ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol Exp 2005, 65: 51-60

Superimposition of illusory patterns with contrast variations

Aleksandr Bulatov and **Algis Bertulis**

Department of Biology, Kaunas University of Medicine, Mickevičiaus 9, LT 3000 Kaunas, Lithuania

Abstract. In psychophysical experiments, a perceived length matching task was performed. The stimuli were made of two spatially superimposed illusory figures that differed in structure and luminance contrast but had the same length and coincided precisely, with their ends matched. The contrast of one of the figures was fixed, and that of the other varied. In experiments with stimuli viewed monocularly, the combined patterns produced illusions of perceived length, the strength of which varied with alterations of contrast of one of the figures. If the figures were presented separately to different eyes of the same subject, changes of contrast did not have a noticeable influence on the illusion's strength. When the two stimulus components were displaced spatially and shown side by side, the monoptic and dichoptic stimuli yielded different results as well. The illusion's strength increased with an increase of the distance between the figures when viewed monocularly, but remained invariable if the figures were presented separately to each eye. The results obtained in experiments with dichoptic stimuli suggest that stimulus length distortions may occur in the monocular retinocortical pathways.

The correspondence should be addressed to A. Bertulis, Email: bertulis@vision.kmu.lt

Key words: perceived length distortions, superimposition of illusory patterns, luminance contrast

INTRODUCTION

Studies of geometrical illusions have a history of about two hundred years, and these illusions still remain an object of a lively interest among researchers. It seems mysterious that some simple two-dimensional figures give the wrong impression of their geometrical properties such as the length, size, or angle. On the assumption that illusions appear when the conditions of sensory system functioning are at the borderline relative to system parameters, the study of these conditions may be useful in understanding the principles of the organization and functioning of the sensory system itself.

Visual geometrical illusions may be divided in two classes: illusions of direction – when the orientation of the stimulus is misjudged; and illusions of extent – when the size or length of the stimulus is misjudged. The present communication deals with two geometrical illusions of extent, caused by the Müller-Lyer and Oppel-Kundt figures. The Müller-Lyer illusion is one of the most famous perceptual illusions and has been studied intensively since the end of 19th century. The Müller-Lyer figure is made of three pairs of wings arranged in a linear sequence, thus, forming two spatial intervals. The length and tilt angle of the wings may vary. In all cases the interval with the inward facing wings appears shorter than that with the outward facing wings, despite the fact that they are physically equal in length.

The Oppel-Kundt illusion has been given less attention by researchers, though its manifestations have been well documented and are fairly well known. The Oppel-Kundt figure has no crossing lines. It is made of stripes forming two spatial intervals: an empty interval, and a filled one. The number of stripes in the filled interval may vary. Although the two intervals are physically the same length, the empty one appears narrower in width than the filled one.

Attempts to explain the phenomenon of illusions are numerous. For brief communication, these explanations may be roughly classified into two groups. The first relates the emergence of geometrical illusions to sensations of depth or perspective (Day 1972, Gauld 1975, Gillam 1980, Gregory 1968, 1972, Lester 1977, Rock and Anson 1979, Smith 1978, Ward et al. 1977). This explanation is supported by the idea that depth perception operates on a size constancy mechanism. Another explanation in this group is stated in terms of adaptation level theory (Helson 1964, Restle and Merryman 1968). According to this view, judgments of length are directly related to the size of a focal stimulus and inversely related to the adaptation level of the observer. Similarly, assimilation theory (Pressey and Bross 1973, Pressey et al. 1971) can be applied: the focal shaft assimilates to (or is averaged with) the magnitude of the contextual figures flanking the shaft.

The stimulus centre of gravity concept (Coren and Hoening 1972, Festinger et al. 1968, Judd 1905, Kaufman and Richards 1969, McLaughlin et al. 1969, Virsu 1971) is based on feedback from efferent commands for eye movements. The concept explains the perceptual distortions by feedback resulting from an inappropriate tendency to fixate the centre of gravity of contextual figures when attempting to fixate the end-points of the focal shaft. However, the original concept of the center of gravity may be supplemented with interpretations in physiological terms of the structure of receptive fields and their interaction. Thus, this concept is related to the second group of explanations.

The followers of the theories belonging to the second group support the idea of relatively low-level localization of the geometrical illusion mechanism and explain the immediate emergence of the illusions by the properties of receptive fields (Walker 1973), contour orientation detectors (Caelli 1977), and spatial filtering (Ginsburg 1984, 1986, Kawabata 1976) caused by lateral inhibition which produces a certain amount of blurring of the retinal image. Some researchers discuss geometrical illusions in terms of uncertainty of perception of stimulus geometry explaining their origin by spatial band-pass filtering (Earle and Maskell 1993, Morgan 1999, Morgan and Casco 1990) or by statistical bias arising due to noise in early visual processing (Fermüller and Malm 2004). Therefore, some authors (Day 1972, Eijkman et al. 1981, Pressey and Di Lollo 1978, Restle and Decker 1977) suggest that simple, straightforward explanations are questionable and that there may be more than one mechanism contributing to the observed effects.

