

EKSPERIMENTINIAI TYRIMAI

Three-part Oppel-Kundt illusory figure

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Key words: *filled-space illusion; length matching.*

Summary. *The Oppel-Kundt illusion was examined in the psychophysical experiments with the classical two-part stimuli and modified three-part figures. The modified versions comprised either one filled medial interval and two empty flanking intervals or one empty space situated in between two fillings. The illusion was measured as a function of the number of filling elements in the referential parts of the figures. The curves obtained by two modified figures and by the original two-part stimulus were quite similar in shape, but the magnitudes of the illusions differed significantly. The figure with two filled intervals yielded about twice-stronger illusory effect than the contrasting figure with a single filled and two empty intervals. The two-part stimulus showed the illusion magnitudes in the midst. Our assumption suggests the illusory effect being related particularly to overestimations of the filled interval when compared with the empty interval displayed side-to-side. The unfilled interval might not contribute to the illusion.*

Background

The German physicist, J. J. Oppel, was the first to demonstrate the filled-space illusion in 1855: an equidistantly divided line looked longer when compared with an undivided line of equal length. A. E. Kundt, another German physicist, further investigated the phenomenon (1). With years of studies, the Oppel-Kundt illusory pattern reshaped into the stimulus formed of vertical stripes with two contiguous spatial extents: one filled up with a regular sequence of stripes having the same size as the terminal ones, and the other extent empty. Still later, an analogous illusory figure formed of spots instead of stripes has emerged. Both for stripes and spots, the strength of the illusion was similar and varied with an increase in the stimulus length, number of the filling elements, and changes of the stimulus orientation in the visual field. The orientation anisotropy of the visual field appeared to be a separate distortion in perception, but it might add algebraically to the strength of the filled-space illusion in a simultaneous manifestation (2, 3).

According to the Hering-Kundt assumption, the filled-space illusion is caused by the perceptual integration of the length of a single part of the divided interval and the number of such parts. But the neural mechanism of the integration has not been established, and the Hering-Kundt assumption was conceived as

a special case of a more general information integrating model (4). The model was shown to be valid for the experimental data without any exception. There was another attempt to explain the Oppel-Kundt phenomenon by the difference of the averaged contour density in the two halves of the figure (5). Contour density may correspond to zero-crossing numbers within a range of spatial scales contributing quantitatively to the illusory effect (6). Yet, such an explanation failed for the illusory pattern with the infinite number of the filling elements, which convert into a continuous segment. According to the other view, the Oppel-Kundt illusion was due to the spatial filtering processes in the visual pathways. Qualitative and quantitative agreements were established between psychophysical measurements of the Oppel-Kundt illusion and predictions of the neurophysiological two-dimensional filtering model (7). The filtering concept was supported by the experiments with the colored Oppel-Kundt figures: the Oppel-Kundt illusion, like the Delboeuf and Zöllner effects, was slightly reduced at isoluminance referring to a lower sensitivity of the chromatic system to the higher spatial frequencies (8, 9). But, the data of the experiments with grouping of the adjacent stripes in the Oppel-Kundt pattern supported still other free-standing view. The illusion is likely to originate at higher functional levels gene-

rating size constancy, figural segregation, and the like (10).

The divergent concepts have made a simple straightforward explanation of the Oppel-Kundt phenomenon questionable. There might be more than one mechanism contributing to the compelling illusory effect. Nevertheless, there is no denying that new observations and experimental testing will appear capable of relating the particular illusion to the particular perceptual processes.

In relation to the idea concerning the perceptual integration of the stimulus elements, the present paper deals with the experimental study of the filled-space illusion generated by the modified Oppel-Kundt patterns in which three spatial intervals were aligned instead of two (Fig. 1). For the study, two symmetric figures formed of spots have been designed: one with the empty interval displayed in between of two filled flanks (Fig. 1A), and the second with a single filled interval flanked by empty intervals on both sides (Fig. 1B). We have put the three-part figures and the classic two-part Oppel-Kundt stimuli (Figs. 1C and D) under the experimental test and measured the magnitudes of the illusions as functions of the number of the filling spots. An objective of the experiments was the ability of the subjects to cope with the length matching task

in the three-space stimulus, and the main goal was the presence or absence of quantitative differences of the strength of illusions caused by different stimuli. In particular, the experiments seek to answer whether the perceptual influence of the two filled flanks differed from that of a single flank and whether a single filled extent was equally effective in the presence of one or two unfilled spaces.

