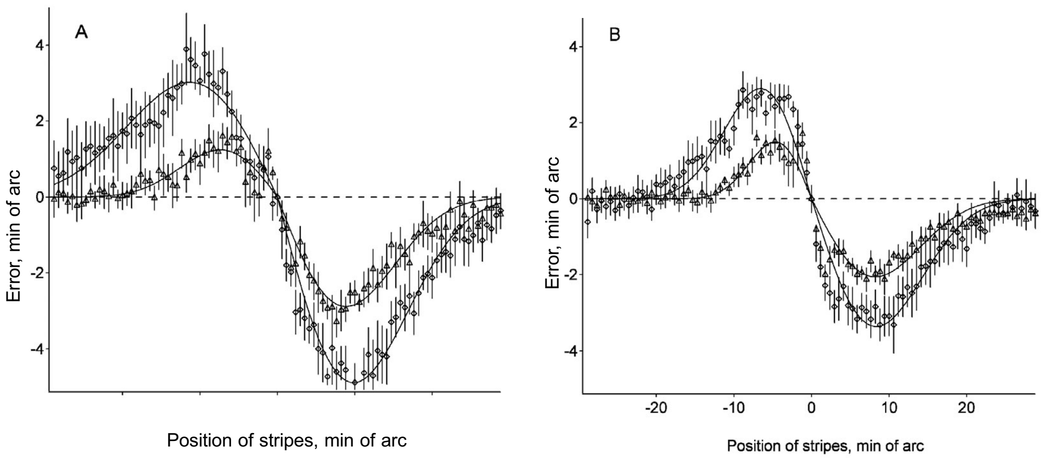

Figure 2. ***Illusion of straightness as a function of the distance between the basic stimulus spots and flanking stripes. Diamonds and*** **triangles** ***represent the data for observers ER and UL, respectively.***
Error bars, ***± one standard error of the mean (SEM). The vertical stimulus orientation in A; the horizontal orientation in B.*** **Solid lines,** ***the least squares fitting by equation (3). The coefficient of determination*** R^2 ***in A: 0.898 and 0.953 and in B: 0.828 and 0.902 for ER and UL, respectively.***

position of the stimulus spot, a perceptual shift of the spot position in the visual field occurs. The perceived contrariwise shifts of the three stimulus spots cause illusory percept of the shape of the interpolated line: the straight line perceptually turns to the curved one. In the following experiment, we go on measuring distortions in the perception of the orthogonal orientations caused by the flanking stripes.

Experiment 2

Method

A right-angle stimulus was formed by three spots (type 2) displayed in a shape of an imaginary triangle with the orthogonal orientations of two sides equal in length (30, 60, or 90 min of arc). Two flanking stripes at the end-spots were oriented in parallel with the imaginary sides; the third stripe at the middle spot was at 45° to the vertical (see Fig. 1 B). When the middle flank was inside the stimulus, the other two were outside, and vice versa. The stripes were 2.5, 5.0, or 7.5 min of arc long, in correspondence to the side length. The stripe-to-spot gap varied within the 25 *min of arc* limits in the 0.5 *min of arc* steps with a random distribution during the experiment. For each distance value, the subjects estimated the interpolated angle size and changed it by adjusting the two end-spots simultaneously and symmetrically into positions that made the angle sides to appear orthogonal. The subjects varied the angle size in a series of 0.2° steps. Twenty-two subjects participated in the experiment, and two of them (ER, UL) participated also in Experiment 1.

Results

The distortions of the right angle perception, caused by the flanking stripes, are shown in Figure 3 and are greater in amplitude (10–15 min of arc) compared to those obtained in the perceived alignment task. Similarly to Experiment 1, the curves show a rather simple regularity in growth of the illusion strength up to maximum when the stripe-to-spot distance increases on either side of the spots, and a gradual diminution of the illusion with the further increase of the distance. The illusion strength is dependent on the stimulus size (Figure 3). The illusion maximum value and its position on the curves linearly increase with increasing the length of the sides of the interpolated angle (Figure 4).

Discussion

The quantitative characteristics of the distortions of the right angle perception (Figure 3) are consistent with the idea of patches of the perceptual influence or centroid biases. The positions of three centroids cause perceptual shifts of positions of the three stimulus spots and lead to the resulting distortion of the perceived size of the angle. When the apex flank is inside the right angle area and the rest two flanks are outside, an acute angle is judged; in the opposite case when the flanks are inside, an obtuse angle is reported by the observers.