Our previous experimental data, as well as the results of modelling (Bulatov 2003, Bulatov et al. 1997) favor the concept of spatial-frequency filtering of an image as one of the major causes of the distortions of length perception. The term “filtering” originates from classical signal processing theory, in which it has a strict mathematical definition: a filter is a linear shift-invariant system which transforms an input signal into a “filtered” output signal. The uncertainty principle, defined by terms of Fourier transform, indicates a certain relation between the extent of the signal and its spectral characteristics (Papoulis 1962). Therefore spatial filtering processes unavoidably produce distortions in the size and shape relations of various parts of an image. The magnitude of the distortions depends on the parameters of the filtering system. In vision, the receptive fields of neurons of retinocortical networks possess properties of linear spatial-frequency filters. The size of receptive fields varies gradually with visual field eccentricity. This causes nonhomogeneity of the filtering parameters of the visual system. Presence of these properties leads to the idea that illusions of extent such as the Müller-Lyer and the Oppel-Kundt illusions are a result of filtering processes in the neural networks of the visual system.

In the present communication, we examine the effects produced by two different illusory patterns when they are combined in one image. Two Müller-Lyer, or one Müller-Lyer and one Oppel-Kundt patterns were superimposed spatially and presented simultaneously. Such stimuli may help us to determine whether or not the summation of illusory patterns causes the summation of illusions. The effect of the summation of illusions was observed in our previous studies (Bertulis and Bulatov 2003, Bulatov and Bertulis 1999). An additivity of geometrical illusion of extent (Oppel-Kundt or Müller-Lyer) and the horizontal-vertical illusion (caused by the visual field anisotropy) has been demonstrated. The effects of two illusions converge on an algebraic summation when presented simultaneously. In the present work we have performed two large groups of experiments: with monoptic stimuli in which two illusory components are combined in one pattern and seen by one eye, and experiments with dichoptic stimuli in which one illusory component is shown to the right eye and the other to the left one where both components are required for the composite percept. We ask if the experimental data on illusions of extent evoked by the combined stimuli would support the idea of low-level localization of the illusion mechanism, and whether the same theoretical approach might be applied to the effects produced by the combined patterns in monoptic and dichoptic stimuli.

According to the concept of linear spatial-frequency filtering, the combination of two illusory patterns at the input of the filtering system should cause linear superimposition of the signals at the output of the system. Therefore, the spatial distortions in the output pattern (e.g, the differences of the lengths of various parts of the pattern) should depend on the differences of the amplitudes (in our case, differences of luminance) of the input signals. When a single illusory pattern is presented at input, the spatial distortions at output should not depend on the amplitude of the input signal. Also, the superimposition of the input patterns does not mean just an algebraic summation of the perceived spatial distortions which might be produced by each pattern.

In our modelling, the input corresponds to the receptor level of the retina and the output to the fourth layer of striate cortex, and the spatial-frequency filtering is mainly performed in the monocular retinocortical pathways (Bulatov 2003) before the binocular convergence occurs at the level of cortical hypercolumns (Hubel and Wiesel 1974). Consequently, one may predict that when two illusory patterns are combined in a dichoptic stimulus, the distortions in output patterns will be caused by separate filtering systems and should not depend on differences of luminance of the illusory components.

To check the predictions of the spatial-frequency filtering hypothesis, we have performed experiments on illusions of extent. The goals of the experiments are: (i) to evaluate quantitatively an influence of luminance contrast variations on the resultant manifestation of combined illusory images; and (ii) to compare the superimposition effects evoked by the monoptic and dichoptic stimuli.

METHODS

Equipment

The experiments were conducted under computer control with 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.

The experiments were carried out in a dark room, so that the display frame could not be discerned. A Cambridge Research Systems VSG 2/3 and Eizo T562 monitor with gamma correction were used to generate images. 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 in the experiments with monoptic stimuli. The right eye was always tested irrespective of whether or not it was the leading eye. The stimuli were presented on a grey elliptical shape background (Fig. 1A,B and C) with luminance of 6, 9, 15, or 21 cd/m^2.

In experiments with dichoptic stimuli, a small non-transparent screen was placed between the subject's eyes and the monitor, so that the subject's left eye viewed only the left half of the monitor screen and the right eye viewed only the right one. The computer program presented different components of the dichoptic stimulus on different screen halves against grey elliptical backgrounds (Fig. 1D,E). To make the binocular fusion of the elliptical backgrounds easy, optical prisms were adjusted in front of the subject's eyes.

Stimuli

The lines that formed the Müller-Lyer, Oppel-Kundt figures, and tree-stripe stimuli were 0.3 min of arc thick. In the Müller-Lyer figure, the shaft line was absent. The Oppel-Kundt figure and the three-stripe stimulus were formed by vertical stripes 15 min of arc in length. The contrast of the stimuli was calculated by Michaelson's formula $(f-b)/(f+b)$, where f is the stimulus luminance, b is the background luminance, and $(f-b)$ is considered to be the stimulus luminance amplitude.

In experiments with monocular stimuli, the combined figures appeared in pairs coinciding precisely with each other and forming a single horizontal pattern 120 min of arc long. There were 4 types of experiments with different monoptic stimuli. When the two Müller-Lyer figures were superimposed (experiments type 1), their orientations differed by 180° (Fig. 1A). Hence, each side of the combined pattern had both inward and outward facing wing pairs. The contrast of one of the figures was fixed, and that of the other varied from presentation to presentation within a range from –1.0 to 0.60. This is why the former was called the passive figure and the latter the active one. The left part of the combined stimulus was considered to be the reference (r) and the other, the test (t).