Material and methods

Stimuli

All visual stimuli were drawn by the *Cambridge Research Systems VSG 2/3* and presented on the monitor *EIZO T562*. The monitor was placed at a distance of 400 cm from the observers at which one screen pixel subtended 0.3×0.3 min of arc. The monitor was calibrated and gamma corrected using a *Cambridge Research Systems OptiCAL* photometer. The stimuli were presented monocularly and centrally on an oval-shaped 200×267 min of arc background of 9 cd/m² luminance. The luminance of the spots was 55 cd/m², and the diameter was 2 min of arc. Movements of observer's head were limited by a chin holder, and an artificial pupil with a diameter of 3 mm was used to minimize the optical distortions. The experiments were conducted under control of computer software

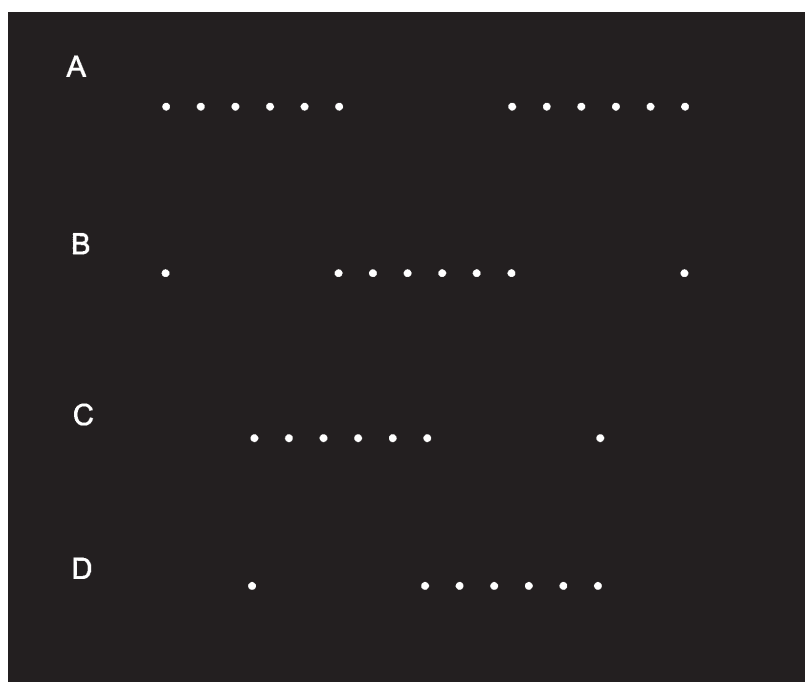


Fig. 1. Facsimiles of the Oppel-Kundt stimuli used for the length matching task

A, three-part figure with two referential intervals on the flanks; B, three-part figure with one referential interval in the middle; C, two-part figure with the referential interval on the left side; D, two-part figure with the referential interval on the right side.

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 the statistical analysis, the nonparametric Friedman ANOVA test was applied to the experimental data. For calculations, the procedures of the statistical toolbox of MATLAB (MathWorks) were used.

