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THE MECHANISMS OF LINES FRAGMENTS ORIENTATION AND LOCATION IN THE DEPTH PERCEPTION

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INTRODUCTION

Vision is the most important human analyzer which assists in providing a person with 90% of information from the environment. One of the main objectives of a person is to orient in the surrounding environment and perceive the objects in this environment. Speaking about vision, it should be pointed out that a person analyzes not objects themselves, but their images reflected in the retina of an eye. Since the receptors are not directly stimulated by an object itself, but its image, the object image is a *proximal visual stimulus* and the object itself is a *distal stimulus*. It should be pointed out that one object (distal stimulus) creates many images in the retina (proximal stimuli). As a result, visual perception becomes more complex – one object image does not define an object itself. A question arises as to which features of an object image are important in perception of an object.

An object image is split in separate fragments in retina (we make the image discrete or create a mosaic image) and excrete local features essential in perception. Since distinct images can contain the same features, one has to be able to create a global image using these local features. This task is not associated with local information processing. Thus there are at least two stages of information processing – local and global. This thesis is concentrated only on the local mechanisms of visual image processing.

It should be determined what local features are significant to image recognition and how these features are coded in a visual system. For example, colors, situation of an object or its fragments in the space are very important features in recognizing the objects. Alongside the list of necessary features, it is also important to know how these features are coded in the visual system. Thus we encounter two different problems. Firstly, it should be estimated what features are essential and then it should be determined how they are coded in the visual system.

For the solution of the first problem, important images seen by a person are being analyzed. In this stage the whole image is fragmented into a number sequence which specifies the intensity of the points (pixels). This kind of number sequence is constructed for various images. Then the statistical analysis of this number array is performed – the minimal number of features are attempted to extract which could help in depicting the images in the surrounding. These calculations usually involve principal component method (described in detail in Olshauseny, Field, 1996, 1997; Hoyer Hyvärinen, 2000;

Hateren, Schaaf (1958); Yin, Allinson, 1995). Surely the list of necessary features depends on the surrounding and the tasks carried out by a person. It was demonstrated that in typical conditions the essential features are a color of separate fragments (i.e., luminance, color tone, and intensity), the orientation of a part of an object image which is in an analyzed fragment, direction and speed in which the fragment is moving, position of a separate fragment in the retina and the interposition of separate fragments, distance between them and etc.

The further question is how the visual system "is able to evaluate specifically" the importance of a feature (for example, the color, the orientation of a contour, the distance between separate fragments and etc.). It also should be determined how separate features are coded in the visual system and if there are any general coding mechanisms.

The features determined by other authors using aforesaid methods were used in this study – object contour orientation and fragment distance. Tilt after-effect and normalization effect were studied in order to explain the coding mechanisms of orientation. TAE – the perceived line orientation depends on the physical line orientation and line orientation, which was presented earlier. Normalization effect – the perceived line orientation shifts while observing the particular line orientation for a long period of time – according to Gibson, it tilts toward the closest vertical or horizontal orientation (Gibson, 1937). Although these effects are studied (TAE is studies more (Clifford ir kt., 2000, Clifford ir kt., 2001, Gibson, 1937, Gibson, Radner 1937, Westheimer, Gee, 2002)), but the aforementioned effects were not used before in order to determine the coding mechanisms. These observed phenomena can be used in general model revision (Fomin et al, 1979; Vidyasagar, 1985, 1987; Vidyasagar, Urbas, 1992; Vidyasagar et al, 1996). No experimental studies were found to do that.

Another important question is how a person determines the orientation of image elements in space and estimates the distance between two points. This question is not studied and understood all through, how a person determines and estimates the distance between two points. For example, according to the concept of "local signal", introduced by Muller and Hering, we cannot understand how a person might perceive the alteration of an object orientation when its image in the retina moves only by one fifth of the photoreceptor (hypersensitivity phenomenon) (Heeley, 1987).

It is known that sometimes the perceived features on an object do not correspond to the physical parameters, for example, the perception of an object size. While the distance to the object changes, the size of an object image also changes in the retina, the image is being distorted, but the change of object perception does not directly depend on the change of object image in the retina; thus the interaction between these two matters is relevant.

It is also known that the image of the surrounding (or an object), which is projected onto the retina of an eye, is thus being distorted – the image which is in the central part of a retina is perceived as larger, and which is perceived in the peripheral part is smaller. There are two explanations of these known phenomena.

Supposedly this phenomenon is associated with mechanisms of attention (alignment mechanisms). Person’s sensitivity to changes of an object location in the field the attention is focused on increases. According to the law of Fechner, minimal, hardly noticeable change is perceived as stable minimal sense measure unit. If different physical distances are a size of a threshold, then subjectively they are perceived similarly. Since the field the attention is focused sensitivity is increased (absolute thresholds are lower), then in this case the same physical distances above the threshold will be perceived as higher in the attention field than in other fields.

The second hypothesis is concentrated on finding physiological mechanisms associated with alignment effect. The cortical magnification factor (CMF) is used (Schwartz, 1994). It was demonstrated that central part of the retina sends signals to the major than the peripheral part of the visual cortex. Therefore, the image in the central part of the retina is projected onto the major part of the visual cortex than the image which is in the peripheral part of the retina, i.e., when the image is sent to the cortex, it is being stretched and enlarged. It is assumed that the size of an image on the cortex is proportionate to the perceived size. Thus the same physical image in the center and in the periphery of the retina will be perceived as of a different size. In the first case it will be perceived as being larger than in the second case. However CMF is valid only when the image is in the central part of the retina (fovea). It is still unclear what happens when the image is created in a non-foveal part, but outside of its range, where only rods are present. Hence the subjective distortions of perception when the image changes its position in the retina of an eye – when it is moved from the central part to the peripheral part of the retina – still remain unclear. Is the change of an image size perception uniform moving the image from the center to the periphery? What does the change in object size perception depend on, when the place of an object image projection changes in the retina of an eye? Therefore one of the study objectives, according to the general feature coding model, is to determine how the object size perception changes when its projection place changes in the retina.

Study results and conclusions would not only assist in understanding the human visual perception, but also would have practical value. For example, in creating the visual aids, exploring the estimating the size, when the objects are projected on the different parts of the retina. Another example is when the driver needs to estimate the distance between the objects correctly, when the object projections reach different parts of the retina, or when the lighting changes, the functioning receptors change. In photopic lighting cones take over most of the vision, when in mesopic lighting rods operate additionally.

The aim of this study is to ascertain how the coding mechanisms of two features significant in perception (contour orientation and distance between separate fragments) can be determined in an experiment.

Objectives.

1. Explore TAE and normalization effects and create an explanatory model.

2. Explore how a person perceives the distance between two points when the sight fixation changes and determine what mechanisms are associated with the phenomena observed in the experiment.

Defended statements.

1. A new and unknown TAE characteristic was determined: alongside with known vertical and horizontal lines, that do not influence the orientation perception of the lines presented afterwards, two additional line orientation of 22,5° and 67,5° exist, that have the same characteristics.
2. New and unknown normalization characteristics were determined. When observing one line for a long period of time, its orientation perception changes, it not only rotates toward the closer vertical and horizontal line (which is already known), but also towards the closer line of the orientation of 45°. Moreover, there are two additional line orientations which change is unstable,

i.e., the direction of change is unstable. These are the lines with orientation of 22,5° and 67,5°.

3. TAE and normalization characteristics can be explained using a model, describing the coding of ratio of two selective to orientation neurons responses.
4. Image size changes unmonotonously, shifting the image from center to periphery of the retina.
5. Image in the center is subjectively increased to maximum, shifting the image from center to periphery, firstly, the perceived image decreases, but at approximately 7-13 degrees of the visual angle, it begins to increase.
6. Uneven perception of the image size when its position changes in the retina of an eye, correlates with the change of general density of photoreceptors: receding from the center of retina the general density of photoreceptors decreases (cones predominate fovea, their density towards the periphery decreases rapidly), later the density of rods is significantly greater that of cones, and their density towards the periphery increases rapidly.
7. The model of subjective image size evaluation is introduced – the central weight of the image position is determined by the ratio of 4 neurons response (similar to the color coding by the ratio of 3 cones response).

METHODS

Influence of prolonged viewing of tilte lines on perceived line orientation: tilt after-effect

Subjects. Three subjects (two men and on woman) who knew nothing about the TAE took part in experiments. All subjects had normal or corrected-to-normal vision with no astigmatism. All subjects were experienced with psychophysical experiments. Informed consent was obtained from the subjects after the explanation of the nature of the study.

Stimuli. There were two kinds of stimuli: the adapting and testing lines displayed at different Times but in the same place of the visual field. Adapting lines were three parallel straight lines of the given orientations ($\varphi_a=\varphi_t+0°$, $\varphi_t \pm 10°$, $\varphi_t +22.5°$, $\varphi_t +35°$, $\varphi_t +45°$ and $\varphi_t +67°$), where φ_t is the orientation of the testing line (see below). Adapting lines were presented in the centre of the monitor screen. They subtended 2x0.1 deg of arc and they were separated from each other by 15 min of arc.

The testing line was of the same length and width as the adapting one. The orientation φ of that was changed by 0.5° steps within interval φt −0.5°n ≤φ ≤ φt +0.5°n_, where n was randomly chosen from 0 to 10, and φt =0°, 22.5°, and 45°. Thus the overall number of the generated testing lines for the given adapting ones was 21.

Procedure. Subjects were exposed about 15 min of complete darkness at the beginning of each experiment. A special bite bar was used to immobilize the subject's head. Subjects viewed the stimuli with one eye through a cilcular aperture positioned 1 m from the screen. The size of the circular visual field was 20 deg of arc. The subjects had to fixate on the center of adapting lines where, after swiching them off, one of the 21 possible testing lines was immediately displayed. Figure 1 demonstrates the sequence of stimuli presentation under investigation of the tilt after-effect phenomenon.

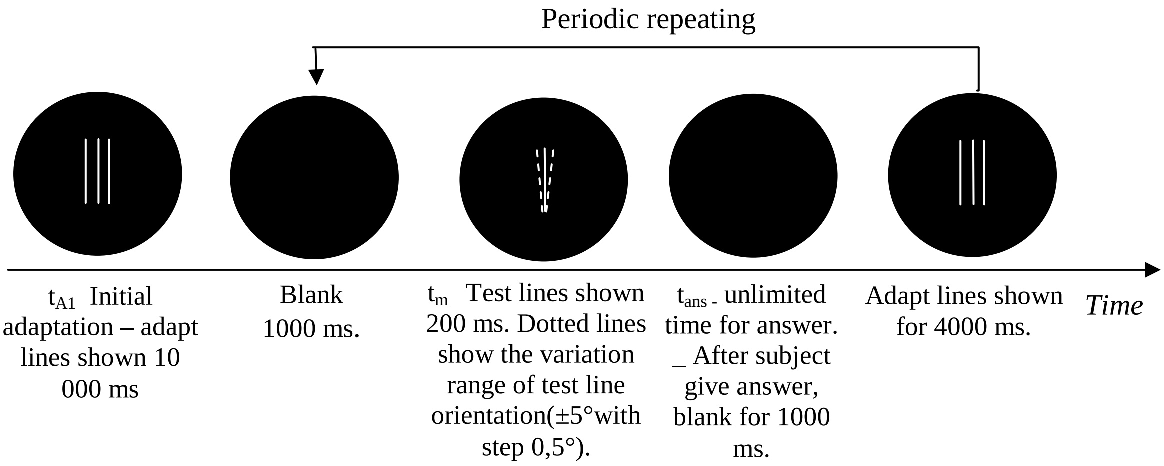

Figure 1. **The sequence of stimuli presentation under investigation of the tilt after-effect phenomenon**

In the beginning of each experiment the subject was adapted about 15 min in an almost completely dark room (the single source of light was a blank monitor screen). After that the adapting lines were generated by PC in the center of the monitor screen for t_{A1}=1–2 min. The testing line followed the adapting ones. It was displayed in the same place on the screen as the adapting lines for about t_m=0.5–1.0 s. The subject had unlimited time t_{ans} to make the decision, but he was encouraged to respond as soon as possible. After a short readaptation time t_{rad}=10 s, over which the subject viewed the blank screen, the adapting lines were again displayed in the center of the screen for 1–2 min. Thus, the adapting lines displayed in the center of the screen were seen only during the adaptation time t_{A1}.