There were two other combinations of the figures used: the active Oppel-Kundt figure was combined with the passive Müller-Lyer figure (Fig. 1B; experiments type 2) or with the simple non-illusory stimulus made of three vertical stripes (Fig. 1C; experiments type 3).

In control experiments (type 4), the monoptic stimuli with a single Müller-Lyer or Oppel-Kundt figure were used.

In a dichoptic stimulus, a figure formed of two pairs of the Müller-Lyer wings was presented to one eye, while another figure formed of the other two wing pairs was presented to the other eye. Due to binocular fusion, the subjects saw the combined stimuli shown in Fig. 1D and Fig. 1E. There were 2 types of experiments performed with dichoptic stimuli. In presentations of the stimuli, the luminance amplitude of one of the figures varied (Fig. 1D; experiments type 5) or the vertical distance between the two figures (Fig. 1E) changed (experiments type 6). Consequently, in a dichoptic stimulus, the figure shown to one of the eyes was considered to be the reference and the passive part of the composite pattern, whereas the other figure presented to the other eye played the role of the test and the active part of the stimulus.

For control experiments (type 7), the reference and the test parts of the dichoptic stimulus were exposed to one eye simultaneously. The vertical distance between the two parts varied.

Procedure

During the experiments with monocular stimulation (types 1–3), the luminance amplitude of the passive figure was fixed and the luminance amplitude of the active figure was considered to be the independent variable. The subjects were asked to change the length of the test part (t) of the combined stimulus and adjusting it to make it appear equal to the perceived length of the reference part (r). The difference in physical length between the test and the reference parts of the stimulus, determined after perceived equality was achieved, was considered to be an indicator of the illusion strength. The subjects were provided with three keyboard buttons, and instructed to manipulate them to achieve perceived equality. They pressed button [›] if they wanted to make the test part of the figure longer and button [‹] if they wanted to shorten it. In our experiments, a single button push varied the size of the test part by one pixel, which corresponded approximately to 0.3 min of arc. Observation time was unlimited, and the subjects manipulated the figure until perceptive length equality was achieved. Then the subject pressed the "Enter" button to transfer the response to the computer program. In the next stimulus presentation, the contrast of the active figure was changed, and the procedure repeated. No instructions concerning a gaze fixation point were given. The initial length of the test part of the stimulus was randomized, and the subjects did not know in advance whether the program would show it longer or shorter, and how much different it might be compared with the length of the reference part. One hundred presentations were included in a single experiment, i.e, 50 values of each parameter were randomized and repeated twice. A single experiment lasted about half an hour. The experiment was repeated five or six times every other day during a session. Thus, there were ten or twelve trials provided for each value of an independent variable in a session, i.e. stimuli were exposed five or six hundred times in a session. Different sessions employed different stimuli. Sessions were organized randomly.

In the control experiments (type 4) with the single-figure stimulus, the contrast of the patterns varied. The subjects performed the same task and adjusted the test part of the stimulus to make it appear equal to the reference one. The physical difference of the lengths was also considered to be the measure of the illusion strength.

Likewise, in the experiments with dichoptic stimuli, the luminance amplitude of the passive figure was fixed. In one series of experiments (type 5), the vertical distance between the figures was fixed at zero and the luminance amplitude of the active figure was accepted as an independent variable. In other experiments (type 6), the luminance amplitude of the active figure was fixed and vertical distance between figures was used as an independent variable. The subjects adjusted the length of the test part of a combined stimulus to make it appear equal to the reference one. The physical difference between the lengths of the test and the reference parts, determined after perceived equality, was interpreted as the illusion strength value. In a session of the experiments, there were also more than ten trials provided for each value of an independent variable.

In control experiments (type 7), the illusion strength was measured as the function of the vertical distance between the reference and the test figures, used for forming the dichoptic stimuli, combined in a single image and presented monocularly.

Subjects

The observers were both the authors, and two volunteers with appropriate previous experience in performing similar psychophysical tasks. All the observers were refracted professionally prior to the experiments. Three of them were found to be emmetropes, and one was wearing spectacles correcting visual acuity with 1.0 D power refractive lenses.

RESULTS

In the experiments with superimposition of illusory figures, two members of the combined pattern had the same size and coincided precisely, with their ends matched. The combined Müller-Lyer pattern (Fig 1A; experiments type 1) evoked an illusion, the strength value of which varied with alterations of the luminance amplitude $(f-b)$ of the active figure in the following situations: either the passive figure was dark, the contrast being –1, or light, the contrast being fixed at 0.54 (Fig. 2A). The function had nearly symmetrical shape within the luminance amplitude range from –9 cd/m^2 to 9 cd/m^2 of the active figure, with clear extremum around 0 cd/m^2, at which the active figure actually could not be discerned. The maximum value of the illusion was about 20 percent of the reference part length, thus matching the average of the illusion's strength seen in the experiments with single figures (Bulatov et al. 1997). If the luminance amplitude of the active figure was –9 cd/m^2 or 9 cd/m^2, the illusion was absent. Consequently, the illusion disappeared if the absolute values of the luminance amplitudes of the two figures were the same, and both figures were dark or light, or one of the figures was as dark as the other was light. If the luminance amplitude was greater than 9 cd/m^2, the illusion was relatively weak and had the opposite sign.