Experiment 3

Method

The perceived distortions of linear extent in the stimulus parts were measured using the interpolated Brentano stimulus formed by identical spot elements (Figure 1 C). The base of the stimulus comprised three spots which served as terminators for two spatial intervals lined up horizontally side by side. One of the intervals was considered to be the reference,

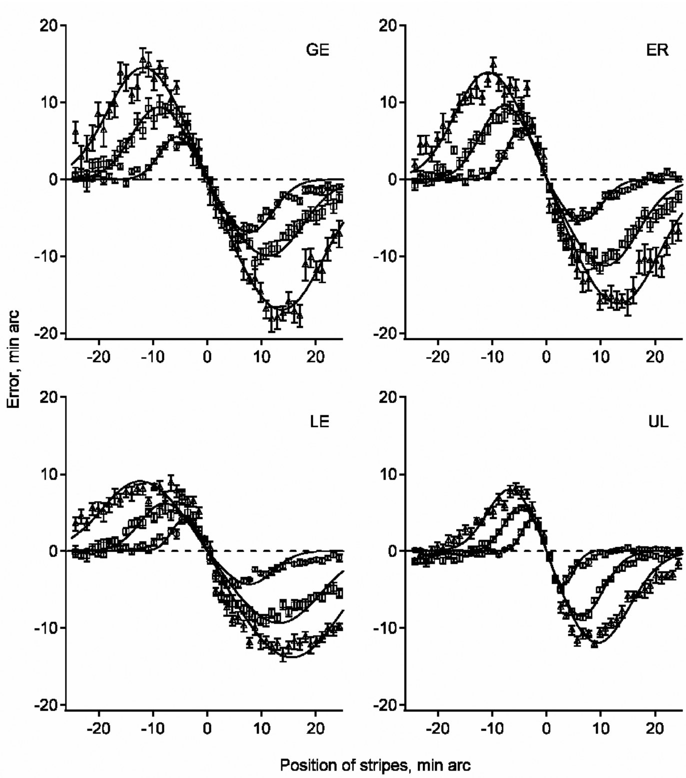

Figure 3. ***Illusion of orthogonal orientations as a function of the distance between the stimulus spots and flanking stripes for four subjects.*** **Circles,** **squares,** ***and*** **triangles** ***represent the data for the right angle stimuli different in side length: 43, 86, and 129*** **min of arc,** ***respectively.*** **Error bars,** **±** ***one standard error of the mean (SEM).*** **Solid lines,** ***the least squares fitting by equation (3). Coefficient of determination*** R^2***: 0.933, 0.969, 0.983 (GE); 0.943, 0.954, 0.97 (ER); 0.839, 0.939, 0.96 (LE); 0.923, 0.96, 0.939 (UL) for the right angle stimuli different in side length 43, 86 and 129 min of arc, respectively.***

and the other as the test. For each central spot, flanking pairs of spots placed above and below the horizontal mid-line formed the distracters, the imaginary wings.

The subjects estimated the horizontal length of the two stimulus intervals and made them appear equal by moving a single cluster of the spots to the right or to the left. After the perceptual equality was achieved, a judgement error was estimated as a physical difference between the reference and test intervals in length. The errors of the length judgment were measured as functions of the length of the wings, *w*, which varied from 0 to 20 min of arc in 0.5 min of arc steps. The internal angle of the wings, α, was fixed at 90º. The stimulus varied in size: the length of the referent part was 32, 64, or 96 min of arc. Observer eye movements were minimized by instructing the subjects to fix on a spot placed 25 min of arc above the central spot of the stimulus. Three subjects participated in the experiments, two of them (ER and UL) also participated in Experiments 1 and 2.