We used a two-alternative forced choise method: the subject had to press the appropriate key indicating if the displayed testing lines were perceptually rotated clockwise or counterclockwise relative to the given line tilted physically by φ_t, which was specified by 0° or 22,5° or 45°. Test line orientation during one experiment session was the same. The session lasted until the subject made five estimations for each line (overall 105 estimations). Each session was repeated at least five times, i.e., we obtained 525 estimations for each adapting line.

Data Analysis. As the aim of the experiment was to estimate the maximal size of TAE we computed the psychometric function. Using the psychometric curve we measured how much the perceived orientation of the given line physically tilted by $\_\varphi_t\_$ was changed after prolonged viewing of the adapting line tilted by φ_t. The maximal value $\Delta\varphi_{alt}\_$ of the TAE was specified for the given orientation (φ_t) of the testing line under 5–7 orientations of the adapting line.

Influence of prolonged viewing of tilte lines on perceived line orientation: normalization effect

Subjects. There were five observers with ages ranging from 25 to 60 years. all subjects had normal or corrected-to-normal vision with no astigmatism. Three subjects were not aware of the purpose of the experiment. All subjects were experienced with psychophysical experiments. Informed consent was obtained from the subjects after the explanation of the nature of the study.

Stimuli. The stimuli were generated by PC on a Philips 201CS monitor (1600x1280), refresh rate 75 Hz, the length of screen diagonal 53,34 cm). The stimuli were presented on a blank screen and luminance was set at 80 cd/m^2. Subjects viewed the stimuli with one eye through a circular aperture positioned 1 m from the screen. The size of the circular visual field was 20 deg of arc. A special bite bar was used to immobilize the subjects head. We displayed adapting and testing lines in different parts of the visual field to assess chantes in the perceived orientation of adapting lines. The distance between adapting and testing lines was equal to 6 deg of arc. Alll lines were 2 deg of arc in lenth, 10 min of arc in width. Adapting lines were separated from each other by 15 min of arc. We used five different orientation of adapting lines φ_a=-10°, 10°, 35°, 55°, 80°. The orientation of testing lines varied randomly every $\Delta\varphi$=0,5n deg where n is a random integer ranging from -10 to 10. There were total of 21 orientations generated. The orientation angle can be expressed as $\varphi=\varphi_a+\Delta\varphi$ (i.e., $\varphi_a-5°\leq\varphi_a+5°$).

Procedure. Figure 2 demonstrates the sequence of stimuli presentation under investigation of the normalization phenomenon.

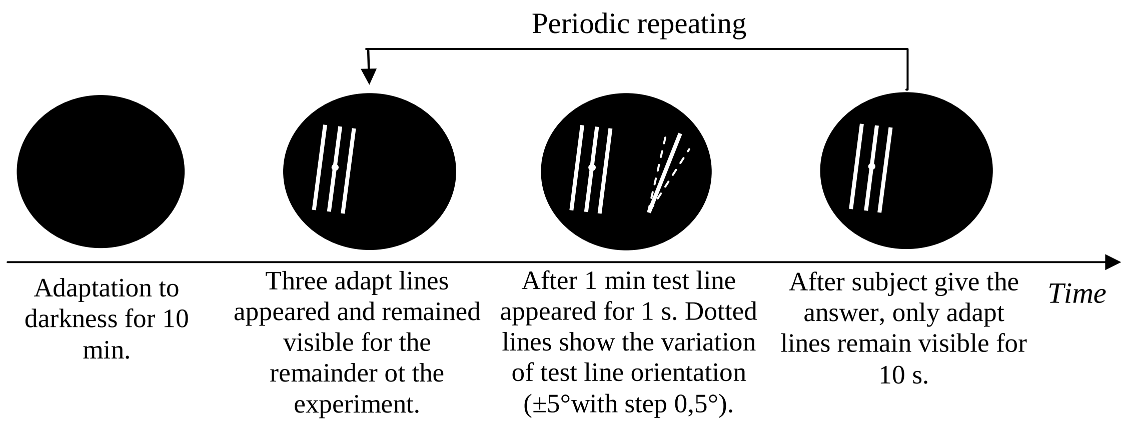

Figure 2. **The sequence of stimuli presentation under investigation of the normalization phenomenon**

Subjects were exposed to 10 min of complete darkness at the begining of each experiment. After that three adapt lines appeared on screen and remained visible for the remainder of the experiment. After 1 min the test line appeared for short time (1 s). Pressing the appropriate key, the subject indicated if the testing line were rotated clockwise or counterclockwise relative to the adapting lines (2-alternative forced choise method). The subject has unlimited time to make the decision, but he was encouraged to respond as soon as possible. Each response by the subject was followed by a 10 s periodo f readaptation.

Data Analysis. As the object of the experiment was to identify only the direction of changes of the perceived line orientation, we did not use the psychometric function. We used a more simple and sensitive method to estimate the direction (not size) of the subjective changes of perceived orientation. We used the Kolmogorov–Smirnov and

Shapiro–Wilk tests to confirm that our data were normally distributed. We also used nonparametric analysis methods to compare and estimate the effect of adaptation on the perception of two groups of lines. The first group of lines was oriented by −10°, 35°, 80°, the second group was oriented by 10° and 55°.

According to predictions mentioned above, the first group of lines should be subjectively rotated clockwise, and therefore the number of *Ra* responses (the testing line is rotated counterclockwise relative to perceived adapting line) should be greater than the *Rc* responses.

Perceived size of a line depending on its projection place on the retina

Subjects. 30 psychology students selected by occasional sampling method participated in the study. 25 of them were women and 5 were men. They were not aware of the study objective. Subjects' vision was normal or corrected till normal. Subjects were trained before every testing, observed during testing if they are doing it correctly; the questions were answered by study investigators.

Study methods and stimuli. The program (designed by Visual Basic 4.0) generated the fixation cross, the horizontal line and marker (all white (D_{65})) in the black background in the center of the monitor. Lines were 5, 7, 10, 13, 15 deg of arc in length, 5-10 min of arc in width. Brightness of stimuli was 40-60 cd/m^2 (Michelson contrast about 0,9). Fixation cross was located to the left or right side of line. The location of fixation cross was chosen to avoid the image of line projection on the blind spot.

Study procedure. Before the experiment the participants were provided with instructions, any ambiguities were explained.

Testing took part in the day lighting (the lighting of the room was 50-100 Lx). The participant had 15 minutes before testing to adapt to the room where the testing took place. The participant sat down comfortably in front of the monitor in order to see clearly the stimuli generated in the monitor. One eye was covered and the position of the head was fixed. If the participant felt tired during testing and he had trouble in focusing, he could take breaks in the same room, so the lighting conditions did not change and the additional time for adaptation was not necessary.

The participant had to focus his sight to the cross and at the same time with the help of the keyboard arrows move the cursor and fix it so the two parts of the line were perceived as the same length (equal). He participant fixed his answer with the press of the key on the keyboard. The participant was not informed about the accuracy of line division. Right after the line division the following line was presented. The computer program was set so that the initial position of the cursor would change randomly with every line presentation, in order to avoid participant learning.

Repetitions. One series of testing with the same length line was called a series, in which the participant divided the line 40 times. 5 participants performed 4-7 and 25 participants performed one testing series. Since there are 5 different line lengths (5, 7, 10, 13, 15 degrees), each one of the 5 participants performed 800 – 1400 line divisions, 25 participants performed 200 line divisions each. 5 participants took part in other studies, therefore their number of tests was larger.

Data analysis. The results were the lengths of line parts in pixels. These lengths were transformed into angular lengths. The mean of line parts, scatter parameters (standard deviation, dispersion) were computed. In order to estimate the accuracy of line division, the ratio of line parts was computed, dividing the part of the line closest to the fixation point by the rest of line length. Distribution of the results was tested using Kolmogorov-Smirnov Z-test. The differences between separate line lengths were compared using Mann-Whitney U-test.

RESULTS

Influence of prolonged viewing of tilted lines on perceived line orientation: tilt after-effect

If the given line with particular orientation stimulates only one neuron (sensitive to line orientation), the adaptation should not influence the perceived orientation (TAE would not be apparent). The aim of this experiment was to examine the mentioned assumption that lines whose orientations are 22,5° and 67,5° the adaptation should not influence the perceived orientation.

The generalized results of all the participants are presented in Figure 3, which illustrates the greatest value (in degrees) of the tilt after-effect depending on the continuous line orientation.

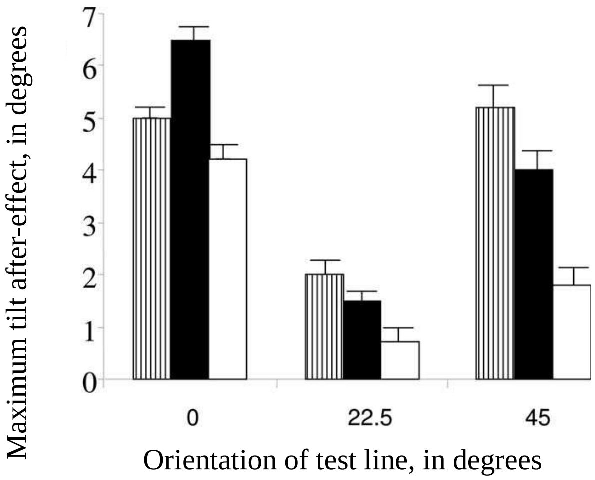

Figure 3. **The greatest value (in degrees) of the tilt after-effect depending on the continuous line orientation in three participants. Confidence intervals of 99% were established. Different bar fillings indicate different participants**.

As we can see in Figure 3, tilt after-effect is lowest when the continuous line orientation is 22,5°. When the continuous line orientation was 0°, 45°, TAE was significantly greater. As we can see, in this case TAE effect is not equal to zero.

This can be explained so that the perceived orientation also depends on the orientation contrast effect (simultaneous contrast, which sharp angles are subjectively enhanced and the blunt angles are reduced), t.y., because of the inertia there is the interaction between the adaptive and continuous lines (Sekuler, Littlejohn, 1974; Vaitkevicius et al, 2009).

Influence of prolonged viewing of tilted lines on perceived line orientation: normalization effect

The aim of the experiment was to test if the perceived line orientation is changing subjectively approaching the vertical, 45°, and horizontal line orientation in the course of adaptation. During the experiment, the participants had to estimate the orientation of the continuous line orientation pressing one of two keys which meant that a perceived continuous line is rotated counterclockwise or clockwise. There was no intermediate answer, therefore if the participants were not sure which way the continuous line was oriented, they had to guess. The distribution of the results was normal (according to Kolmogorov-Smirnov Z-test, $p \leq 0,2$). General results of all the participants are presented in Figure 4.