Similar effects were observed in the experiments (type 2) with superimposition of the Oppel-Kundt and Müller-Lyer figures (Fig. 1B). The experimental curve was also symmetrical around the zero value of the luminance amplitude of the active Oppel-Kundt figure.

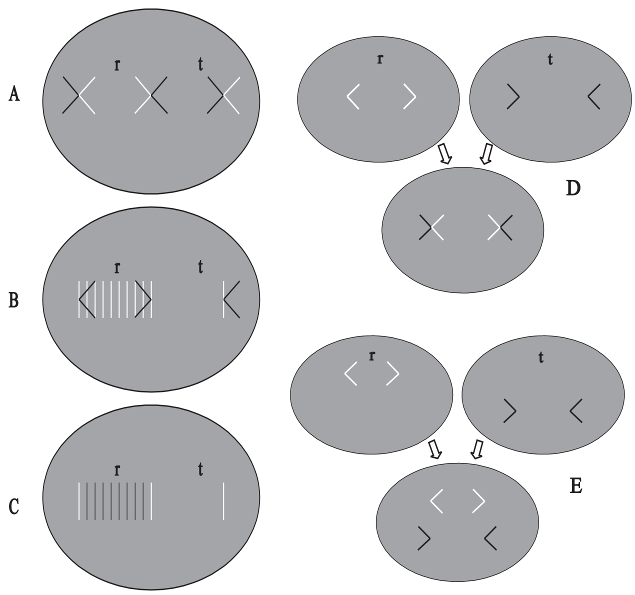

Fig. 1. Facsimiles of the stimuli with superimposition of two illusory patterns. For other explanations, see the text.

This similarity of the experimental data on superimposition of various illusory figures became more evident when the values of the strength of illusions were considered as functions of the contrasts of the active figures seen against various backgrounds (Fig. 2B). The curves for superimposition of two Müller-Lyer figures, shown by triangles, squares, and circles, and the curve for combination of Oppel-Kundt and Müller-Lyer figures, shown by a continuous line, are similar to one another in shape and almost overlap. The data indicate that the illusion strength does not depend noticeably on the contrast of the passive figure and remains the same in combinations of different types of illusory patterns.

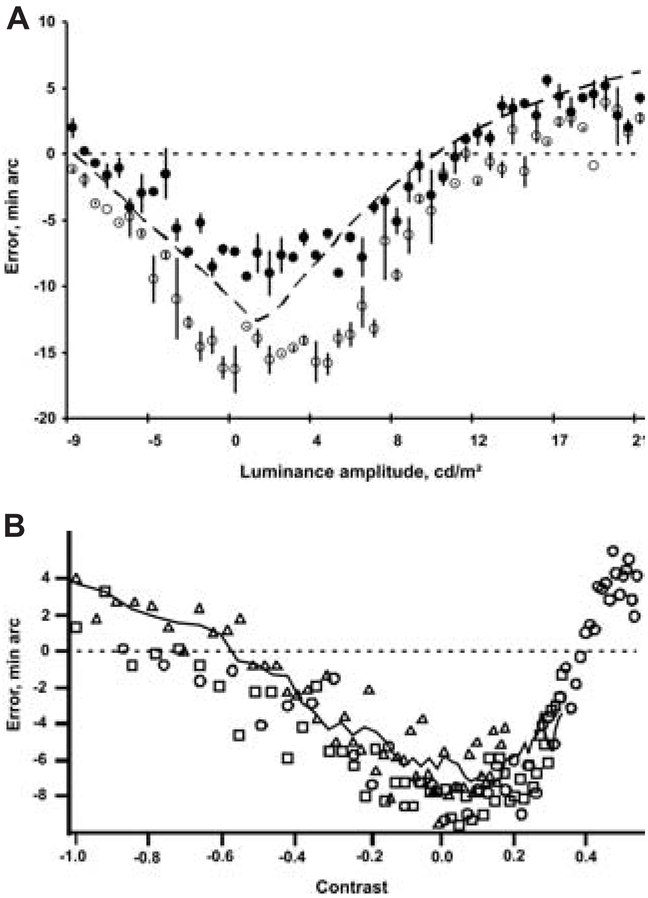

Fig. 2. Illusion strength as a function of the luminance amplitude of the active Müller-Lyer figure (A), and as functions of the contrast of the active Oppel-Kundt or Müller-Lyer figures (B). In (A): luminance amplitude of the passive Müller-Lyer figure was –9 cd/m^2 and its contrast, –1.0; the background luminance was 9 cd/m^2; the length of the reference part of the stimulus, 60 min of arc; the wing length, 15 min of arc; and the tilt angle of the wings, 45°. Subjects TR (filled symbols) and UL (open symbols); modelling data (dashed line). In (B): the continuous curve indicates the illusion as the function of contrast of the active Oppel-Kundt figure shown against a background with luminance of 15 cd/m^2; the symbols illustrate the illusion measured with the active Müller-Lyer figure against backgrounds with luminance of 21 cd/m^2 (triangles), 15 cd/m^2 (squares), 9 cd/m^2 (circles). Subject TR. For other explanations, see the text.