Results

The data obtained (Figure 5A) are similar to

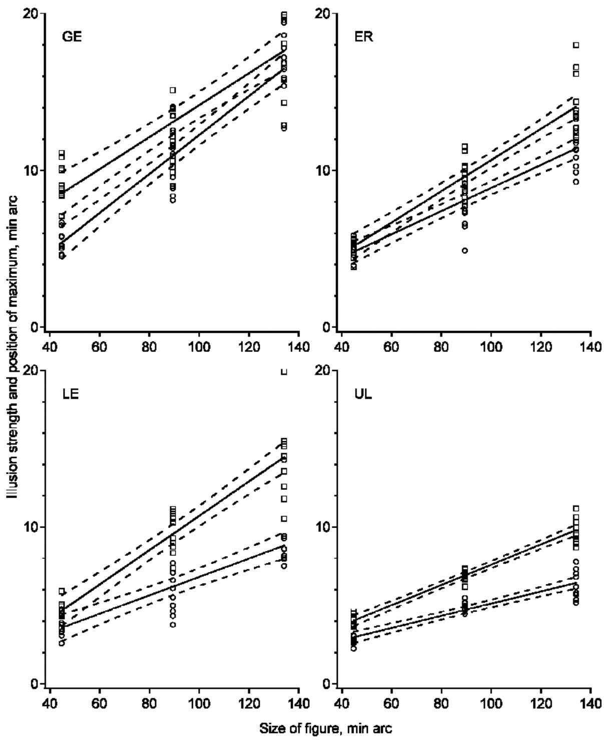

Figure 4. ***Illusion of orthogonal orientations: maximum value and position as functions of the size of the stimuli,*** **lower** ***and*** **upper lines*****, respectively.*** **Dashed lines*****, 95% prediction bounds.***

those of the two previous experiments, and the magnitudes of the distortions are similar to those found in Experiment 2. The illusion strength changes as a function of the wing length, reaching a maximum then gradually decreasing. These data also support the explanation of the origin of distortions by the local integration processes within the proximal surroundings of the stimulus parts and by a perceptual shift of the positions of the stimulus basic spots toward the flanking spot pairs. The perceived shifts of the three basic spots cause underestimation of the length of the stimulus interval with the flanks-in and overestimation of the length of the interval with the flanks-out.

Discussion

The experimental data show that the maximum value of the illusion depends on the stimulus size (Figure 5A). The stimulus size changes are exclusively determined by varying positions of the lateral basic spots of the stimulus in relation to the fixation spot, i.e. by the retinal eccentricity. Analysis of the experimental data shows a linear dependence of the maximum value and the width of the pooling patch on the retinal eccentricity (Figure 5B). It is known that the linear scaling is related to the linearity of the inverse value of the cortical magnification factor due to logarithmic mapping between the retina and the striate cortex (Schwartz, 1980;