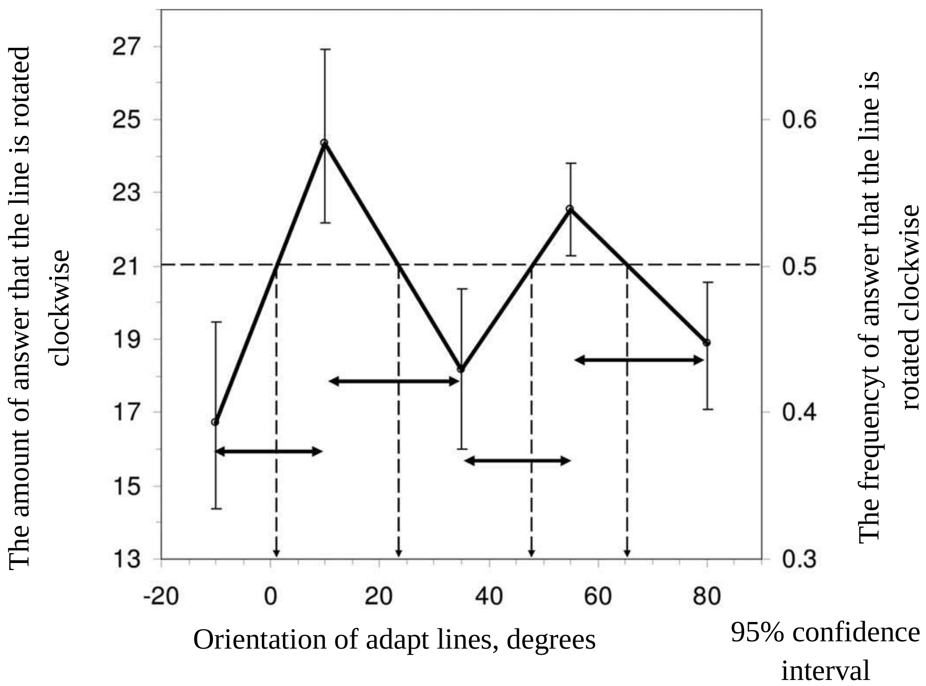

Figure 4. **Response, that a continuous line is rotated clockwise, number and relative frequency dependence on the line after-effect in degrees. Black points are the values of the perceived tilt effect. Vertical line – confidence interval of 95%. X-axis – orientation in degrees. Horizontal arrows indicate the changed direction of perceived orientation.**

Figure 4 presents dependence of the chosen answer on the adaptive line orientation. The result explanation can be the following. If the participants chose the answer more often that the line is rotated clockwise, then the tilted lines subjectively appeared to be rotated counterclockwise to the participants. Positive angles mean that a tilted line was perceived as rotated clockwise from the vertical. The dotted line shows the possible answer frequency if there were the same number of answers that a continuous line is rotated clockwise as the answers that a continuous line is rotated counterclockwise. In this case the participant would decide randomly and the mean of perceived orientation would be equal to the value indicated by the dotted arrow (mean deviation from this value would be equal to zero). Solid horizontal arrows show the direction of subjectively perceived change in orientation. In the course of adaptation the line subjectively rotates toward the closest vertical (0°), horizontal (90°) or 45° orientation. Lines whose orientations are 22,5° and 67,5° are perceived as stable with insignificant changes.

This way the dotted arrows show the orientations which should not be influenced by adaptation – the normalization should not be present here. So that the normalization effect is not present while observing the vertical (φ=0°) and horizontal (φ=90°) lines was observed by J. Gibson. However, the fact that this is also characteristic to other line orientations ~22,5°, ~45°, and 67,5°, is not known.

Perceived size of a line depending on its projection place on the retina

The obtained results – the lengths of line parts in pixels were transformed to arc lengths (in degrees) in order to compare the results of individual participants. Then the ratio of line part near the fixed (F) cross (*further indicated as A*) and the rest part of the line (*further indicated as B*) was computed.

The ratio A/B shows how accurate was the participant in dividing the line. If the ratio A/B is equal to 1, the parts of the line are equal (A=B) and the line is bisected exactly in the middle. If the ratio A/B is lower than 1, then the part of the line near the fixed cross is shorter than the rest of the line (A<B). If the ratio A/B is greater than 1, the part of the line near the fixed cross was indicated as longer than the rest of the line (A>B).

During study, five lines of different lengths were presented, therefore it was analyzed how the accuracy of line bisection changes (according to the ratio of the line parts A/B) depending on the line length. The study results show that the participants divide different lines in different accuracy – some line lengths are bisected with least accuracy. Line bisection accuracy (line part ratio) dependence on the length of the line is not even – there is a breaking point. The results of the participants were grouped into three groups, according to the place of the breaking point in the line part ratio A/B depending on the line length. The first (results of 20 participants) and the second (results of 5 participants) group mean results are presented in Figures 5 and 6, and the third group (5 participants) was not analyzed, because line part ratio A/B curve order had no clear tendency.

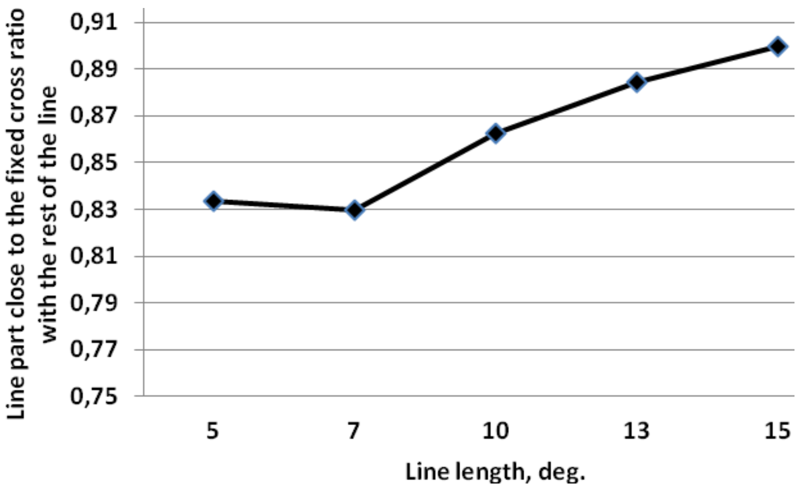

Figure 5. **Line part ratio dependence on the line length. Mean results of 20 participants. Axis X represents line length in degrees, axis Y represents line part ratio – line part close to the fixed cross ratio with the rest of the line.**

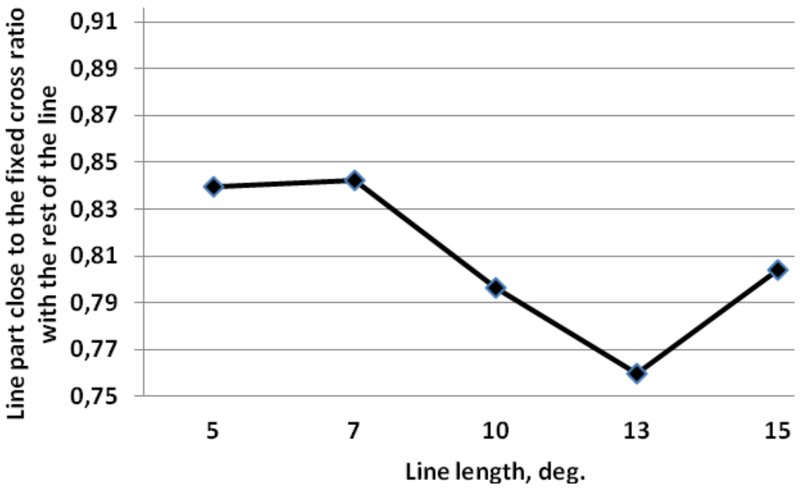

Figure 6. **Line part ratio dependence on the line length. Mean results of 5 participants. Axes represent the same values as in Figure 5.**

We can see that participants are dividing the lines not exactly in the middle. Line part A close to the fixation cross is estimated as shorter that the rest of the line. It was also observed that the ratio A/B of different length line parts depending on the line length changes unevenly (Figures 5 and 6). First group consists of the results of 20 participants; they made the greatest error (the ratio A/B of line parts was lowest), when the lines were 5-7 degrees in angular length (Figure 5). Second group consists of the results of 5 participants' they made the greatest error (the ratio A/B of line parts was lowest), when the lines were 13 degrees in angular length (Figure 6). The rest of the 5 participants' line part ratio A/B dependency on the line length curve did not have a clear change tendency, therefore it was not included in either of the two groups and were not included in further analysis.

It was tested if differences in line bisection accuracy, dividing lines of different lengths, are statistically significant. Since not distributions of the results were normal, nonparametric Mann-Whitney U-test was chosen in order to compare if the accuracy of different line length bisection is significantly different. Mann-Whitney U and p-values, according to Mann-Whitney U-test, of the first group are presented in Table 1.

1 table. **Mann-Whitney U and p-values are obtained estimating the difference significance in accuracy of line bisection in the first group of participants.**

Line length, degrees	Mann-Whitney U value	p-value
5-7	596307,0	0,326
7-10	512027,0	0,000*
10-13	512577,0	0,000*
13-15	524726,0	0,001*

[1]According to Mann-Whitney U-test

Statistically significant difference between the accuracy in bisection of different line lengths were not obtained, except when comparing the ratios of line parts of 5 and 7 degrees in angular length. All the rest line part ratios when compared in pairs of adjecent line lengths (7-10, 10-13, 13-15), statistically significant differences were found.

As we can see from the change tendency of the line part ratio in the first group, the curve minimum is when the line length is 7 degrees. Therefore it is important to ascertain if the minimum of this curve (when the line length is 7 degrees) is significantly different from the adjacent points (when the line lengths are 5 and 10 degrees). As we can see from p-values in Table 1, the accuracy of 7 degree angular line length bisection is significantly different from the accuracy of 10 degree angular line length bisection, but is not significantly different from the line of 5 degrees in angular length.

Mann-Whitney U and p-values, according to Mann-Whitney U-test, of the second group are presented in Table 2.

2 table. **Mann-Whitney U and p-value[1] is obtained when compared the ratios of the line parts in the second group of participants.**

Line length, degrees	Mann-Whitney U value	p-value
5-7	123046,0	0,522
7-10	78886,0	0,000*
10-13	93134,5	0,000*
13-15	88319,5	0,000*

[1]According to Mann-Whitney U-test

Statistically significant difference was not obtained only when the ratios of 5 and 7 degrees in angular length were compared. Whereas, the rest of the line part ratios in comparison with the adjacent pairs of line lengths (7-10, 10-13, 13-15) are significantly different.

As we can see from p-values presented in Table 2, the reduction of the line part ratio (curve breaking point – extremum), when the line is 13 degrees in angular length is significantly different from the line bisection accuracy of 10 and 15 degrees in angular length. Therefore the second group of participants was the least accurate to divide the lines of 13 degrees in length. As we can see, all the participants the line part closer to the center increase subjectively in comparison with the line which is further away from the center. However, the dependency of A ratio from the line length is not monotonous. When the bisected line reaches the visual angle of 5-7 or about 13 degrees in length, the ratio A begins to increase. If the accepted model assumptions are true, then it is not difficult to show that ratio A begins to increase when the lengthened line is projected to the place in retina where the density of photoreceptors increases.