Procedure

The experiments were carried out in a darkened room, and subjects were asked to adjust the length equality in the three (or two) stimulus intervals. The filled intervals of the figures were considered as the references, and the empty spaces as the tests. The method of adjustment was used to establish 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 subjects manipulated the keyboard buttons varying the length of the test interval (or two intervals simultaneously) in the required directions by one pixel at a time. The initial length of the test interval of the stimulus was randomized: the length differences between the test and referential intervals were distributed evenly within a range of 15 min of arc. The subjects did not know in advance whether the computer program would show them longer or shorter than the length of the referential intervals. The length of the referential interval was always the same, 50 min of arc. The number of the filling spots varied from 0 to 24 in the referential intervals and was considered the independent variable. The number of spots in the two flanking references during a single stimulus presentation was identical. The spots were distributed regularly within the referential intervals with the same distance between the spots. The subjects were given no instructions concerning their gaze fixations in experiments. The 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

Seven observers, the University teachers and students, 20–68-year-old males and females, took part in the study. All the participants were normally sighted or were wearing their usual optical corrections. Five

of the subjects were naïve with respect to the goals of the study, and all gave their informed consent before taking part in the experiments performed in accordance with the ethical standards of the 1964 Helsinki Declaration. Permission for the experiments was received from the Ethics Committee of Kaunas Biomedical Research (protocol No. 23/2004).

Results

In the experiments with the stimuli comprising three spatial intervals, the subjects reported no difficulties in performing the length matching task. Like in the experiments with the two-interval stimuli, the subjects were able to judge whether the test parts differed in length from the references, and they could achieve the required equality by varying the terminal spots of the test intervals. The results obtained are compatible with the earlier discovered most important findings (11–14) on the illusion: spaces containing nothing look less wide than spaces divided by a regular sequence of objects; the strength of the illusion changes as a function of the number of the filling objects; the illusion maximum appears at intermediate numbers. The summarized results of our experiments performed by seven observers are shown in Fig. 2. The upper and lower curves in Fig. 2A correspond to the three-part stimuli with the filled and unfilled flanks, respectively. The middle curve shows the averaged data obtained using the left and right orientations of the two-part stimulus. Evidently, the magnitudes of the three illusions differ. The results of the Friedman ANOVA testing, shown in Fig. 2B, confirm the statistically significant difference between the means of the three data sets. The three-part Oppel-Kundt figure with two empty intervals causes the smallest illusion. It is about 1.3–1.5 times weaker than that of the two-part stimulus and about 1.8–2 times weaker than that of the three-part figure with two filled intervals. The corresponding maximum values are 8.7, 12.5, and 15.5 min of arc. However, the shapes of the three curves appear to be similar. The strength of the three illusions grows with an increase in the number of the spots in the referential intervals of the stimuli from 0 to 4 independently of the stimulus type. The maximum values are achieved by 4 filling spots (plus 2 terminal ones). The numbers more than 4 yield a tendency of the illusions to decrease gradually, which remains relatively strong even when the spot number increases up to 24.

The three-part Oppel-Kundt figure displayed vertically provided about the same magnitude of the illu-

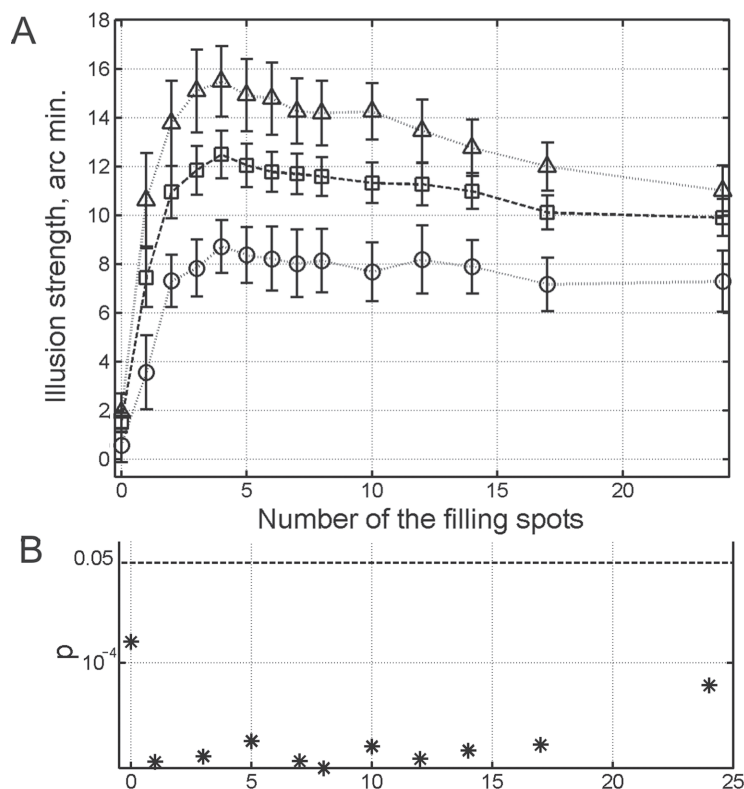


Fig. 2. The Oppel-Kundt illusion as a function of the number of the filling spots for seven observers