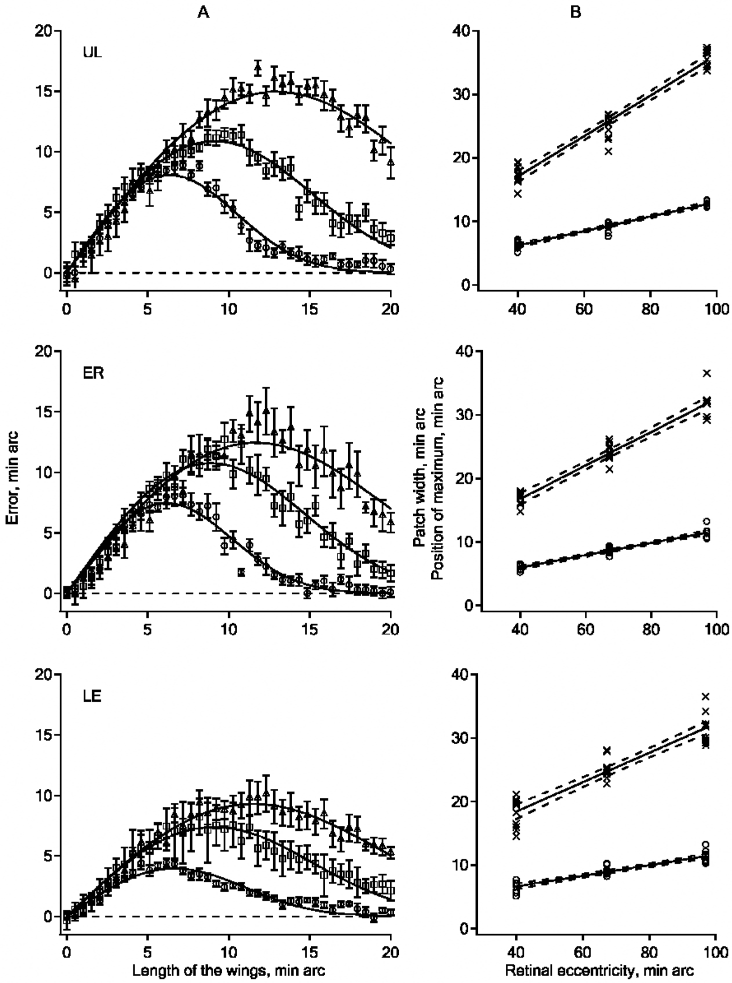

Figure 5. ***Illusion of extent as a function of the length of the wings (*****w*****) for three subjects. In*** *A:* **circles, squares,** ***and*** **triangles** ***represent the data for the stimulus referential part different in length: 32, 64, and 96*** **min of arc,** ***respectively.*** **Error bars,** ***± one standard error of the mean (SEM).*** **Solid lines,** ***the least squares fitting by equation (2). In*** *B:* ***position of the illusion maximum and width of the pooling patch as functions of the retinal eccentricity,*** **lower lines** ***and*** **upper lines,** ***respectively. The width includes three standard deviations*** ó ***on either side of the mean.*** **Dashed lines,** ***95% prediction bounds. The coefficient of determination*** R^2: ***0.976, 0.955, 0.952 (UL); 0.942, 0.950, 0.947 (ER); 0.944, 0.943, 0.918 (LE) for the stimulus referential part length, 32, 64 and 96 min of arc, respectively.***

Letelier & Varela, 1984; Polimeni et al., 2006). Consequently, the parameters of the linear scaling obtained in Experiment 3 (also in Experiment 2) can refer to the invariant scale of the integrative procedures across the cortex.

General Discussion

We propose an analytical description of our experimental data. The calculations are based on the following statement: if mass M_a at $x = X$ is added to mass M at $x = 0$, the position of the centroid of the resulting system is defined by the equation

$$\Delta(X) = \frac{XM_a}{M+M_a} = X\frac{m}{1+m}, \qquad (1)$$

where the normalized *mass* (m) = M_a/M; in the present approach, *mass* is considered as an amplitude of the neural excitation proportional to the luminance amplitude.

A hypothetical mechanism determining the centroid position, $\Delta(X)$, can be assembled of the summation units with the linear weighting profiles. Convolution of the weighting profile with the function of the distribution of mass yields the centroid position which corresponds to that of the summation unit with zero response. In the visual system, the receptive fields with linear weighting profiles are presumably absent, and the first derivative of two-dimensional Gaussian distribution can be used as an appropriate odd function for the weighting profile of the units determining the centroid position. Substituting the linear profile by the first Gaussian derivative leads to a slight change of the centroid position, $\Delta(X)$, as weighted by the Gaussian derivative:

$$\Delta(X)_G \approx X\frac{m}{1+m}e^{-BX^2}.$$

For our modeling, we assume that: i) the two-dimensional Gaussian derivative is a weighting profile of the pooling patches, and ii) the first derivative of the two-dimensional Gaussian distribution with the same width is an odd function of the weighting profile of the integrative units which form the system determining the centroid position.

To simplify the calculations, we assume that the excitation profile of the three-spot cluster part of the stimulus (Figure 1c) consists of three cylinders, their widths being equal to the spot diameter s and their heights (excitation amplitudes) to 1. Multiplication of the two profiles, the excitation and the pooling patch, shows that the *mass* corresponding to the terminator spot is

$$M = \iint_{-0.5s}^{0.5s} e^{-B(x^2+y^2)}\,dxdy =$$
$$= \frac{\pi}{B} erf\left(0.5s\sqrt{B}\right)^2$$

and the *mass* corresponding to the contextual flank made of two spots is

$$m_{dd} \cong 2Me^{-B(X^2+Y^2)} = 2Me^{-Bw^2},$$

where $X = wcos(0.5\alpha)$, and $Y = wsin(0.5\alpha)$, and $B=0.5\sigma^2$; σ determines the width of the Gaussian derivative.

In accordance with the assumptions, we have developed the following equation to fit the data shown in Figure 5A:

$$\Delta_{dd}(w,\alpha) = AX\frac{m_{dd}}{M+m_{dd}}e^{-BX^2} =$$
$$= Awcos(0.5\alpha)\frac{2e^{-Bw^2[1+cos(0.5\alpha)]^2}}{1+2e^{-Bw^2}}, \qquad (2)$$

where w is the wing length; α, the internal angle of the wings; A, scale coefficient; $B = 1/2\sigma^2$ which determines the width of the Gaussian profile of the pooling.