DISCUSSION

Influence of prolonged viewing of tilted lines on perceived line orientation: tilt after-effect

The size of TAE effect differs depending on the adaptive line orientation. It was estimated that the lowers TAE is when the participant has to evaluate the line of 22,5°. The question arises how can these results be explained?

We hypothesize that our visual system has two detectors responsible for the perception of line orientation. Supposedly the activity of one of the detectors is a function of sin 2(φ +22,5°) of a double angle, and the other is a function of cos2(φ+22,5°). This neuron response dependence on the line orientation is presented in Figure 7. In this case, the line of which the orientation is equal to zero, will activate both neurons equally, and the line oriented by 22,5° will stimulate most only the neuron with sinus characteristics. If the persona adapts to some line orientation, then the detector activity to certain line orientation decreases.

According to this hypothesis, if one of the detectors are not stimulated (for example, a neuron with a cosine characteristics), then its sensitivity does not change over time, i.e., there is no adaptation and the orientation of the vector does not change in the course of adaptation. Only its length and module change, but the perceived line orientation does not change. Consequently, there is no normalization effect.

After the adaptation a line with orientation of 22,5° will stimulate only one neuron, independently on the adaptive line orientation. Thus, the perceived orientation of this line will not depend on the adaptation, i.e., there will be no TAE.

The other line with orientations of 0° and 45° stimulate both neurons equally and their response changes equally in the course of adaptation (the ratio of responses and the vector orientation does not change). Therefore, the perceived orientation of these lines should not change in the course of adaptation – there is no normalization effect. However, the perceived orientation of these lines will greatly depend on the adaptation to the line seen before. This effect is maximal if a person is observing the line oriented by the 22,5° angle for a long time, because this line will stimulate only one neuron. Therefore, only one vector component will decrease, and the other will stay unchanged. This can be seen in the Figure 7.

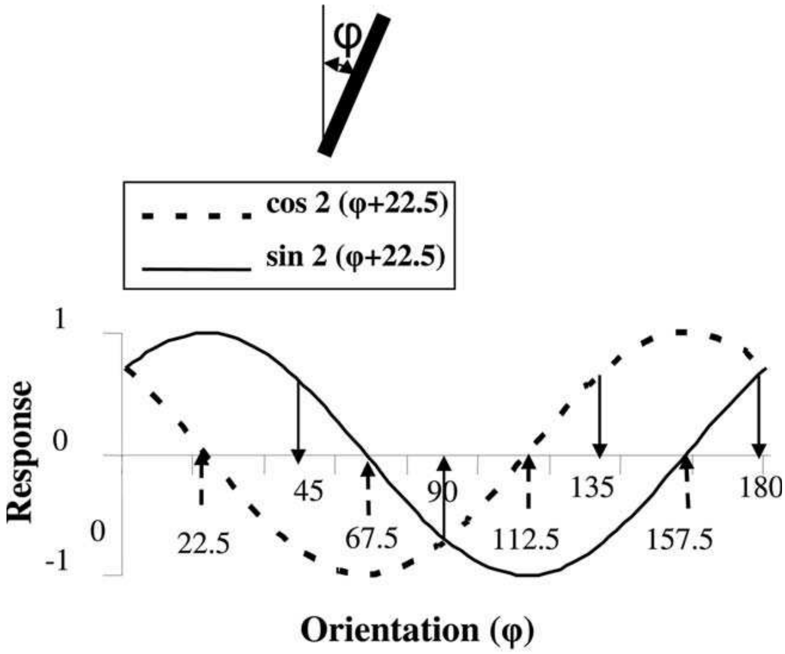

Figure 7. **Two neuron dependency on the line orientation φ. Solid line – a function of neuron with sinus sensitivity, dotted line – with cosine sensitivity.**

Now we can quantify the changes in vertical line orientation depending on the adaptive line orientation. An angle between the vectors, which code vertical line before and after adaptation, needs to be calculated. The perceived vertical line orientation in this case is equal to half of the computed angle. This dependency has been computed by other authors (Fomin et al., 1979) and their results are shown in Figure 8. In this figure, the X-axis represents the adaptive line orientation and the Y-axis represents the perceived change of vertical orientation.

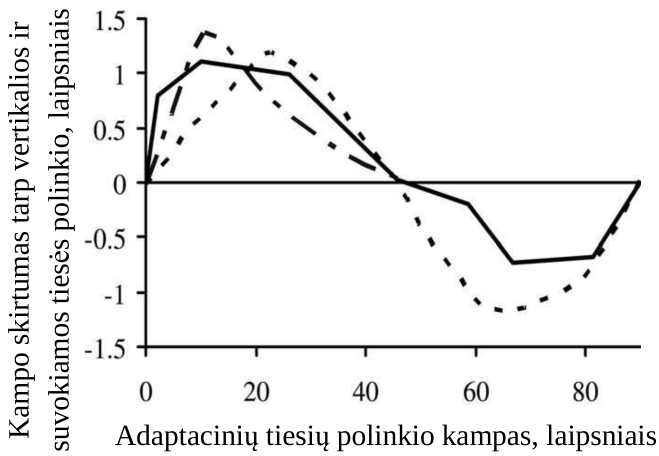

Figure 8. **The influence of adaptation on the vertical line perception. The solid line shows the results obtained by Gibson (1933), and Gibson and Radner (1937). The dotted line with dots shows the results of Campbell and Maffei (1971). The dotted line shows the results of the theoretical model**.

As we can see, the calculation results can explain the other author experiments results only qualitatively. Can the differences be reduced? What could also influence TAE? Sekular and Littlejohn (1974) tested the hypothesis if TAE could be explained by the simultaneous orientation contrast which causes the acute angles are perceived as greater and the obtuse angles as lesser. In their experiment the adaptive line was show before presenting the vertical line. Vertical line could be shown with certain delay Δt after the adaptive line. They measured how the perceived orientation of vertical line depended on the time of the delay Δt. They showed that the shorter the time of the delay, the greater the influence of the adaptive line. According to the authors, the adaptive line does not disappear right away, but its trace stays in the visual system because of the inertia and it interacts with the shown vertical line (simultaneous contrast). However, the authors did not appreciate the fact that TAE effect is equal to zero when the adaptive line makes up the 45° angle with the vertical. Meanwhile, the simultaneous contrast disappears only when this angle is equal to 90°. For this reason the above mentioned authors explanations were refused. However, it can be assumed that this effect can have an influence on TAE. If this hypothesis is accepted, then the observed TAE is the sum effect of the adaptation and simultaneous contrast. In order to test this hypothesis, we tried to sum two functions, one of which describes TAE and the other describes simultaneous contrast of orientations. Both dependencies were calculated separately in the study (Fomin et.al, 1979). Only the evaluation of the sum effect is left. The result is presented in Figure 9. The figure shows theoretical results of vertical line estimation, according to the simultaneous contrast and adaptation, and the results of the experiment.

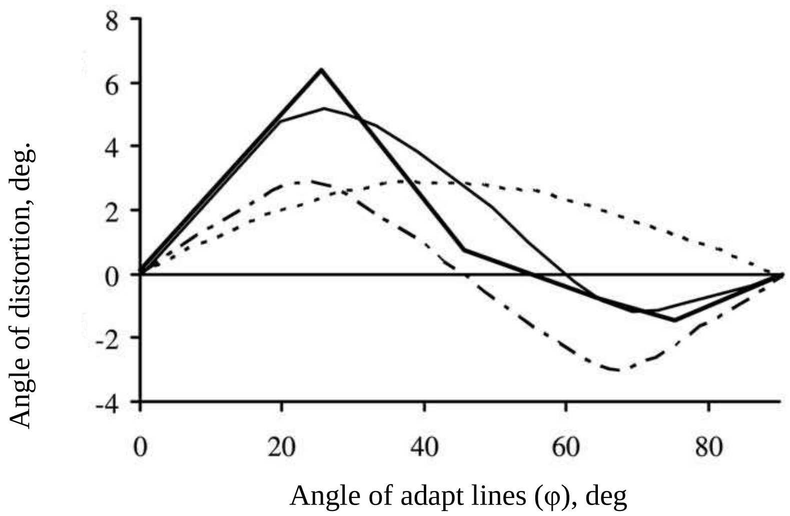

Figure 9. **The influence of simultaneous contrast and adaptation on the perceived orientation of continuous line. The dotted line shows the influence of side inhibition to perceived line orientation. The influence of adaptation on the perceived line orientation is marked by dotted line with dots. Thin continuous line shows theoretically calculated results. Thick continuous line shows the results of the experiment.**

As we can see in Figure 9, the results of the experiment are like the sum of the theoretical adaptation and simultaneous contrast results.

Consequently, the results allow us to assume that the perceived line orientation depends only on two neuron response ratio. It is accepted in the literature to state that the perceived orientation depends on significantly greater responses of neuron detectors, i.e., the orientation vector is of great measure.

The question arises if there is any data that two neurons selective to orientation possess this kind of sensitivity characteristics: sin 2(φ +22,5°), and the other cos2(φ+22,5°). Psychophysical studies by D. Foster and his colleagues appeared recently (Foster, Ward, 1991; Foster, Westland, 1998) which show that the perception of line orientation can be explained by the two neuron response ratio. Moreover, their optimal orientations are equal to ±22,5°, 112,5°. Since the neurons cannot transmit negative signals, then instead of one “sinus” and “cosine” neurons there should be two neurons, that each of them transmits only positive signal. Appreciating this, it can be assumed that the chosen characteristics of neuron sensitivity are close to those described by D. Foster.

Influence of prolonged viewing of tilte lines on perceived line orientation: normalization effect

The results show that adapting to certain line orientation, the perception of orientation either rotates towards the lines or 0°, 45°, 90°, or adapting to the lines of 22,5° and 67,5° their perceived orientation hardly changes. Supposedly, some detectors are sensitive to line orientation. Exposed to prolonged observation of certain line orientation, the sensitivity/ activity of the detectors sensitive for this orientation changes – it decreases over time. It is known that detectors sensitive to horizontal and vertical line orientation are more that 45°. That is, statistically, exposed to prolonged observation of some line orientation the perceived line orientation should change towards the vertical or horizontal, because there most detectors sensitive to these orientations. However, according to our models this might not be the case. Theory described in the literature could explain TAE, but would not explain the normalization effect. Meanwhile, both phenomena can be explained by using two detectors.

Perceived size of a line depending on its projection place on the retina

The participants dividing the lines into two subjectively equal parts made errors – line part A by the fixed cross was determined to be shorter in reality than the rest of the line B, i.e., the line part ratio was A/B<1. That means that the line part A was perceived to be greater and the line part B to be smaller than the existing physical length. Although these facts are described in the literature a long time ago (Пиаже, 1978; Вюрпило, 1978; Georgeson, 1980), it still remains unclear if the ratio (A/B) is stable or if it changes and depends on the line image in the retina. There are efforts to link the characters of line length perception to so called cortical magnification factor (CMF) (Daniel, Whitteridge, 1961; Schwartz, 1994). It is already shown that central part of the retina sends signals to the greater area of the visual cortex than the peripheral part of the retina. Since it is assumed that the perceived part of the line is greater if its image (projection) is greater in the visual cortex, then the images of similar line lengths in the center and the periphery of the retina will be perceived as of the different length – the first line will be perceived as longer than the second one. However, CMF is true only to the central (fovea) part (Florack et al, 1999; Koenderink, 1994). Also, it is unclear if subjective distortions are similar in all central part of the retina (fovea part), i.e., if the ratio (A/B) is stable.