In the experiments (type 3) with superimposition of the Oppel-Kundt figure and non-illusory stimulus made of three vertical stripes (Fig. 1C), the first figure was active and the second was passive. The illusion varied with alteration of the luminance amplitude of the Oppel-Kundt figure (Fig. 3). The illusion was stronger when both figures had the same sign of the luminance amplitudes (e.g, all stripes were light), and weaker when they had different signs. The illusion disappeared when the luminance amplitude of the active illusory figure approached zero.

The data of the control experiments (type 4) with single Müller-Lyer or Oppel-Kundt figures (Fig. 4) showed an invariance of the illusion strength for stimulus luminance amplitudes ranging from 3 to 24 cd/m^2 (contrasts ranging from 0.2 to 0.67). The results are consistent with other reports (Dworkin and Bross1998, Li and Guo 1993, 1995, Long and Murtagh 1984, Pollack and Jager 1991, Spehar and Gillam 1998, Wickelgren 1965).

For dichoptic presentation of two illusory figures (Fig. 1D), the subjects reported that the figure with inward-facing wings was seen as being shorter than that with the outward-facing wings when in fact the physical lengths of both the figures were equal. The illusion strength was found to be as large as 20 percent of the reference figure length. It did not change noticeably with

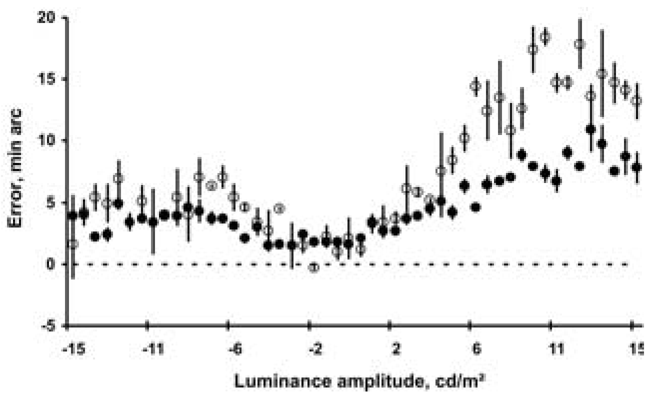

Fig. 3. Illusion strength as a function of the luminance amplitude of the Oppel-Kundt figure combined with the three-stripe stimulus (luminance amplitude of 6 cd/m^2). Background luminance was 15 cd/m^2. Subjects TR and VL.

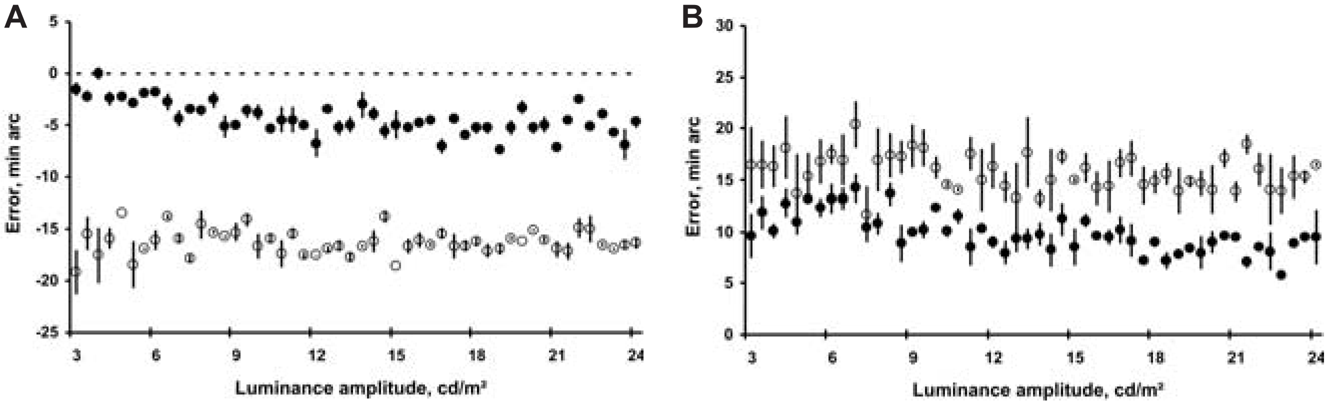

Fig. 4. Illusion strength as a function of the luminance amplitude of a single Müller-Lyer (A) or Oppel-Kundt (B) figure against a background with luminance of 6 cd/m^2. The length of the reference part of the stimulus, 60 min of arc; the wing or stripe length was 15 min of arc; the tilt angle of the wings was 45°. Subjects were TR (filled symbols) and UL (open symbols).

