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Short communication

Distracting effects in length matching

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Abstract. In psychophysical experiments, subjects matched two spatial intervals of a three-spot stimulus into what appeared to them to be equal. The stimulus was flanked by stripes. The length matching errors increased in proportion to the referent interval of the stimulus and approached 6–12 percent of its length. Also, the error increased with an increase of the width of the gaps between the spots and the distracting stripes. Error reached a maximum at gaps equal to 10–15 percent of the length of the referent interval of the stimulus. When the luminance of the stripes increased or decreased, in comparison to the luminance of the background, length matching errors grew symmetrically and became approximately constant at higher contrasts. The experimental findings show the presence of local positional averaging which may be described quantitatively by means of spatial filtering procedures.

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The phenomenon of length matching distortions (illusions of extent) has been demonstrated in experiments with the Baldwin (1895), Müller-Lyer (1896), Obonai (1954) as well as other figures which are widely known and well documented. In these illusions the perceived lengths of different stimulus parts are distorted by the presence of contextual flanking objects like rectangles, circles, wings, or just additional line segments attached to the shaft line. Subjects who are instructed to bisect a line flanked by contextual figures of unequal size tend to overestimate the extent of the shaft nearer to smaller figure (or conversely, to underestimate the extent nearer to the larger figure) and, therefore, place the bisector closer to the smaller object producing significant length matching errors.

Obviously, contextual objects appended to a stimulus influence its apparent size, but the strength of this influence depends on what the appendage is. In the case of the presence of rectangular frames surrounding a shaft line (or an amputated version of the rectangular frame comprising two vertical stripes on both sides of the shaft line), the illusion magnitude can approach about half of the effect of adding fins covering the same horizontal extent. Day (1977) showed that adding small lines of the same orientation to a horizontal shaft line exerts only a slight effect on its apparent length. Predebon (1992) demonstrated illusions of extent with the Müller-Lyer figure when wings were placed at some distance apart from the shaft line. This study showed that, even in the case of a slight displacement of the wings, the illusion is markedly reduced. Di Maio and Lansky (1998), in experiments with an interpolated Müller-Lyer figure, made of only a few separate dots, found that the magnitude of the illusion depended on the number of dots forming the arrowheads and on their mutual position.

In the present communication, we demonstrate length matching distortions which are induced by rather simple contextual objects set in a three-spot stimulus having no shaft line. Three vertical stripes identical in size, shape and luminance are the flanking and distracting objects (Fig. 1). The gap between the spots and stripes, as well as the height and luminance of the stripes, are treated as independent variables. The aim of the present investigation is to obtain information on the regularities of the length matching distortions as functions of the different parameters of the stimuli. Another goal is to check whether the present illusion might be interpreted in terms of spatial frequency filtering performed in the visual pathways, and whether the filtering model (Bulatov and Bertulis 2004) is able to cope with the qualitative characteristics of the distortions of extent obtained experimentally.

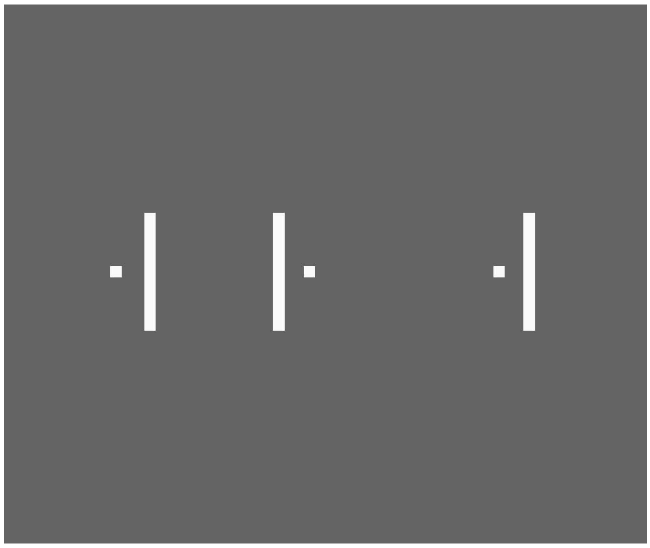

Fig. 1. Example of the stimulus. For explanations, see the text.