Theoretical model is based on the assumption that the position of point object (or light centroid) in RL or in a fragment is determined on the response of 4 neurons with Gabor weight functions (Sokolov, Vaitkevicius, 1989; Sekular, Blake, 2002, Fleet et al, 1996): $x_1(\alpha) = a(\rho) \sin \lambda\alpha$, $x_2(\alpha) = a(\rho) \cos \lambda\alpha$, $x_3(\beta) = a(\rho) \sin \lambda\beta$, $x_4(\beta) = a(\rho) \cos \lambda\beta$, here α and β are horizontal and vertical visual angles of an object, and λ is constant that depends on the fragment or RL size, $a(\rho)$ is a Gauss centroid distance (ρ) from RL center. Since our stimulus is a horizontal line, we would assume that only horizontal visual angle changes and further we will analyze only the responses of two neurons, which are the components of a two-dimensional vector: $E(\alpha)= a(\rho)(\sin \lambda\alpha, \cos \lambda\alpha)$. According to the model presented earlier, the distance between two points which coordinates are α_1 and α_2 RL is proportionate to the angle between $E(\alpha_1)$ and $E(\alpha_2)$, i.e. Δ=arc cos ($E(\alpha_1)$, $E(\alpha_2)$) arc cos $\lambda(\alpha_2 - \alpha_1)$. The sensitivity of a system increases as this angle increases. This angle cannot be greater than 180°, because when the distance increases the angle between the vectors begins to decrease. Consequently, there is $0 \le \lambda(\alpha_2 - \alpha_1) \le \pi$. The distance between two points is ultimate when the points are in the opposite sides of RL. If RL is of the form of a circle, then the ultimate distance is equal to the diameter of a circle D. Consequently, max $(\lambda(\alpha_2 - \alpha_1)) = \lambda cD = \pi$, and $\lambda = \pi/cD$, here c is a constant. As we can see, the lower the RL the greater the value of λ. Based on this assumption, the distance between the points in the opposite sides of RL will be perceived as similar, though physically it is different, if the size of RL will change by D. The value of D indicates the size of RL, which depends on the sum of receptor signals needed to reliably extract a signal from the noise (Hateren, 1992 a, b, 1993 a, b). If the characteristics of receptors do not differ, then the number of receptors in RL should be alike (in this case the ratio of signal/ noise is equal to all RL), and the size of RL field (value of D) depends on the density of photoreceptors in the retina. This ratio varies. Also there two types of receptors: cones and rods, which have different characteristics. For example, rods are more sensitive and react to dim light. Therefore, it is more likely that the signal generated by the rods the influence of interference is greater than that of the cones. Different kinds of cones differ in their resistance to interference – “red” or L cones are less resistant to interference, than S or “blue“ cones. However, we cannot estimate the aforementioned matters because of the lack of knowledge, so we would assume that the size of RL depends only on the density of photoreceptors. While increasing the distance between the points, they will project not on only one RL, but in a few adjacent ones. The estimation of distance will depend on the size of RL (i.e., from the density of photoreceptor). It is known that the same number of retina receptors send information to the same areas of cerebral cortex and the same areas of cerebral cortex are perceived alike. In our case, the divided line which is projected on the retina, stimulate the sequence of receptors which belong to different RLs. The longer the line the longer the sequence of RLs and photoreceptors. In order to determine the perceived middle of the line, the place in the line equally dividing the number of the receptors in two and perceived as equal was determined. These kind of calculations can be performed because we know the place in the retina of an eye in which the line projects. Since the study participants had to fix their sight to the fixation point, the part of the line near the fixation point projects on fovea and the further part of the line projects on the periphery.

It is known that the alteration of general density of photoreceptors is not a monotonous function: in the center of retina the density of photoreceptors – cones is large. Going further from the center the density decreases, but at the same time the number and density of rods increases. At approximately 5-7 degrees from the center the density of photoreceptors begins to increase. The increase is present up to 20 degrees. If the density of photoreceptors influences the perception of the line length, then the decreasing density of photoreceptors would be associated with the same physical line length perceived as lesser. When the density of photoreceptors begins to increase, the same line should be perceived as greater. In order to test this hypothesis the second task was stated. Not knowing how sizes of RL change going further from the center of the retina, when types of the photoreceptors also change, the accurate theoretical insight about length perception is impossible. However, it can be tested if indeed the nature of length perception changes in places where the density of photoreceptors is minimal and again begins to increase.

According to our results (see Figures 5 and 6), we can see that the ratio A/B is not stable, i.e., increasing the general length of the bisected line, the perception of A and B line lengths changes disproportionately, because the relative difference of perceived line part lengths changes. Speaking about the nature of these distortions, Brown (1953) experiments should be mentioned – it was determined that the bisection of the same length line to subjective two parts changes over time when performing the repeated bisections. However, the changes in “adaptive” ration are observed as low (no greater than 1-2 min of the visual angle) and are monotonous. The changes determined in our testing are a few times bigger that the described “adaptive” ones and, also, they are not monotonous: when line images are in the central part of the retina (the lines are relatively short) the ratio decreases and then it begins to increase again. Depending on the characters of the function A/B=*f(l)*, the participants were divided into two groups. In the first, most numerous participant group, the function *f(l)* had the minimum when the length of the bisected line was 7 degrees of visual angle (arcdeg). At first there was a little decrease of A/B ratio in the interval (*l* = 5÷7 arcdeg), and then it increased rapidly, approaching 1 (the systemic bisection error decreased, i.e., the difference of both line lengths decreased relatively) (Figure 5). In the second participant group, the function A/B=*f(l)* had the minimum when the length of the bisected line was 13 degrees of the visual angle (arcdeg). In this case (in the interval of 5-7 lengths) the ratio A/B, decreased a little, like earlier, but when the line length was increased, this ratio began decreasing rapidly and it reached the minimum, when the length of the bisected line was 13 degrees of the visual angle. Further increasing the line length, this ratio begins to increase (Figure 6).

According to CMF line part ratio A/B dependence on the line length, the extremum should not appear, because the density of cones from fovea to the periphery is decreasing all the time. However, the general density of photoreceptors changes unevenly (Figure 10). We can assume that when dividing the line not only the density of the cones, but also the rods are important in the retina of an eye. Why the influence of the cones and rods could be different? It is known that the rods are more sensitive than the cones. For this reason, the random interference can have more influence to the rod response than that of the cones. In order to extract a signal from the noise, signals from the greater number of the rods should be summed, than the number of needed cones (van Hateren, 1992). Thus, one neuron in the visual cortex, indicating the local retina lighting, should sum the signals from the greater number of rods. For this reason the neuron, receiving the signals from rods, will sum the signals from the greater area of the retina than the neuron receiving the signals from the cones. This would mean that the retina area containing rods sends signals to the smaller areas of the visual cortex than the cones. Also, the density of rods in the central area of the retina is low and it increases toward the periphery (see Figure 10 – dotted line marked in squares) – it is greatest in the central area of the retina, it decreases evenly toward the periphery. Based on the facts described above, it can be assumed that two lines of the same size which images are in the cone and rod areas of the retina will be perceived differently – images in the cone areas will be perceived as larger than the same images in the rod areas.

Based on the facts described above and estimating the decrease of the density of cones going further from the center of the retina, the conclusion follows that the line part closer to the fixation center should be perceived as greater than its part which is further away from the center. This should be true only to the part of the retina where the number of cones is large. Since almost all the cones are situated concentrically around the center (in the area of 6-8 visual angle (see Figure 10), the sum of the photoreceptors was calculated using data provided by Sekular, Blake (2002)), then the described dependency should be true while the length of the bisected line is not larger than 6-8 of the visual angle.

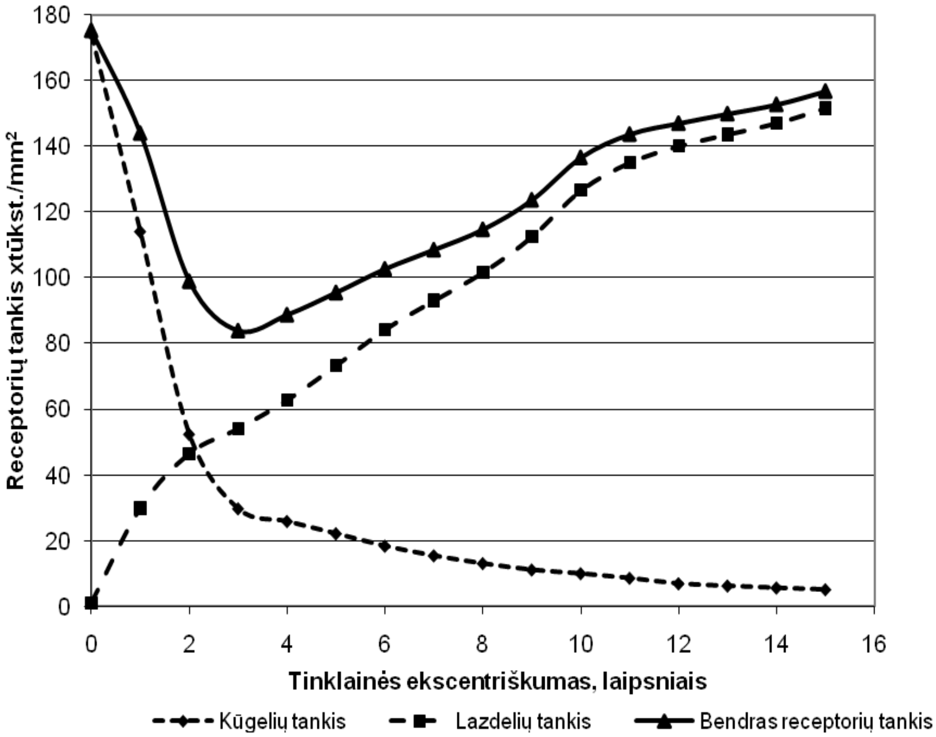

Figure 10. **The distribution of the density of photoreceptors in the retina of an eye. The sum of photoreceptors was calculated using data provided by Sekular, Blake (2002).**

When give lines are longer, their images (at least the part of it) are in the area dominated by rods. The density of rods in the central part of the retina is low and going further from the center, their density is increasing (to 20 degrees of the visual angle – Sekular, Blake, 2002). When the density of rods changes, the central part of the line should be perceived as shorter than the line of the same length which is further from the center, i.e., the participant sound increase the line A and decrease the line B and the ratio should be A/B>1. Thus, the character of the tested ratio should change while increasing the line and when the line (or its part) is projected to the area of rods in the retina. This should happen in 6-10 degrees of the visual angle. As we saw, about 66,7% of the participants (A/B) the character of ratio change does not contradict these conclusions. However, (5 participants – 16,7%) the ratio (A/B) breaking point is further away from the center than the predicted breaking point. Why is it this way? A few hypotheses are worth to be mentioned.

- Firstly, the participant fixes the sight not on the cross, but his sight is shifted towards the other end of the bisected line. The results of the preliminary tests with three participants registering the eye movements do not contradict this hypothesis. The tests show that participants selecting the fixation point can shift their eyes unconsciously so that the image of the point is not in the centre of the retina. It was computed what is the range when the eye moves while dividing the line and constantly fixing the sight on the fixation cross. The results are presented in Table 3.