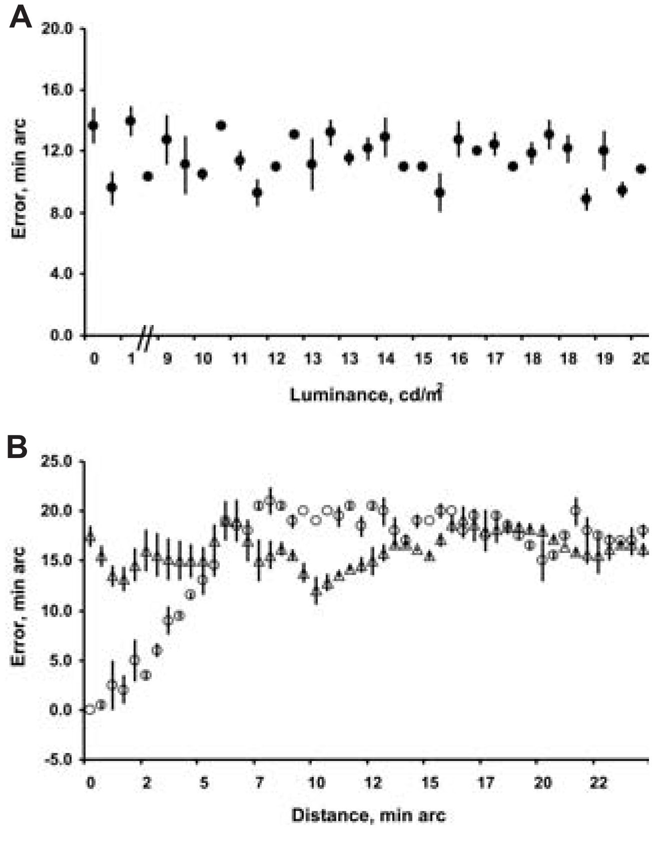

Fig. 5. Illusion strength as a function of the luminance of the active Müller-Lyer figure (A) and as a function of the vertical distance between two Müller-Lyer figures (B). In (A): the active and passive figures were presented to different eyes of the same observer; the luminance of the passive figure was 0 cd/m^2; its contrast, –1.0; the background luminance, 6 cd/m^2. In (B): two figures presented together to one eye (circles) or to different eyes of the same observer (triangles); the luminance of the figures was fixed at 0 cd/m^2 and 20 cd/m^2; the background luminance was 6 cd/m^2. Subject TR.

alterations in difference of the contrasts of the figures, (Fig. 5A; experiments type 5). The strength of the illusion also did not vary with increasing distance between the figures (Fig. 1E) from 0 to 24 min of arc (Fig. 5B, triangles; experiments type 6). On the contrary, the illusion's strength grew with an increase of the distance when these figures were combined in one single image and presented monocularly (Fig. 5B, circles; experiments type 7). When the distance between the figures was about 6 min of arc, illusion strength saturated and took on the same value as in the case of dichoptic stimuli.

DISCUSSION

Analysis of the experimental findings suggests that two figures combined in one monocular stimulus, despite their type, produce one common illusion which depends on the luminance differences of the illusory components. In the perceived length matching task, a visual pattern seems to be processed as a single object, regardless of the subjects' ability to recognize the separate components if necessary. The experimental data obtained indicate the absence of an algebraic summation of two separate illusions, when two illusory patterns are superimposed and presented simultaneously to the same eye. This conclusion is based on the following experimental findings: (i) the strength of illusion does not depend on the absolute value of the luminance amplitude of the stimulus comprising a single figure (Fig. 4; experiments type 4); and (ii) the strength of illusion smoothly varies with alterations of the absolute value in the luminance amplitude of one of the objects of a compound stimulus (Fig. 2 and 3; experiments types 1, 2). If two separate illusions were present at superimposition of the two figures, they would eliminate each other because of their opposite signs. A complete elimination would be observed at any contrast values of the active figure, and the subjects would not make errors as great as 20 percent in the perceived length matching task. Instead of the curves of Fig. 2, a flat line situated close to the abscissa axis would be obtained, and the illusion would be anticipated to arise only when the luminance amplitude of the active figure approached the zero value.

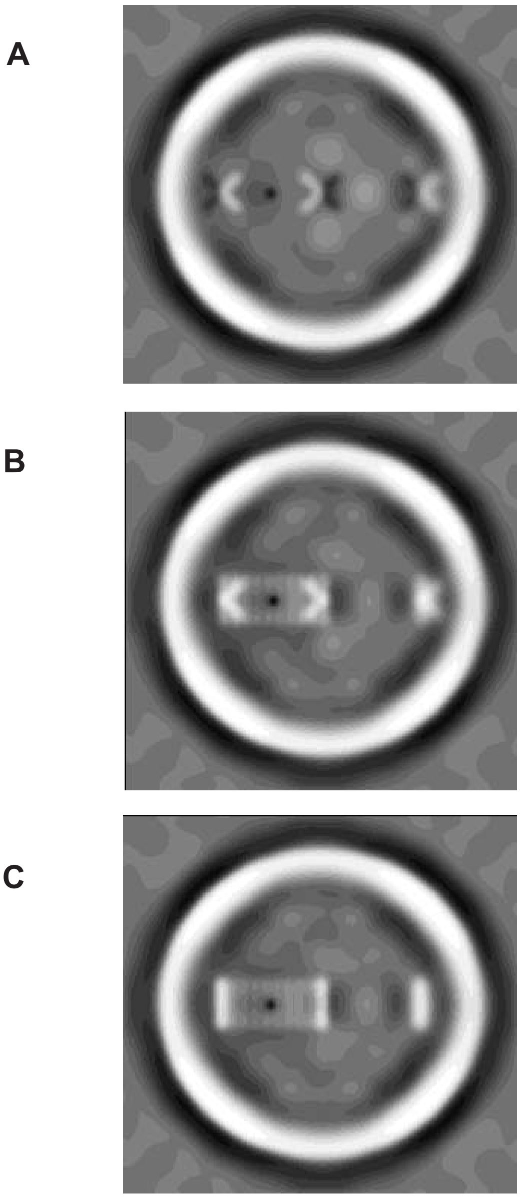

Fig. 6. The output patterns of the filter model at superimposition of different figures: (A) two Müller-Lyer figures; (B) the Oppel-Kundt figure and the Müller-Lyer figures; (C) the Oppel-Kundt figure and the tree-stripe stimulus.