A, the three-part horizontal stimulus with two and one referential intervals, upper and lower curves, respectively, and of the two-part stimulus, middle curve. Vertical bars, 0.95 confidence intervals. The averaged data for seven observers. B, probability of equality of the three data sets. (Subjects, A.B., A.I., A.L., E.O., S.A., T.A., T.O.).

sion as the horizontal one (Fig. 3A). The experiments with two-part vertical stimuli showed also approximately the same magnitude of the illusion as that with the horizontal stimulus orientation, but the opposite versions of both the horizontal and vertical stimuli showed different magnitudes (Figs. 3B and C).

Discussion

The data of the present experiments indicate that the magnitude of the Oppel-Kundt illusion is strongly influenced not only by the number of the filling elements but also by the number of the stimulus parts and their composition. An extra interval, filled or empty, added to the classical two-part stimulus causes the changes in the illusion strength: the empty interval makes the illusion weaker, whereas the filled one makes it greater. These effects ensure an impression that the illusory effect might be related both to the filled and empty intervals, i.e., the illusion may be due to an integration of overestimations with underestimations of the contrasting stimulus parts like in the Müller-Lyer and related illusions of extent. In

accordance to such a point of view, a set of conclusions might be drawn: 1) overestimation of a single filled interval appears to be reduced in the presence of two empty flanks; 2) simultaneous overestimations of two filled intervals overbalance the overestimation of one filled interval; 3) underestimation of a single empty interval is enlarged in the presence of two filled intervals; and 4) underestimation of a single empty interval overbalances underestimations of two empty intervals. All four statements taken individually do not contradict the experimental data, but if combined together in relations to one another, they suggest some other scheme in the illusion interpretation. The illusory effect may be due to the filled intervals only while the empty intervals do not contribute to the effect. The hypothetical neural information integration processes give rise to a homogenous extension of the excitatory pattern of the filled interval and leads to an increase of the perceived distance between the terminators, but not to the terminator mislocations into the opposite directions. The perceived changes in the excitatory pattern of the empty interval are relatively