Table 3. **The values of eye movements in three participants while fixing their sight on the fixation cross while dividing the line.**

Subject	Horizontal eye movement while fixating sight, deg.	Vertical eye movement while fixating sight, deg.
AD	0,77	2
AS	1,6	1,6
DR	2,63	2,63

Table 3 shows the approximate distance values. Detailed eye movements of each of the participants are presented in figures in the appendix. The presented results show that eye movements differ in participants by their size – usually it is a cloud seen in the graph around the fixation cross, but this cloud is not necessarily of the regular shape. As we can see, the participant AD eye movements vertically were greater more than twice than those horizontal. Recalling the test results of line bisection, the minimum of line part ratio curve in the second group of participants was when the line length was 13 degrees (Figure 6). Since the eyes moved in a quite large area around the fixation cross, this could influence the results and it could be assumed that the participants in the second group had difficulty in fixating the sight, consequently, the minimum of line part ratio curve "shifted". However, this assumption needs to be supported by more comprehensive studies.

- Secondly, it is still unclear, what is the influence of cones and rods in perceiving the line length. The long line projects on the area where only cones are present or the rods, and also to the area where both types of photoreceptors are present. The perception of line length can depend on the cone and rod weight in determining the sum ratio (A/B) value of line parts.

Naturally, there is a possibility that both factors can influence the results of the described experiments.

Data of five participants was not analyzed because their ratio A/B of line part dependency on the character of line length curve did not have a clear tendency for change, differently from other two groups of participants. It is possible that these participants had difficulty in fixing their sight on the fixation cross during one testing series.

The question arises how these results can be important in explaining the perception of the visual space? As it is known, the sized of object images in the retina depend on their distance to the observer. Further object images in the retina are smaller than those of the same size which are closer object images in the retina. However, it is known that the person is able to perceive the same size objects as being the same size independently of them being in different distance away from the observer, i.e., independently of the object image sized in the retina (constant size and distance perception effect). It was attempted to explain this constant perception by experience and learning, but this failed (Вюрпило, 1978). It is supposed that this phenomena is influenced by the innate physiological features of the visual system. According to the data it can be assumed that the central area of the visual field which is projected on the area of central retina, is subjectively increased compared to the peripheral part which projects on the peripheral area in the retina. Thus, if the person shifts his sight to the further object, the object image is in the centre of the retina and it is perceived as being larger. And the images of closer objects in the retina in this case are in the periphery and their perceived size is decreased. Consequently, for this reason, the projective distortions are compensated. As our analysis showed (Dzekevičiūtė, 2007), the full compensation of projective distortions is possible only in the certain part of the visual space, which position depends on the character of the ratio (A/B).

Also the results can be helpful in explaining why the in the case of binocular vision the longitudinal horopter is not synchronized with Vieth-Muller circle (cited from Vaitkevičius, 2002).

It is still studied, that is the influence of subjective distortions associated only with the fovea in the retina on the space perception (Schwartz, 1994) and the influence of the periphery is not studied. Also knowing the influence of peripheral subjective distortions on the space perception, it could be predicted how a person would perceive distances between the objects in various situations when he is fixing his sight on separate objects. This has a great practical value when it is important to quickly estimate the distances between the observed objects, also it is important to consider in architecture (already ancient Greeks considered it, according to the empirical knowledge).

Currently the person is forced to work in the mezopic lighting (for example, while driving a car in the evening). In this case both rods and cones are functioning. Considering that the ratio (A/B) depends on the kind of the functioning photoreceptors, the perceived distance between the objects in the mezopic lighting will differ from the distance perceived in photopic and scotopic lighting. It is important to appreciate it while driving. .

CONCLUSIONS

1. It is confirmed that the adaptation to line orientation changes the perceived line orientation – the perceived orientation of the continuous line is rotating so to constitute a greater angle between the orientations of adaptive and continuous lines. It was determined that the lowest tilt after-effect is when the continuous line orientation was 22,5 degrees.

2. It was confirmed that when exposed to a prolonged line observation the perceived line orientation changes (normalization effect). The perceived line orientation rotates toward the closest orientations of 0, 45, and 90. Lines oriented at 22,5° and 67,5° are perceived as stable with insignificant shifts.

3. The tilt after-effect and normalization effect can be defined by a hypothetical model which describes only two detectors which response changes are described by the functions of sin 2(φ+22,5°) and cos2(φ +22,5°).

4. It was determined that when the person fixes the sight, he bisects the line unequally – the part of the line close to the fixation point is determined as smaller than the rest of the line because it is perceived as larger. The systemic line bisection erro changes unmonotonously and depends of the line length. Lines of certain lengths (one group of participants – 7 degrees of visual angle, the other – 13 degrees) are bisected with the greatest systemic error. Further the accuracy of bisection increases.

5. The accuracy of line bisection is influenced by general number of photoreceptors, but the contribution of cones and rods is different.

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Vaitkevicius H., Viliunas V., Bliumas R., Stanikunas R., Svegzda A., **Dzekeviciute A.,** Kulikowski J. (2009). Influences of prolonged viewing of tilted lines on perceived line orientation: the normalization and tilt after-effect. *Journal of the Optical Society of America. A.* Vol. 26, No. 7: 1553-1563. ISSN:1084-7529 (print) ISSN: 1520-8532 (online).

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REZIUMĖ

ĮVADAS

Rega svarbiausias žmogaus analizatorius, kuriuo pagalba žmogus gauna apie 90% informacijos susijusios su aplinka. Todėl tyrimų susijusių su rega yra labai daug. Tačiau iki šiol yra daug neišaiškintų regimojo suvokimo fenomenų. Pavyzdžiui, neaišku, pagal kokius objekto atvaizdo požymius suvokiame objektą, kadangi vienas ir tas pats objektas akies tinklainėje gali sukurti daug atvaizdų.

Manoma, kad objekto atvaizdas akies tinklainėje suskaldomas į atskirus vaizdus, kuriuose išskiriami suvokimui reikalingi lokalūs požymiai, iš kurių vėliau sudaromas globalus vaizdas. Taigi yra bent du informacijos apdorojimo etapai - lokalus ir globalus. Šiame darbe tirsime tik lokalius regimojo vaizdo apdorojimo mechanizmus. Taip pat apsiribojame dviejų požymių – objektų kontūro pakrypos ir fragmentų tarpusavio nuotolio analize. Aiškinant orientacijos kodavimo mechanizmus buvo tiriami taip vadinamieji liekamasis adaptacijos poveikis (TAE) ir normalizacijos efektai. TAE – suvokiama tiesės pakrypa priklauso nuo fizinės tiesės pakrypos ir tiesės pakrypos, kuri buvo pateikta prieš tai. Normalizacijos efektas – ilgai stebint tam tikros pakrypos tiesę, suvokiama tiesės pakrypa kinta – pagal Gibsoną sukasi link artimiausios vertikalios arba horizontalios pakrypos (Gibson, 1933, 1937). Nors šie efektai yra tiriami (TAE efektas yra tyrinėtas daugiau (Clifford ir kt., 2000, Clifford ir kt., 2001, Gibson, 1937, Gibson, Radner 1937a,b, Westheimer, Gee, 2002)), tačiau iki šiol minėti efektai nebuvo panaudoti siekiant išsiaiškinti kodavimo mechanizmus. Šios stebimus reiškinius galima panaudoti apibendrintų modelių patikrai (Fomin et al, 1979; Vidyasagar, 1985, 1987; Vidyasagar, Urbas, 1992; Vidyasagar et al, 1986). Nepavyko rasti eksperimentinių darbų, kur tai būtų daroma.

Kitas svarbus klausimas, kaip žmogus nustato vaizdo elementų padėtį erdvėje ir atstumą tarp jų. Šis klausimas iki galo nėra ištirtas ir suprastas, kaip žmogus nustato ir įvertina atstumą tarp dviejų taškų. Žinoma, kad kartais suvokiami objekto požymiai neatitinka fizikinių parametrų. Pavyzdžiui, objekto dydžio suvokimas. Keičiantis atstumui iki objekto, objekto atvaizdo akies tinklainėje dydis kinta, atvaizdas yra iškraipomas, tačiau objekto suvokimo kitimas nėra tiesiogiai priklausomas nuo objekto atvaizdo akies tinklainėje kitimo, todėl sąveikos tarp šių dalykų klausimas yra aktualus.

Taip pat yra žinoma, jog aplinkos (ar objekto) vaizdas, kuris projektuojasi į akies tinklainę yra iškraipomas tokiu būdu – centrinės akies tinklainės dalyje esantis vaizdas suvokiamas didesnis, periferijoje – mažesnis. Šie žinomi reiškiniai aiškinami dvejopai.

Manoma, kad šis reiškinys susijęs su dėmesio mechanizmais (centravimo mechanizmas). Žmogaus jautrumas objekto padėties pokyčiams srityje, į kurią jis nukreipia dėmesį, padidėja. Kadangi srityje, kuriai skiriama daugiau dėmesio, jautrumas yra didesnis (absoliutūs slenksčiai yra mažesni), tai šiuo atvejų dėmesio srityje tie patys viršslenkstiniai fiziniai atstumai bus suvokiami didesni, negu kitose srityse.

Antra hipotezė mėgina rasti fiziologinius mechanizmus susijusius su centravimo efektu. Tam naudojamas vadinamasis žievės (žievinis) didinimo veiksnys (cortical magnification factor (CMF) - Schwartz, 1994). Yra parodyta, kad centrinė tinklainės dalis siunčia signalus į didesnę regos žievės dalį, negu periferinė jos dalis. Taigi, vaizdas centrinėje tinklainės dalyje projektuojamas į didesnę žievės sritį, negu vaizdas esantis periferinėje jos dalyje, t.y. perduodant vaizdą į žievę jis ištempiamas, padidinamas. Daroma prielaida, kad atvaizdo dydis žievėje proporcingas jo suvokiamam dydžiui. Tokiu būdu toks pat fizinis vaizdas esantis tinklainės centre ir periferijoje bus suvokiamas skirtingo dydžio. Pirmuoju atveju jis bus suvokiamas didesnis, negu antruoju atveju. Tačiau CMF galioja tik tuomet, kai vaizdas yra centrinėje tinklainės dalyje (fovea). Lieka neaišku, kas vyksta, kai vaizdas sukuriamas ne foealinėje dalyje, o už jos ribų, kur yra tik lazdelės. Taigi neaišku, kokie yra suvokimo subjektyvūs iškraipymai, kai objekto vaizdas keičia padėtį akies tinklainėje – iš centrinės akies tinklainės dalies perkeliamas į periferiją. Ar vaizdo dydžio suvokimo kitimas yra tolyginis, stumiant vaizdą iš centro į periferiją? Nuo ko priklauso objekto dydžio suvokimo kitimas, kai keičiasi objekto vaizdo projekcijos vieta akies tinklainėje?

Tyrimo rezultatai ir išvados pasitarnautų ne tik geriau suprantant žmogaus regimąjį suvokimą, tačiau turėtų ir praktinę vertę. Pavyzdžiui, kuriant regos protezus, tiriant žmogaus dydžio įvertinimą, kai objektai projektuojasi į skirtingas tinklainės vietas. Pavyzdžiui vairuotojui svarbu teisingai įvertinti atstumą tarp objektu, kai jo projekcijos patenka į skirtingas tinklainės vietas, arba keičiantis apšvietai kinta funkcionuojantys receptoriai. Esant fotopiniai apšvietai veikia kūgeliai, o esant mezopiniai apšvietai papildomai veikia ir lazdelės.