The experiments were carried out in a dark room. A Cambridge Research Systems VSG 2/3 and Eizo T562 monitor with gamma correction were used to generate stimuli. The distance between the subject's eyes and the screen was 400 cm. A chin holder limited movements of the subject's head. An artificial pupil with a diameter of 3 mm was used. The right eye was always tested irrespective of whether or not it was the leading eye. The experiments were conducted under control of computer software of our own design arranging the order of the stimuli, presenting them on the monitor, introducing alterations according to the subject's command, recording the subject's responses, and handling the results.

Horizontally arranged stimuli (Fig. 1) were presented monocularly against a background with luminance of 0 or 7 cd/m^2. The spots forming the stimulus were 2 min of arc in diameter and the stripes were 1 min of arc thick. The left part of the stimulus (spatial interval between the left and the central spot) was considered to be the reference interval and the other, the test interval.

We performed four series of experiments in which different parameters of the illusory stimulus varied. In the first series, the length of the referent interval of the stimulus was considered as an independent variable. It varied from 10 to 100 min of arc. The stripe height and spot-to-stripe gap increased in proportion to the length

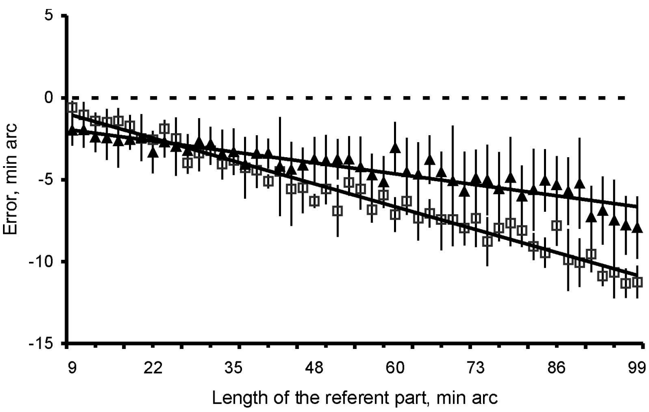

Fig. 2. Magnitude of the illusion as a function of the referent interval length. The background luminance was 0 cd/m[2]; the spot and stripe luminance – 12 cd/m[2]; the gaps between spots and stripes, and the stripe height increased in proportion to the referent interval length: the relative values were 12% and 40%, respectively. Subjects: squares –AB; triangles – NB.

of the referent part of the stimulus. In the second series of experiments the gaps between the stripes and adjacent spots changed from 0 to 30 min of arc, and the number of the distracting stripes present in the stimulus varied from one to three in different experiments. The other parameters of the stimulus remained unchanged. In the third series, the height of the distracting stripes varied from 2 to 50 min of arc, and in the fourth series, the luminance of the stripes varied from 0 to 15 cd/m[2].

During the experiments, the subjects were asked to change the length of the test interval by adjusting its end-spot into position that made the test interval appear equal to the perceived length of the referent interval. The initial length of the test interval of the stimulus was randomized according to the given length of the reference part. The lengths differences between the reference and the test were distributed evenly within a range of ± 5 min of arc.

The subjects were provided with keyboard buttons, and instructed to manipulate them to achieve perceived equality. A single button push varied the size of the test interval by one pixel, which corresponded approximately to 0.3 min of arc. When the test interval length was varied by the subject, the spot-to-stripe gaps remained constant in size. The difference in physical length between the test and referent intervals of the stimulus, determined after perceived equality was achieved, was considered to be the value of the illusion strength. The subjects were given no instructions concerning gaze fixation point. Observation time was unlimited. One hundred presentations were included in a single experiment, i.e., 50 values of each parameter were randomized and repeated twice. For each independent variable, each observer carried out at least ten experimental runs on different days.

Four observers with appropriate previous experience in performing similar psychophysical tasks were tested. All the observers were refracted professionally prior to the experiments. Since all four observers showed quantitatively similar results, we have selected for illustration the data for two of them.

In the experiments, the inside stripes caused an underestimation of the interval length, whereas the outside ones, conversely, induced an overestimation. The absolute value of the magnitude of the illusion grew with the size of the referent interval of the stimuli (Fig. 2; r=0.982, b_1=-0.109, $F_{1,48}$=1 316, P<0.001 for subject AB; r=0.924, b_1=-0.052, $F_{1,48}$=280, P<0.001 for subject NB). Consequently, the relative value of the illusion's strength was about the same for all sizes of the stimuli used.