In addition, the experimental data with superimposition of the Oppel-Kundt figure and the stimulus made of three vertical stripes also demonstrate not just a simple Oppel-Kundt illusion (Fig. 3; experiments type 3). If they did, the illusion strength ought to be constant because the three-stripe stimulus did not evoke illusion of extent, and the Oppel-Kundt illusion *per se* did not vary with alterations of the contrast values.

The changes of illusion strength as a function of differences in luminance amplitude supports the concept that two-dimensional spatial filtering (Bulatov 2003, Bulatov et al. 1997) could be responsible for the geometrical illusions under consideration. We have applied our filtering model to the present experimental data. An illustration of the output patterns of the model is shown in Fig. 6. The model shows a sufficiently good fit (the dashed line in Fig. 2A) of the findings representing distortions produced by the combined patterns in human vision. Both for the visual system and for our model, the resulting distortions during length matching depend on the differences in luminance amplitudes of the combined input patterns. Also, the resulting illusion does not depend on the luminance amplitude of the isolated illusory component. This supports the prediction that the superimposition of two illusory patterns causes an effect different from that obtained just by the algebraic summation of two separate illusions.

In the experiments with monocular stimuli, the illusion's strength grew with an increase of the distance between the two illusory figures up to 6 min of arc (Fig. 5B, circles; experiments type 7). This result serves as an additional argument in favor of the assumption that the spatial-frequency filtering of an image causes the illusions of extent. The value of 6 min of arc reliably agrees with the data on the sizes of the "aggregate" receptive fields, which correspond to hypercolumns in the foveal representation of the striate cortex (Hubel and Wiesel 1974). When the distance between two figures is less than 6 min of arc, the tips of the wings of the figures are processed by the same "aggregate" receptive fields. At larger distances, they are filtered by the separate receptive field systems and, therefore, the illusion strength saturates and does not depend on the distance between the figures.

The results obtained with dichoptic stimuli support the prediction that illusions of extent can occur separately in the monocular retinocortical pathways. Firstly, the changes in the luminance amplitude of the active figure do not exert a noticeable influence on illusion strength (Fig. 5A; experiments type 5), as if a single figure was presented (Fig. 4). Secondly, the illusion's strength remains invariable with increase of the vertical distance between the figures (Fig. 5B, triangles; experiments type 6), as if the two patterns were processed in different neural networks and were not spatially interrelated. This is a distinct effect of the monoptic stimuli: the illusion's strength grows with an increase of the distance between the two figures when they are presented to the same eye (Fig. 5B, circles) and, presumably, processed in a single monocular network.

In general, the data obtained indicate that the spatial-frequency filtering responsible for the illusion may be performed below the level at which the monocular signals converge. Obviously, the level is even lower than that at which the mechanisms of identification of objects might be situated. Psychophysical studies (Shevelev et al. 2003) have demonstrated better recognition of figures with crossing lines and corners than ones with lines only. However, both the Müller-Lyer figure that is formed of corners and the Oppel-Kundt figure made up only of lines have shown the same illusory effect in simultaneous presentation.

CONCLUSIONS

In psychophysical experiments, the effect of spatial superimposition of illusory patterns on the illusion strength was tested.

Combined illusory patterns produced an illusion, the strength of which varied with alterations of the contrast of one of the components.

Illusions evoked by single Müller-Lyer and Oppel-Kundt figures did not depend on variations of stimulus contrast.

During dichoptic presentations of two illusory figures, the illusion's strength did not change with alteration of the contrast differences. The strength of the illusion also did not vary with increasing distance between the figures. In contrast, during monocular presentations, the illusion's strength grew with an increase of the distance between the figures.

The experimental data and modelling outcome provide support for low-level processes of spatial filtering in the monocular retinocortical pathways as the cause for illusions of extent.

REFERENCES

Bertulis A, Bulatov A (2003) Distortions of length perception: anisotropy of the visual field and geometric illusions. Russ J Physiol 89: 1265–1280.

Bulatov A (2003) Influence of striate visual cortex topography on the parameters of image filtering. Russ J Physiol 89: 1258–1264.

Bulatov A, Bertulis A (1999) Distortions of length perception. Biol Cybern 80: 185–193.

Bulatov A, Bertulis A, Mickiene L (1997) Geometrical illusions: Study and modelling. Biol Cybern 77: 395–406.

Caelli T (1977) Is perceived length affected by interactions between orientation detectors? Vision Res 17: 837–841.

Coren S, Hoening P (1972) Effect of non-target stimuli upon length of voluntary saccades. Percept Mot Skills 34: 499–508.

Day R.H (1972) Visual spatial illusions: A general explanation. Science 175: 1335–1340.

Dworkin L, Bross M (1998) Brightness contrast and exposure time effects on the Oppel-Kundt illusion. Perception 27 (suppl): 87.

Earle DC, Maskell S (1993) Fraser cords and reversal of the café wall illusion. Perception 22: 383–390.