*Šio **darbo tikslas** – ištirti, kaip eksperimente nustatyti dviejų suvokimui svarbių požymių (kontūro pakrypos ir atstumo tarp atskirų fragmentų) kodavimo mechanizmus.*

Uždaviniai.

1. Ištirti TAE ir normalizacijos efektus, bei sukurti juos aiškinantį modelį.

2. Ištirti, kaip žmogus suvokia atstumą tarp dviejų taškų kintant žvilgsnio fiksacijai ir įvertinti, kokie mechanizmai gali būti susiję su eksperimente gautais reiškiniais.

Ginamieji teiginiai.

1. Nustatyta nauja, dar nežinoma TAE savybė: greta jau žinomų vertikalių ir horizontalių tiesių, prie kurių adaptacija neįtakoja po jų pateikiamų tiesių pakrypos suvokimo, yra dar dvi papildomos tiesės pakrypos 22,5° ir 67,5°, kurios pasižymi tokiomis pat savybėmis.

2. Nustatyta naujos dar nežinomos normalizacijos savybės. Ilgai stebint vieną ir tą pačia tiesę, jos suvokiama pakrypa kinta, ji sukasi link artimesnės ne tik vertikalės ir horizontalės tiesės (kas jau žinoma), bet ir link artimesnės tiesės, kurios polinkis yra 45°. Be to, yra dar dvi tiesės pakrypos, kurių normalizacijos poslinkis (dreifas) nėra stabilus, t. y. poslinkio kryptis nėra stabili. Tai tiesės, kurių pakrypos yra 22,5° ir 67,5°.

3. TAE ir normalizacijos savybes galima paaiškinti modeliu, kuris aprašo pakrypos kodavimą dviejų selektyvių pakrypai neuronų atsakų santykiu.

4. Vaizdo dydžio suvokimas kinta nemonotoniškai, stumiant vaizdą iš tinklainės centro į periferiją.

5. Vaizdas tinklainės centre maksimaliai subjektyviai padidinamas, slenkant vaizdą iš centro į periferiją jo suvokiamas dydis iš pradžių mažėja, bet apie 7-13 laipsnių regimojo kampo, jis vėl pradeda didėti.

6. Netolygaus vaizdo dydžio suvokimas keičiantis jo padėčiai akies tinklainėje koreliuoja su bendru receptorių tinklainėje tankio kitimu: tolstant nuo tinklainės centro bendras receptorių tankis mažėja (fovea vyrauja kūgeliai, į periferiją jų tankis greitai mažėja), vėliau lazdelių tankis yra ženkliai didesnis negu kūgelių, ir jų tankis einant į periferiją greitai didėja.

7. Siūlomas vaizdo dydžio subjektyvaus įvertinimo modelis - vaizdo svertinas svorio centro padėtis nustatoma 4 neuronu atsaku santykiu (panašiai, kaip spalva koduojama trijų kūgelių atsakų santykiu).

METODIKA

Ilgai stebimos tiesės suvokimo polinkio pokyčiai: *liekamasis adaptacijos poveikio* efektas

Tyrimo dalyviai. Tyrime dalyvavo trys tiriamieji – du vyrai ir viena moteris. Visi tiriamieji turėjo normalų arba koreguotą iki normalaus regėjimą. Visi tiriamieji turėjo patirties psichofizikiniuose eksperimentuose. Paaiškinus tyrimo esmę visi tiriamieji davė sutikimą dalyvauti tyrime.

Stimulai. Dvi rūšys tiesių – trys adaptacinės ir viena testinė. Tiesės buvo pateikiamos vienu metu, bet ne vienoje regimojo lauko vietoje. Adaptacinių tiesių pakrypos $\varphi_a=\varphi_t+0°$, φ_t ±10°, φ_t +22.5°, φ_t +35°, φ_t +45° and φ_t +67°, kur φ_t testinės tiesės pakrypa. Adaptacinės tiesės buvo pateikiamos vaizduoklio ekrano centre. Adaptacinių tiesių ilgis 2°, storis 0,1°, atstumas tarp tiesių 15. Testinė tiesė buvo to paties ilgio ir storio kaip adaptacinės. Testinės tiesės pakrypa φ kito su 0,5° žingsniu intervale $\varphi t–0{,}5°n \le \varphi \le \varphi t +0{,}5°n$, kur n parinkta atsitiktinai iš intervalo nuo 0 iki 10, ir φt =0°, 22,5° ir 45°. Iš viso vienai adaptacinės tiesės pakrypai buvo generuojama 21 testinės tiesės pakrypa.

Tyrimo eiga. Tiriamieji 15 min. adaptavosi tamsoje kiekvieno bandymo pradžioje. Jų galva buvo įtvirtinta specialiu stovu. Tiriamieji į stimulus žiūrėjo viena akimi pro 1 m. popierinį cilindrą (matymo lauko skersmuo 20°). Iš pradžių buvo įjungiamos adaptacinės tiesės (pirminė adaptacija truko 10000 ms, visos kitos 4000 ms), į kurias turėjo fiksuoti žvilgsnį. Tada pateikiamas tuščias ekranas 1000 ms. Vėliau buvo įjungiama testinė tiesė, kurios pakrypa viena iš 21 galimos (200 ms). Tiriamasis turėjo dviejų atsakymų priverstinio atsako metodu atsakyti, ar testinė tiesė pasisukusi prieš ar pagal laikrodžio rodyklę nuo duotų pakrypų (0°, 22,5°, 45°, prieš bandymą tiriamasis žinojo su kokios pakrypos tiese reikia lyginti testinę tiesę). Po tiriamojo atsakymo pateikiamas tuščias ekranas (1000 ms.) ir tik tada įjungiamos adaptacinės tiesės (4000 ms). Toliau bandymas buvo kartojamas, kol visos adaptacinių ir testinių tiesių kombinacijos buvo pateikiamos tiriamajam.

Duomenų analizė. Iš gautų rezultatų buvo brėžiamos psichometrinės kreivės ir iš jų paskaičiuojama maksimalus TAE dydis – kiek suvokiama pakrypa keičiasi priklausomai nuo adaptacinių tiesių pakrypos.

Ilgai stebimos tiesės suvokimo polinkio pokyčiai: *normalizacijos* efektas

Tiriamieji. Tyrime dalyvavo penki tiriamieji, kurių amžiaus intervalas nuo 25 iki 60 metų. Visi tiriamieji turėjo normalų arba koreguota iki normalaus regėjimą be astigmatizmo. Trys tiriamieji nežinojo apie tyrimo tikslus. Visi tiriamieji turėjo patirties psichofizikiniuose eksperimentuose. Paaiškinus tyrimo esmę visi tiriamieji davė sutikimą dalyvauti tyrime.

Stimulai. Stimulai buvo pateikti kompiuterio Philips 201CS vaizduoklio ekrane (rezoliucija 1600x1280), atnaujinimo dažnis 75Hz. Stimulai buvo pateikiami tuščiame ekrane skaistis 80 cd/m^2. Į stimulus tiriamieji žiūrėjo viena akimi per popierinį cilindrą 1 m atstumu nuo ekrano, jiems buvo įtvirtinta galva, kad nejudėtų. Regimojo lauko, matomo pro cilindrą, skersmuo 20°. Tiriamiesiems buvo pateikiama adaptacinės ir testinė tiesės, kurių ilgis 2°, storis 0,1°, atstumas tarp adaptacinių tiesių 15 min. Adaptacinių tiesių pakrypos -10°, 10°, 35°, 55°, 80°. Testinių tiesių pakrypos kito ±5° nuo adaptacinių tiesių pakrypos su 0,5° žingsniu.

Kadangi pateikiant stimulus toje pačioje erdvės vietoje dėl adaptacijos keičiasi suvokiama tiesės pakrypa, todėl adaptacinės ir testinė tiesės buvo pateiktos skirtingose erdvės vietose. Atstumas tarp jų buvo 6° regimojo kampo.

Tyrimo eiga. Kiekvieno bandymo pradžioje tiriamasis 10 min. adaptacija tamsoje. Po to buvo įjungiamos adaptacinės tiesės, kurios nebuvo išjungiamos viso bandymo metu. Tiriamasis 1 min. matė tik adaptacines tieses ir turėjo fiksuoti žvilgsnį į ant vidurinės adaptacinės tiesės pažymėtą fiksacijos taškelį. Tada trumpam (1 s.) buvo įjungiama testinė tiesė. Tiriamasis turėjo įvertinti, ar testinės tiesės pakrypa pasisukusi prieš ar pagal laikrodžio rodyklę lyginant su adaptacinėm tiesėm (dviejų pasirinkimų priverstinio atsako (angl. two alternative *force choise*) metodas). Nors tiriamiesiems atsakymo laikas nebuvo ribojamas, tačiau jie buvo skatinami atsakymą pateikti kuo greičiau. Po tiriamojo atsakymo sekė pakartotinė adaptacija 10 sekundžių, kai tiriamasis matė tik adaptacines tieses.

Duomenų apdorojimas. Iš tyrimo rezultatų buvo siekta nustatyti tik suvokiamos tiesės pakrypos kryptį, todėl nebuvo naudojamos psichometrinės funkcijos. Buvo naudotas Kolmogorov-Smirnov ir Shapiro-Wilk statistikiniai kriterijai įvertinti, ar duomenys pasiskirstę pagal normalinį skirstinį. Taip pat naudojome neparametrinius analizės metodus palyginti ir įvertinti dvi adaptacijos tiesių grupes – -10°, 35°, 80° ir 10°, 55°. Po adaptacijos pirmos grupės adaptacinių tiesių pakrypa subjektyviai turėtų suktis pagal laikrodžio rodyklę, antroji – prieš laikrodžio rodyklę.