The illusion varied with the size of the gaps between spots and distracting stripes (Fig. 3). The strength of the illusion increased with growth of the gap and reached the maximum (6–12 percent of the referent interval

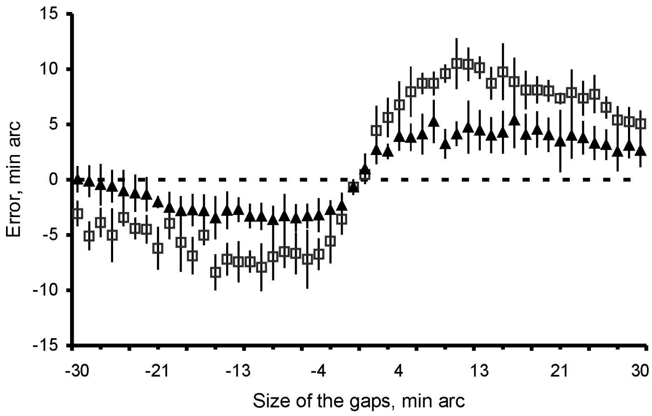

Fig. 3. Magnitude of the illusion as a function of the gap size (stripe position in relation to the referent and test interval dots). Negative values indicate the inside positions in the referent interval, and positive ones show outside positions. Background luminance – 0 cd/m[2]; the spot and stripe luminance – 12 cd/m[2]; referent interval length – 75 min of arc; the height of the stripes – 30 min of arc. Subjects: squares – AB; triangles – NB.

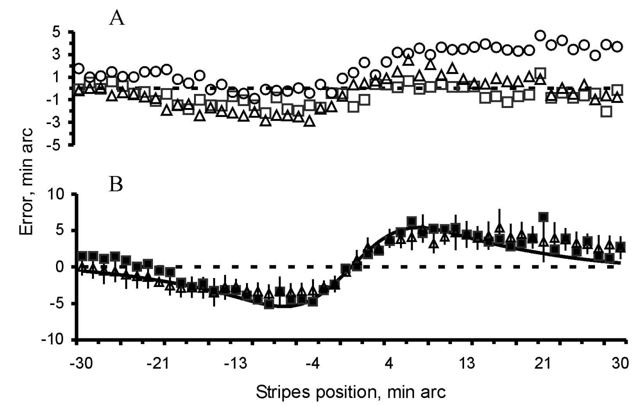

Fig. 4. Magnitude of the illusion as a function of the gap size. (A) Illusion caused by single distracting stripes: the central (according to the Fig. 1) – triangles; the left – squares; the right– circles. The referent interval length – 75 min of arc, the stripe height – 30 min of arc. (B) The sum of three single-stripe curves taken from Fig. 4A – squares; the three-stripe curve taken from Fig. 3 – triangles; the modeling curve – the solid line. Subject: NB.

size) at gaps equal to 10–15 percent of the referent interval length and monotonously diminished with further increase of the gap. The curves of Fig. 3 appear to be symmetrical in respect to a zero gap and show opposite signs of the illusion strength for the inside and outside stripes combined with the referent interval. Also, the curves shown in Fig. 4 illustrate an effect of accumulation of contributions from each distracting stripe:

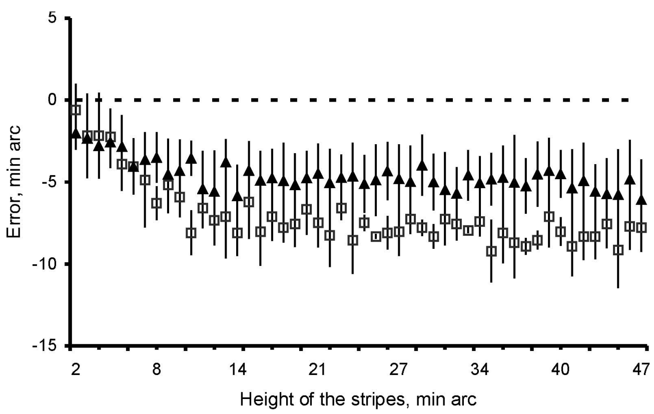

Fig. 5. Strength of the illusion as a function of the height of the stripes. Three distracting stripes were present. The background luminance was 0 cd/m2; the spot and stripe luminance – 12 cd/m^2; the gap size – 9 min of arc; the referent interval length – 75 min of arc. Subjects: squares –AB; triangles – NB.

the three-stripe curve is similar in shape to the sum of three single-stripe curves obtained by the stimuli with the left, central, and right stripes separately.

The illusion grew with the height of the stripes, asymptotically approaching the -9 min of arc value for subject AB, and -6 min of arc for subject NB (Fig. 5).