Eijkman EGJ, Jongsma HJ, Vincent J (1981) Two-dimensional filtering, oriented line detectors, and figural aspects as determinants of visual illusions. Percept Psychophys 29: 352–358.

Fermüller C, Malm H (2004) Uncertainty in visual processes predicts geometrical optical illusions. Vision Res 44: 727–749.

Festinger L, White CW, Allyn MR (1968) Eye movements and decrement in the Müller-Lyer illusion. Percept Psychophys 3: 376–382.

Gauld A.A (1975) A note on inappropriate constancy-scaling and the Müller-Lyer illusion. Br J Psychol 66: 307–309.

Gillam B (1980) Geometrical illusions. Sci Am 242: 102–111.

Ginsburg AP (1984) Visual form perception based on biological filtering. In: Sensory Experience, Adaptation and Perception (Spilman L, Wooten GR, eds.). Erlbaum, Hillsdale, NJ, p. 53–72.

Ginsburg AP (1986) Spatial filtering and visual form perception. In: Handbook of Perception and Human Performance. Cognitive Processes and Performance (Boff KR, Koufman L, Thomas JP, eds.). Wiley, New York, p. 34.1–34.41.

Gregory RL (1968) Visual illusions. Sci Am 219: 66–67.

Gregory RL (1972) Illusory contours. Physiological or cognitive. Nature 238: 51–55.

Helson H (1964) Adaptation-Level Theory. Harper and Row, New York.

Judd CH (1905) The Müller-Lyer illusion. Psychol Rev Monogr Suppl 7: 55–81.

Hubel D.H, Wiesel T.N (1974) Uniformity of monkey striate cortex. A parallel relationship between field size, scatter, and magnification factor. J Comp Neurol 158: 295–306.

Kaufman L, Richards W (1969) Spontaneous fixation tendencies for visual forms. Percept Psychophys 5: 85–88.

Kawabata N (1976) Mathematical analysis of the visual illusion. IEEE Trans SMC-6: 818–824.

Lester G (1977) Size constancy scaling and the apparent thickness of the shaft in the Müller-Lyer illusion. J Gen Psychol 97: 307–308.

Li CY, Guo K (1993) Quantitative studies on discrimination of simple geometric patterns and related visual illusions. Sheng Li Hsueh Pao 45: 486–497.

Li CY, Guo K (1995). Measurements of geometric illusions, illusory contours and stereo-depth at luminance and colour contrast. Vision Res 35: 1713–1720.

Long G. M, Murtagh M.P (1984) Task and size effects in the Oppel-Kundt and irradiation illusions. J Gen Psychol 111: 229–240.

McLaughlin SC, De Sisto MJ, Kelley MJ (1969) Comment on "Eye movement and decrement in the Müller-Lyer illusion". Percept Psychophys 5: 288.

Morgan MJ (1999) The Poggendorff illusion: A bias in estimation of the orientation of virtual lines by second-stage filters. Vision Research 39: 2361–2380.

Morgan MJ, Casco C (1990) Spatial filtering and spatial primitives in early vision: An explanation of the Zöllner-Judd class of geometrical illusions. Proc R Soc Lond B Biol Sci 242: 1–10.

Papoulis A (1962) The Fourier Integral and Its Applications. McGraw-Hill Companies, New York, 63 p.

Pressey AW, Bross M (1973) Assimilation theory and the reversed Müller-Lyer illusion. Perception 2: 211–217.

Pressey AW, Di Lollo V (1978) Effects of distance between standard and comparison lines on the Müller-Lyer illusion. Percept Psychophys 24: 415–419.

Pressey AW, Butchard N, Scrivner L (1971) Assimilation theory and Ponzo illusion: Quantitative predictions. Can J Psychol 25: 486 – 497.

Pollack RH, Jager TB (1991) The effects of lightness contrast on the colored Müller-Lyer illusion. Percept Psychophys 50: 225–229.

Restle F, Decker J (1977) Size of the Müller-Lyer illusion as a function of its dimensions: theory and data. Percept Psychophys 21: 489–503.

Restle F, Merryman CT (1968) An adaptation theory account of a relative-size illusion. Psychol Sci 12: 229–230.

Rock I, Anson R (1979) Illusory contours as the solution to a problem. Perception 8: 665–681.

Shevelev I.A, Kamenkovich V.M, Sharaev GA (2003) The role of lines and corners of geometric figures in recognition performance. Acta Neurobiol Exp (Wars) 63: 361–368.

Smith DA (1978) A descriptive model for perception of optical illusions. J Math Psychol 17: 64–85.

Spehar B, Gillam BJ (1998) Modal and amodal completion in the Poggendorff illusion. Br J Percept 27(suppl.): 91.

Virsu V (1971) Tendencies to eye movement, and misperception of curvature, direction, and length. Percept Psychophys 9: 65–72.

Walker EH (1973) A mathematical theory of optical illusions and figural aftereffects. Percept Psychophys 13: 467–486.

Ward LM, Porac C, Coren S, Gingus JS (1977) The case of misapplied constancy scaling: Depth associations elicited by illusion configurations. Am J Psychol 90: 604–620.

Wickelgren BG (1965) Brightness contrast and length perception in the Müller-Lyer illusion. Vision Res. 5: 141–150.

Received 3 February 2004, accepted 15 October 2004