Atkarpos ilgio suvokimo priklausomybė nuo jos projekcijos vietos akies tinklainėje

Teorinis modelis. Teorinis modelis remiasi prielaida, kad taškinio objekto (ar šviesos centroido) padėtis RL arba fragmente nustatoma iš 4 neuronų atsakų su Gaboro svorio funkcijom (Sokolov, Vaitkevicius, 1989; Sekular, Blake, 2002, Fleet et al, 1996): $x_1(\alpha) = a(\rho) \sin \lambda\alpha$, $x_2(\alpha) = a(\rho) \cos \lambda\alpha$, $x_3(\beta) = a(\rho) \sin \lambda\beta$, $x_4(\beta) = a(\rho) \cos \lambda\beta$, čia α ir β čia horizontalus ir vertikalus objekto regimieji kampai, o λ - konstanta, kuri priklauso nuo fragmento arba RL dydžio, $a(\rho)$ - yra Gauso centroido atstumas (ρ) nuo RL centro. Kadangi mūsų stimulas yra horizontali atkarpa, tai laikysime, kad kinta tik horizontalus regėjimo kampas ir toliau nagrinėsime tik dviejų neuronų atsakus, kurie yra dvimačio vektoriaus komponentės: $E(\alpha)= a(\rho)(\sin \lambda\alpha, \cos \lambda\alpha)$. Pagal anksčiau pasiūlytą modelį atstumas tarp dviejų taškų, kurių koordinatės yra α_1 ir α_2 RL yra proporcingas kampui tarp $E(\alpha_1)$ ir $E(\alpha_2)$, t,y. $\Delta=\arccos (E(\alpha_1), E(\alpha_2)) \arccos \lambda(\alpha_2 - \alpha_1)$. Sistemos jautrumas didės, didėjant šiam kampui, kuris negali būti didesnis negu 180°, kadangi didinat atstumą kampas tarp vektorių pradės mažėti. Taigi turime $0\leq\lambda(\alpha_2 - \alpha_1)\leq\pi$. Atstumas tarp dviejų tašku bus maksimalus, kai taškai bus priešinguose RL kraštuose. Jeigu RL yra skritulio formos, tai maksimalus atstumas bus lygus apskritimo diametrui D. Vadinasi turime: $\max (\lambda(\alpha_2 - \alpha_1)) = \lambda cD = \pi$, ir $\lambda=\pi/cD$, čia c - konstanta. Kaip matome kuo mažesnis RL, tuo didesnė λ reikšmė. Remiantis šia prielaida, atstumas tarp taškų, esančių skirtinguose RL pusėse, bus suvokiamas vienodas, nors fiziškai jis bus skirtingas, jeigu kis RL dydis D. Dydis D nusako RL dydį, kuris priklauso, kiek receptorių signalų reikia sumuoti, kad patikimai ištraukti signalą iš triukšmų (Hateren, 1992 a,b, 1993). Jeigu receptorių savybės nesiskiria, tai receptorių skaičius RL turėtų būti vienodas (šiuo atveju signalas/triukšmo santykis bus vienodas visiems RL), ir RL lauko dydis (reikšmė D) priklausys nuo receptorių tankio tinklainėje. Šis santykis kinta. Be to, yra du receptorių tipai: kūgeliai ir lazdelės, kurių savybės skiriasi. Pavyzdžiui, lazdelės yra žymiai jautresnės ir reaguoja į silpną šviesą. Taigi tikėtina, kad lazdelių generuojamame signale trikdžių įtaka bus didesnė negu kūgelių. Skirtingų kūgelių rūšių atsparumas trikdžiams taip pat skiriasi - "raudoni" arba L kūgeliai yra mažiau atsparūs trikdžiams, negu S arba "mėlyni" kūgeliai. Tačiau šiuo metu minėtų dalykų įvertinti dėl žinių stokos negalime, todėl kelsime prielaidą, kad RL dydis priklauso tik nuo receptorių tankio. Didinat atstumą tarp taškų jie projektuosis ne viename RL, bet keliuose gretimuose. Nuotolio įvertinimas priklausys nuo RL dydžio (t.y. nuo receptoriaus tankio). Žinoma, kad vienodas akies tinklainės receptorių skaičius siunčia informaciją į vienodus smegenų žievės plotelius, o vienodi smegenų žievės ploteliai yra suvokiami vienodai. Mūsų atveju dalinama atkarpa projektuojama tinklainėje sužadina receptorius, kurie priklauso skirtingiems RL-ams, sekos. Kuo ilgesnė atkarpa, tuo ilgesnė RL ir receptorių seka. Norint surasti suvokiamą atkarpos vidurį, buvo ieškoma tokia atkarpos vieta, kuri receptorių skaičių dalintų į dvi lygias dalis, kurios ir turėjo būti suvokiamos, kaip esančios lygios. Tokius skaičiavimus galime atlikti, nes žinome, kur akies tinklainėje projektuojasi atkarpa. Kadangi tyrimo metu tiriamieji turėjo fiksuoti žvilgsnį į fiksacijos tašką, tai atkarpos dalis, esanti šalia fiksacijos taško projektuojasi į fovea, toliau esanti atkarpos dalis projektuojasi į periferiją.

Žinoma, kad bendras receptorių tankio kitimas nėra monotoninė funkcija: tinklainės centre receptorių - kūgelių tankis yra didelis, Toliau nuo centro jis mažėja, bet tuo pačiu didėja lazdelių skaičius ir jų tankis. Maždaug apie 5-7 laipsnius nuo centro receptorių tankis vėl pradeda didėti. Didėjimas stebimas iki 20 laipsnių. Jeigu receptorių tankis įtakoja atkarpos ilgio suvokimą, tai mažėjant receptorių tankiui to paties fizinio ilgio atkarpa turėtų būti suvokta mažesnė. Kai receptorių tankis vėl pradeda didėti, ta pati atkarpa vėl turėtų būti suvokiama didesnė. Siekiant patikrinti šią hipotezę buvo suformuluotas antras šio darbo uždavinys. Nežinant, kaip kinta RL dydžiai tolstant nuo akies tinklainės centro, kai kinta ir receptorių tipai, tiksli teorinė ilgio suvokimo įžvalga negalima. Tačiau galima patikrinti, ar tikrai ilgio suvokimo pobūdis kinta ten, kur receptorių tankis pasiekia minimumą ir vėl pradeda didėti.

Tiriamieji. Tyrime dalyvavo 30 psichologijos studentų, atrinkti proginės atrankos būdu, iš kurių 25 moterys ir 5 vyrai. Jie nežinojo apie tyrimo tikslus. Tiriamųjų regėjimas normalus arba pakoreguotas iki normalaus. Prieš kiekvieną bandymą tiriamieji buvo mokomi, bandymo metu stebimi, ar teisingai atlieka bandymą, buvo atsakoma į iškilusius klausimus.

Tyrimo priemonės ir stimulai. Visual Basic 4.0 buvo sukurta speciali programa, kuri kompiuterio vaizduoklio centre generuodavo žvilgsnio fiksacijos kryželį, horizontalią atkarpą (abu balti (D_{65})) juodame fone ir žymeklį. Atkarpų ilgiai: 5, 7, 10, 13, 15 laipsnių regimojo kampo. Atkarpų storis 5-10 min. Stimulų ryškumas 40-60 cd/m^2 (Michelson kontrastas apie 0,9). Fiksacijos kryželis buvo pateikiamas prie dešiniojo arba kairiojo atkarpos galo. Nustatant fiksacijos kryželio padėtį taip pat buvo atsižvelgta, kad dalinant ilgesnes atkarpas, atkarpos dalies, esančios toliau nuo fiksacijos kryželio, projekcija nepatektų į akląją dėmę.

Tyrimo eiga. Prieš tyrimą tiriamiesiems buvo pateikiama instrukcija, paaiškinami kilę neaiškumai.

Bandymas vyko prie dienos šviesos (patalpos apšvietimas 50-100 Lx). Prieš bandymą tiriamasis 15 min. adaptuodavosi patalpoje, kur vyko bandymas. Tiriamasis patogiai atsisėsdavo priešais kompiuterio vaizduoklį taip, kad aiškiai matytų vaizduoklyje generuojamus stimulus. Buvo uždengiama viena akis, fiksuojama galvos padėtis. Jei tiriamasis bandymo metu pajusdavo nuovargį, jam tapdavo sunku išlaikyti žvilgsnį, buvo daromos pertraukos, kurios vykdavo toje pačioje patalpoje, todėl apšvietimo sąlygos nesikeitė ir papildomo laiko adaptacijai skirti nereikėjo.

Tiriamasis turėjo nuolat fiksuoti žvilgsnį į kryželį, tuo pačiu metu klaviatūros rodyklių pagalba stumdyti žymeklį ir nustatyti jį taip, kad abi atkarpos dalis suvoktų vienodo ilgio (lygias). Savo atsakymą tiriamasis fiksuodavo klaviatūros klavišo paspaudimu. Tiriamasis apie padalinimo tikslumą nebuvo informuojamas. Iš karto po atkarpos padalinimo buvo pateikiama kita atkarpa. Kompiuterinėje programoje buvo nustatyta, kad žymeklio pradinė padėtis kistų atsitiktinai su kiekvienu atkapos pateikimu, siekiant išvengti tiriamojo išmokimo.

Pakartojimų skaičius. Viena bandymo serija su vieno ilgio atkarpa buvo laikoma serija, kurios metu tiriamasis atkarpą padalindavo 40 kartų. 5 tiriamieji su kiekviena atkarpa atliko po 4-7, 25 tiriamieji po vieną bandymų seriją. Kadangi iš viso yra 5 skirtingų ilgių atkarpos (5, 7, 10, 13, 15 laipsnių), tai kiekvienas iš 5 tiriamųjų iš viso atliko 800 – 1400 atkarpų dalinimų, 25 tiriamieji atliko po 200 atkarpų dalinimų. 5 tiriamieji dalyvavo ir kituose tyrimuose, todėl jų atliktų bandymų skaičius buvo didesnis.

Duomenų tvarkymas. Gauti rezultatai buvo atkarpos dalių ilgiai pikseliais. Šie ilgiai buvo perskaičiuoti į kampinius ilgius. Paskaičiuotas atkarpos dalių vidurkis, sklaidos parametrai (standartinis nuokrypis, dispersija). Atkarpos padalinimo tikslumui įvertinti buvo paskaičiuotas atkarpos dalių santykis dalinant atkarpos dalį, esančią prie fiksacijos taško iš likusios atkarpos dalies. Rezultatų normalumas įvertintas Kolmogorov-Smirnov kriterijaus pagalba. Skirtingų ilgių atkarpos dalių skirtumai lyginti Mann-Whitney U kriterijumi.

PAGRINDINIAI REZULTATAI IR IŠVADOS

1. Patvirtinta, kad adaptacija tiesių pakrypai keičia suvokiamą tiesės pakrypą – testinės tiesės suvokiama pakrypa sukasi taip, kad susidarytų kuo didesnis kampas tarp adaptacinių ir testinės tiesės pakrypų. Tyrimo metu nustatyta, kad mažiausias liekamasis adaptacijos poveikis, kai testinės tiesės polinkis buvo 22,5 laipsniai.

2. Patvirtinta, kad ilgai stebint tiesę, keičiasi jos suvokiama pakrypa (normalizacijos efektas). Suvokiama tiesės pakrypa sukasi link artimiausių 0, 45 ir 90 laipsnių pakrypų. Tiesės, kurių polinkis yra artimas 22,5° ir 67,5° adaptacijos metu suvokiamos nekintančiomis, bet dėl atsitiktinių poveikių jų suvokiama pakrypa yra nestabili - jos subjektyviai sukasi link artimesnių tiesių arba (0° ir 45°) arba (45° ir 90°).

3. Liekamojo adaptacijos poveikio ir normalizacijos efektus galima paaiškinti hipotetiniu modeliu, kuris aprašo tik dviejų detektorių, kurių atsakai, kaip pakrypos kampo φ funkcija, aprašoma $\sin 2(\varphi+22{,}5°)$ ir $\cos 2(\varphi +22{,}5°)$.

4. Nustatyta, kad esant fiksuotam žvilgsniui žmogus padalina atkarpą nelygiai – atkarpos dalis, esanti prie fiksacijos taško nustatoma mažesnė nei likusi atkarpos dalis, kadangi suvokiama didesnė. Atkarpos padalinimo sisteminė paklaida kinta nemonotoniškai ir priklauso nuo atkarpos ilgio. Tam tikro ilgio atkarpas (vienai grupei tiriamųjų 7 laipsnių regimojo kampo, kitai – 13) žmogus padalina su didžiausia sistemine paklaida. Toliau dalinimo tikslumas gerėja.

5. Atkarpos padalinimo tikslumui įtakos turi bendras tinklainės, kur yra dalinamos atkarpos atvaizdas, receptorių skaičius, tačiau kūgelių ir lazdelių indėlis skirtingas.

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