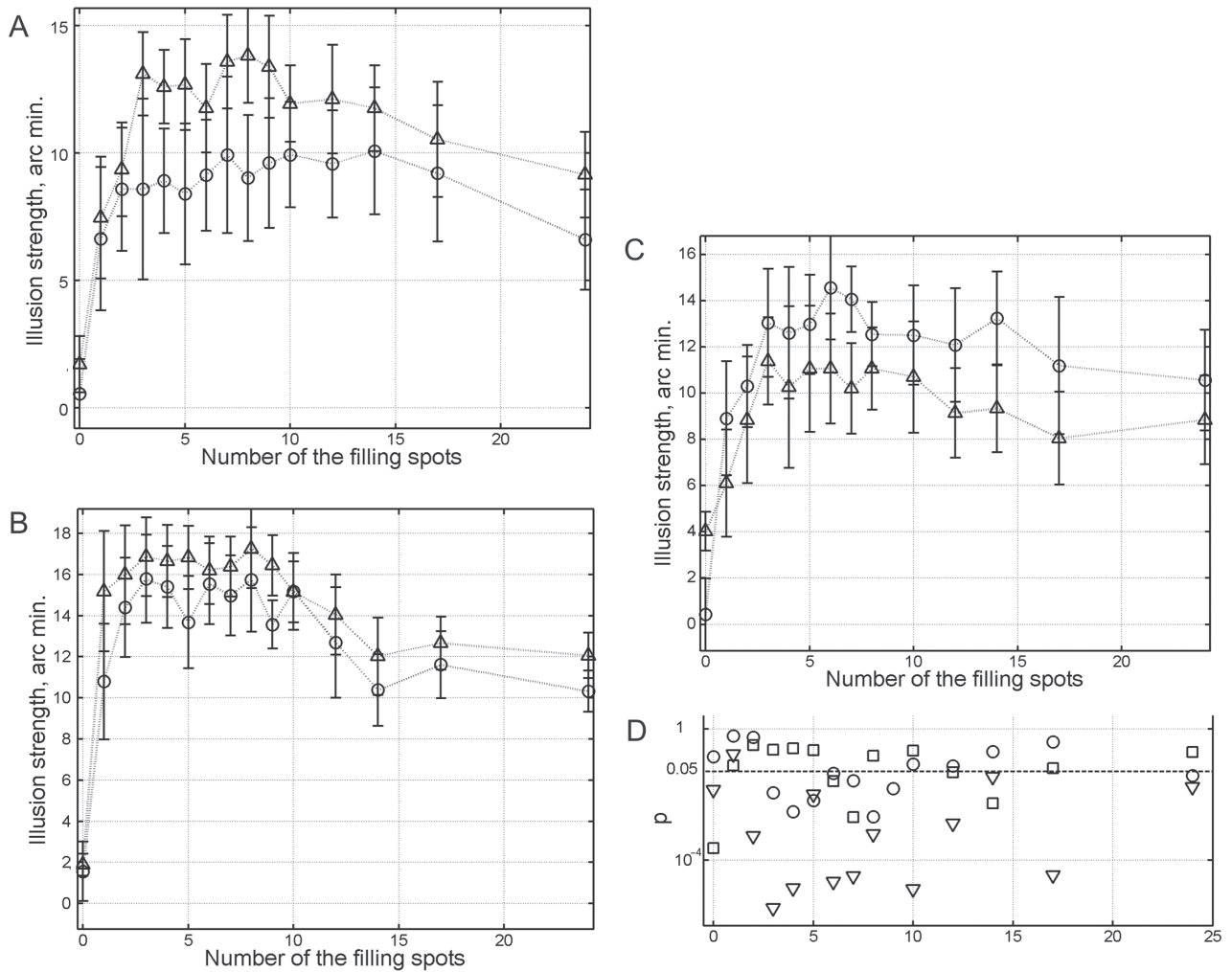


Fig. 3. The Oppel-Kundt illusion as a function of the number of the filling spots

A, in the two referent intervals of the three-part vertical (circles) and horizontal (triangles) stimulus; B, in the referential interval of the two-part horizontal stimulus with the left (circles) and right (triangles) orientations; C, in the referent interval of the two-part vertical stimulus with the top (circles) and bottom (triangles) orientations. Vertical bars, 0.95 confidence intervals. D, probability of equality of means of the data sets given in plot A (circles), in plot B (rectangles) and C (triangles). Subject, A.I.

small, if any, because only two spots are present. Therefore, the excitation patterns of the empty intervals remain perceptually constant in size. The sizes of two contrasting excitation patterns appear to be estimated as separate entities in the performances of the length averaging, or bisection, or matching tests, irrespective that the medial terminator is common for both the filled and empty spaces.

The ratios of the maximum values of the illusion strength found in the present experiments (Fig. 2) are 8.7:12.5:15.5 min of arc. They provide a support for information integration rather than for summation of the lengths of single segments within the divided intervals during the length averaging procedure in the Oppel-Kundt stimulus. For instance, the number of

segments is the same in the two-part and three-part figures with one filled interval, but the illusion strength is different, i.e., 12.5 and 8.7, respectively. This leads to an assumption that the illusory effect is proportional to the relative length of the referential filled space (referential length / total stimulus length). Therefore, the illusory error may be shown as kL/n , where L is the physical size of the filled part of the stimulus, n is the number of intervals of the same size, and k is the proportionality coefficient. In the two-part Oppel-Kundt stimulus, when the two different objects – filled and empty intervals – are matched in length, the perceptual error may be estimated as $kL/2$. For the three-part stimulus, the length matching task requires averaged judgments on the perceived equality between