Integrating along the vertical line, the length of which is h and the width is s, yields the *mass* corresponding to the contextual stripe:

$$m_{ds} = e^{-BX^2}\sqrt{\frac{\pi}{B}}erf\left(0.5s\sqrt{B}\right)\int_{-0.5h}^{0.5h} e^{-By^2}\,dy =$$
$$= \frac{\pi}{B}e^{-BX^2}erf\left(0.5h\sqrt{B}\right)erf\left(0.5s\sqrt{B}\right).$$

Then, the centroid bias corresponding to the perceived shift of the terminator spot is

$$\Delta(X) = X\frac{m_{ds}}{M + m_{ds}}e^{-BX^2} =$$

$$= X\frac{e^{-2BX^2}erf(0.5h\sqrt{B})}{erf(0.5s\sqrt{B}) + e^{-BX^2}erf(0.5h\sqrt{B})}.$$

Assuming that

$$\int_0^x e^{-b\tau^2}dx = \frac{1}{2}\sqrt{\pi b^{-1}}\,erf(x\sqrt{b}) \approx$$

$$\approx \frac{1}{2}\sqrt{\pi b^{-1}\left(1 - e^{-bx^2}\right)},$$

a second equation has been derived to fit the data shown in Figures 2 and 4:

$$\Delta_{ds}(d) = Ad\frac{e^{-\left[\frac{d}{\sigma}\right]^2}\sqrt{1-e^{-0.125\left[\frac{h}{\sigma}\right]^2}}}{\sqrt{1-e^{-0.125\left[\frac{s}{\sigma}\right]^2}}+e^{-0.5\left[\frac{d}{\sigma}\right]^2}\sqrt{1-e^{-0.125\left[\frac{h}{\sigma}\right]^2}}} \quad (3)$$

where *s* is the spot diameter (1.5 min of arc); *d*, stripe-to-spot gap; *h*, stripe height. A good correspondence between the experimental and modeling data has been achieved (Figures 2, 3 and 5A, *symbols* and *solid lines*).

These results have led us to conclude that the local integrating processes may contribute to the illusions of alignment, orthogonal orientation and length matching. Also, the processes may cause similar illusions of the Müller–Lyer type related to various contextual flanks: single or double stripes, wings, triangles. The local integrative processes may also explain some other effects like "puffy" arcs of a circle with the inscribed triangle or the Giovanelli illusion. Seemingly, the procedure of the centroid positional coding provides a distorted sensory input to different visual mechanisms which are generally tuned to the location estimation in 2D and possibly 3D space. However, the perceptual goal of the procedure in the visual system is generally different. The biological significance of the mechanism of the positional coding via centroids is probably the ability of *an unconscious, fast* and *reliable* estimation of the location of an object as a whole, independently of its size, shape complexity, and its position in the scenery. It is little wonder for all of us that visible objects are located at the centroids in their light distributions (Westheimer & McKee, 1977; Watt & Morgan, 1983; Morgan & Aiba, 1985).

Conclusions

In the study, illusions of alignment, orthogonal orientation, and length matching were investigated. Quantitative characteristics of different illusions within a relevant range of the spatial stimulus parameters were obtained. The experimental data can be accounted for by a model based upon the centroid bias concept.

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PAPILDOMŲ OBJEKTŲ ĮTAKA STIMULO ILGIO IR KAMPO DYDŽIO SUVOKIMUI

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Santrauka

Šiame straipsnyje aprašomi eksperimentai, kuriuose stebėtojų prašoma pastumti vieną iš trijų pagrindinių stimulo dėmelių į vietą, tenkinančią reikalavimą: 1) trys dėmelės išsirikiuoja viena linija arba 2) išsidėsto stačiu kampu, arba 3) abu Brentano tipo iliuzinės figūros intervalai tampa vienodo ilgio. Suvokimo klaidų dydis matuojamas kaip atstumo tarp dėmelių ir šalia jų esančių papildomų objektų funkcijos. Gautos šių objektų sukeliamų skirtingų geometrinių iliuzijų kiekybinės charakteristikos. Eksperimentų duomenys interpretuojami, remiantis lokalios jaudinimų integracijos ir svorio centro postūmio samprata. Pasiūlytos atitinkamos analitinės funkcijos gana tiksliai aproksimuoja eksperimentines kreives. Išskaičiuotieji erdviniai lokaliosios integracijos parametrai yra tiesiškai susiję su bendruoju stimulo dydžiu.

Pagrindiniai žodžiai: tiesumo, stataus kampo ir ilgio iliuzijos, papildomi šalia esantys objektai, lokalioji integracija, svorio centro postūmis.

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