Illusion strength varied with changes of the luminance of the stripes (Fig. 6). The illusion diminished when the stripe luminance approached the background luminance value (7 cd/m^2), and the stripes were hard to discern. When the stripe luminance increased or decreased compared to the background luminance, the illusion strength increased symmetrically, but saturated at a luminance level of about 4 cd/m^2 and 10 cd/m^2 and remained approximately constant afterwards. That is, the illusion strength depended mainly on the absolute values of the luminance amplitude of the stripes (stripe luminance minus background luminance) and did not depend on the contrast sign, i.e., whether the stripes were light or dark.

The perceived distortions produced by our stimulus with contextual stripes are consistent with and similar to those caused by the Baldwin (Brigell et al. 1977), Müller-Lyer (Bulatov and Bertulis 2005, Bulatov et al. 1995, 1997, Di Maio and Lansky 1998), Obonai (Brigell et al. 1977), and Predebon (1992) illusory figures. The magnitude of the illusion depends on different parameters of the stimulus: stimulus size, stripe height, luminance difference, and stripe-to-spot gap. The experimental data obtained are in agreement with the predictions of perceptual assimilation theory (Pressey 1967, 1971, Pressey and Bross 1973) and the model of averaging (Anderson 1974): a shift of the perceived position of the end-point of an interval toward the position of an appropriate flanking pattern. Particularly, the proportional growth of the illusion within a certain range of the positions (Fig. 3) and heights (Fig. 5) of the stripes indicates the presence of local positional averaging. On an assumption that the perceived locations of spots and stripes are at peaks of a certain local excitation areas, the local positional averaging means that the neighboring spots and stripes placed close together produce overlapping excitatory areas, and the sum of excitations yields a shift of the peaks toward each other. Thus, neighboring spots and stripes in an image are perceived closer in distance. This leads to an overestimation of the two-spot spatial interval flanked by the outside stripes and to an underestimation of an interval having the inside stripes.

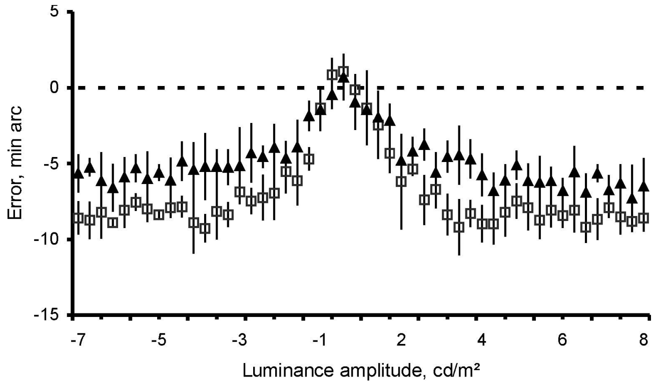

Fig. 6. Magnitude of the illusion as a function of the luminance amplitude of the stripes. The background luminance – 7 cd/m^2; the spot luminance – 12 cd/m^2; the gap size – 9 min of arc; the referent interval length – 75 min of arc, the height of the stripes – 30 min of arc. Subjects: squares –AB; triangles – NB.

The dependence of illusion magnitude on luminance changes (Fig. 6) and the cumulative effect of illusory magnitudes induced by single different stripes (Fig. 4) serve as additional cues for an assumption of a weighted averaging process. Uncertainty of an image features (Fermüller and Malm 2004) or spatial filtering in visual pathways could be a primitive averaging mechanisms. Spatial filtering causes neural blurring of the excitation pattern evoked by an image. The blurring effect results in an integration of excitatory profiles and influences on the perceived locations of spots and adjacent stripes of our stimuli making them closer in distance.

A pilot filtering model formed of concentric receptive fields, the weighting functions of which have Gaussian profiles, provides computational results similar to the present experimental findings (Fig. 4). In our model, as well as in the visual system, the receptive field size grows with its displacement toward the visual field periphery. This causes larger blurring of the remote image elements and also explains the proportional growth of the illusion with the increase of the size of the stimulus (Fig. 2). More details of the filtering model used were given in our previous communication (Bulatov and Bertulis 2004).

In conclusion an illusion of extent has been demonstrated in psychophysical experiments with three-spot stimuli comprising contextual stripes. The magnitude of the illusion varied regularly with the changes of the parameters of the stimuli: referent interval length, stripe-to-spot gap, stripe height, and luminance. Spatial frequency filtering may be used to interpret the experimental data obtained.

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