the medial interval and two flanks. When the two filled flanks are displayed, the perceptual error is $k2L/3$. When the two empty parts are at flanks of the central filled interval, the matched error is $kL/3$. Consequently, the ratios of the illusory percept of the stimuli comprising either two empty flanks, or a single filled-empty pair, or two filled flanks are $1/3:1/2:2/3$, i.e., $2:3:4$. These are close to the ratios of the maximum values of the illusion strength found in the present experiments, which might be represented as $2.12:3.05:3.80$. More, the found ratios of the illusion strengths averaged within the interval of the filling spot number from 1 to 10 are $2.03:3.07:3.89$ (Friedman ANOVA test, $P<0.05$).

The illusion strength of the two-filled-flank stimulus in the vertical and horizontal orientations is supposed to be the same – $k2L/3$. The illusion strength obtained in the experiments with the two orientations does not differ significantly (Fig. 3). There may be some explanations of the absence of the anisotropy manifestation: the stimulus elements, the spots, do not show any orientation cue and remain identical in appearance when the stimulus is rotated; the three-part Oppel-Kundt figures are symmetrical patterns in contrast with the two-part stimulus, which has the top- and down-, left- and right-winged orientations; the length averaging procedure is evidently performed in the tests with three-part stimulus.

Our experimental data testify to the illusion origin being related to the filled intervals exclusively. The computational modeling is beyond the limits of the present communication, but the development of pre-

vious models of the illusory percept can be suggested for adequate studies with employment of both the two-part and three-part figures. Two versions of the three-part Oppel-Kundt figure formed of spots demonstrate their individual properties, and both the patterns might become an object of interest in studies of the illusion origin.

Conclusions

New versions of the Oppel-Kundt stimulus – the three-part illusory figures formed of spots – were proposed. One version comprised an empty central interval and two filled flanks, the other, conversely, consisted of a filled central interval and two empty flanking ones.

The magnitudes of the illusions obtained by two versions of the modified stimulus and by the classical two-part figure were found to be different: the ratios of the illusion strengths averaged within the interval of the filling spot number from 1 to 10 were $3.89:2.03:3.07$.

The magnitude of the Oppel-Kundt illusion is influenced not only by the number of the filling elements, but also by the number of the stimulus parts and their composition. In the three-part stimulus, the two filled references are more influential than a single one, and their resulting effect may appear as twice large.

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Trijų dalių Oppel-Kundt iliuzinė figūra

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Raktažodžiai: užpildyto intervalo iliuzija, ilgių palyginimas.

Santrauka. Tiriama Oppel-Kundt iliuzija, panaudojant psichofizikiniams eksperimentams standartinę dviejų dalių stimulą bei modifikuotą trijų dalių simetrinę figūrą. Standartinę stimulą sudarė vienas tuščias ir vienas užpildytas intervalai, o modifikuotąją – viduryje tuščias, o šonuose du užpildyti intervalai arba užpildytasis viduryje ir du tuštieji šonuose. Buvo matuojama iliuzijos stiprumo priklausomybė nuo užpildomųjų elementų skaičiaus. Trijų stimulių eksperimentinės kreivės yra panašios forma, tačiau patikimai skiriasi iliuzijos stiprumo reikšmėmis. Simetrinė su dviem užpildytomis dalimis figūra sukelia beveik dukart stipresnę iliuziją nei analogiška vieno užpildyto intervalo figūra. Dviejų dalių stimulo sukelta iliuzija yra tarpinio stiprumo. Daroma prielaida, kad Oppel-Kundt iliuzijos tiesioginė priežastis yra būtent užpildytojo intervalo erdvinė struktūra, kai lyginami to intervalo ir greta esančių tuščiųjų ilgiai. Pastarieji patys savaime įtakos iliuzijai neturi.

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