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Investigation of the Scintillating Grid Illusion in Patients with Amblyopia

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Abstract—The study is devoted to the study of the manifestations of the scintillating grid illusion in patients with amblyopia. Overall, 133 schoolchildren with bilateral refractive amblyopia and 146 control group schoolchildren without ophthalmopathology were observed. In the study, we used our own test images developed on the basis of classical images that cause the scintillating grid illusion. It is shown that the phenomenon of illusory disappearance is more pronounced, and the strength of the scintillating grid illusion is significantly lower in children with amblyopia compared with children without ophthalmopathology. When the test images are rotated by 45°, an increase in the phenomenon of illusory disappearance is observed both in children with amblyopia and in children of the control group. The severity of the scintillating grid illusion in children with amblyopia is significantly lower than in children without ophthalmopathology.

Keywords: scintillating grid illusion, the illusion of knowledge, amblyopia

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INTRODUCTION

Despite many years of research and numerous publications in the field of visual illusions, their study continues to be one of the topical areas in the physiology of vision, especially considering the active development of virtual reality technologies [1–4]. At the same time, it should be taken into account that many visual illusions arise as a result of the action of several factors at different stages of analysis of visual information. Among these factors, there are features of the optical system of the eye, the nature of connections and relationships between the neuronal structures of the retina and visual cortex, and the state of binocular visual functions [1–3].

The scintillating grid illusion (phosphene illusion) is currently an understudied visual phenomenon. The classic image that evokes it is the Hermann grid, consisting of several black squares separated by white lines perpendicular to each other [5]. Looking at such an image and moving one's gaze along it, the observer perceives illusory dark spots (phosphenes) appearing and "extinguishing" at the intersections of white lines, mainly on the periphery (outside the zone of central fixation). Later, researchers created other variants of the Hermann grid, the Bergen grid (blurred grid) and the scintillating grid (Fig. 1) [6–9].

In our previous study of the manifestations of the flickering grid illusion in school-age children with partial optic nerve atrophy (PONA), we used our own image modification. Causing the illusion of a scintillating grid, the main difference of which from the classical image was the presence of white disks at the intersections of light lines, the diameter of which increased from 1.5 mm in the first test image to 5 mm in the last (sixth) test image. In addition, the children were presented with 45° rotated versions of our test images. As a result of the study, it was shown that in children with PONA, compared with children in the control group without ophthalmopathology, there is a "shift" of the maximum severity of the scintillating grid illusion towards the maximum value of disk diameters (DDs) in the presented test images. It can be assumed that this may be due to the larger size of retinal receptive fields in these patients with PONA, which is probably due to destructive changes at the level of retinal ganglion cells [10].

Taking into account the results obtained earlier, we devoted the next stage of the study to the analysis of manifestations of the scintillating grid illusion in children with a normal state of the fundus, but with the presence of inhibition of visual information processing at the level of the central part of the visual analyzer.

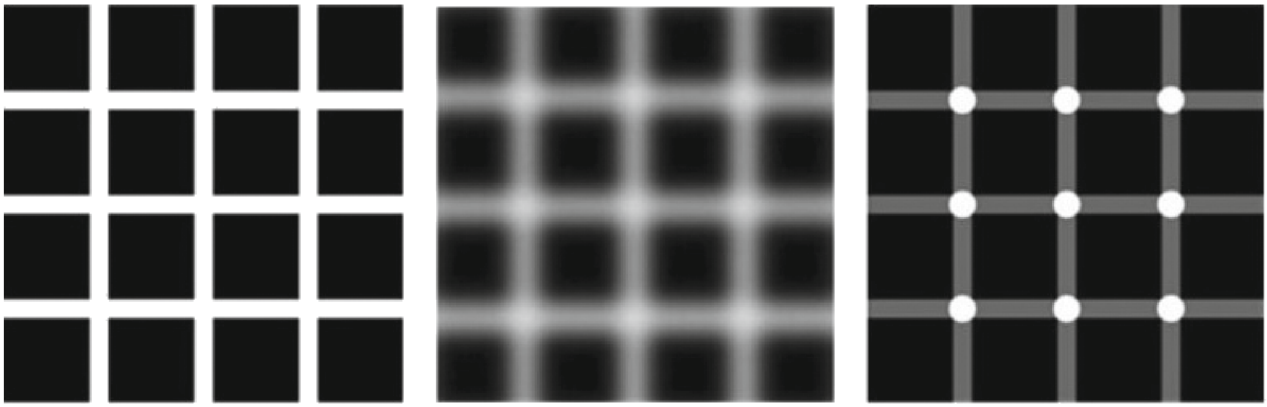

Fig. 1. Classic test images that cause the scintillating grid illusion.

Objective—To study the manifestations of the scintillating grid illusion in schoolchildren with amblyopia.

METHODS AND MATERIALS

Overall, 133 children with bilateral refractive amblyopia were observed and 146 children without ophthalmopathology constituted the control group. Table 1 presents the clinical characteristics of the study groups.

Studying the manifestations of the scintillating illusion grids in children with amblyopia and children in the control group was performed according to the method used in the previous study of this illusion in children with PONA. We developed modifications of the classic test image that causes the scintillating grid illusion, black squares, 5 × 5 cm in size, with gray stripes 1.5 mm wide perpendicular to each other, presented on the monitor screen from a distance of 70 cm from the eyes. At the intersections of the gray stripes, there were white disks, four disks in the central zone of each black square and four on its periphery. In addition, variants of the same test where images rotated by 45° were used in the study. The size of the black squares and the width of the gray bars (GBs) in all test images were the same, and DDs from the first test image to the last increased and amounted to: in Figs. 1a and 1b—1.5 mm; in Figs. 2a and 2b—2 mm; in Figs. 3a and 3b—2.5 mm; in Figs. 4a and 4b—3 mm; in Figs. 5a and 5b—4 mm; and in Figs. 6a and 6b—5 mm (Fig. 2).

Given the lack of significant difference ($p > 0.05$) in visual acuity of the better seeing and worse seeing eye in children of both groups, the experiment was carried out in all children under binocular observation conditions (both eyes are open). In the course of the study, the child was asked to examine a test image presented on the screen, moving his gaze smoothly over its surface, and talk about his visual impressions. Test images with disks of different sizes were changed randomly.

The method developed by us for studying the scintillating grid illusion made it possible to carry out not

Table 1. Clinical characteristics of the studied groups of children: groups with amblyopia and control groups

Characteristics of the study groups of children		Patient groups	
		children with amblyopia ($n = 133$)	children of the control group ($n = 146$)
Age $M \pm m$, years		11.45 ± 0.3	9.83 ± 0.3
Number in the group of boys/girls, %		51.9/48.1	54.8/45.2
Visual acuity of the better seeing eye, arb. units		0.71 ± 0.05	1.1 ± 0.01
Visual acuity worse than the seeing eye, arb. units		0.69 ± 0.02	1.0 ± 0.005
Number of children with different types of refraction (absolute number, %)	Emmetropic	–	146 (100%)
	Hyperopic	55 (41.3%)	–
	Myopic	59 (44.5%)	–
	Mixed astigmatism	19 (14.2%)	

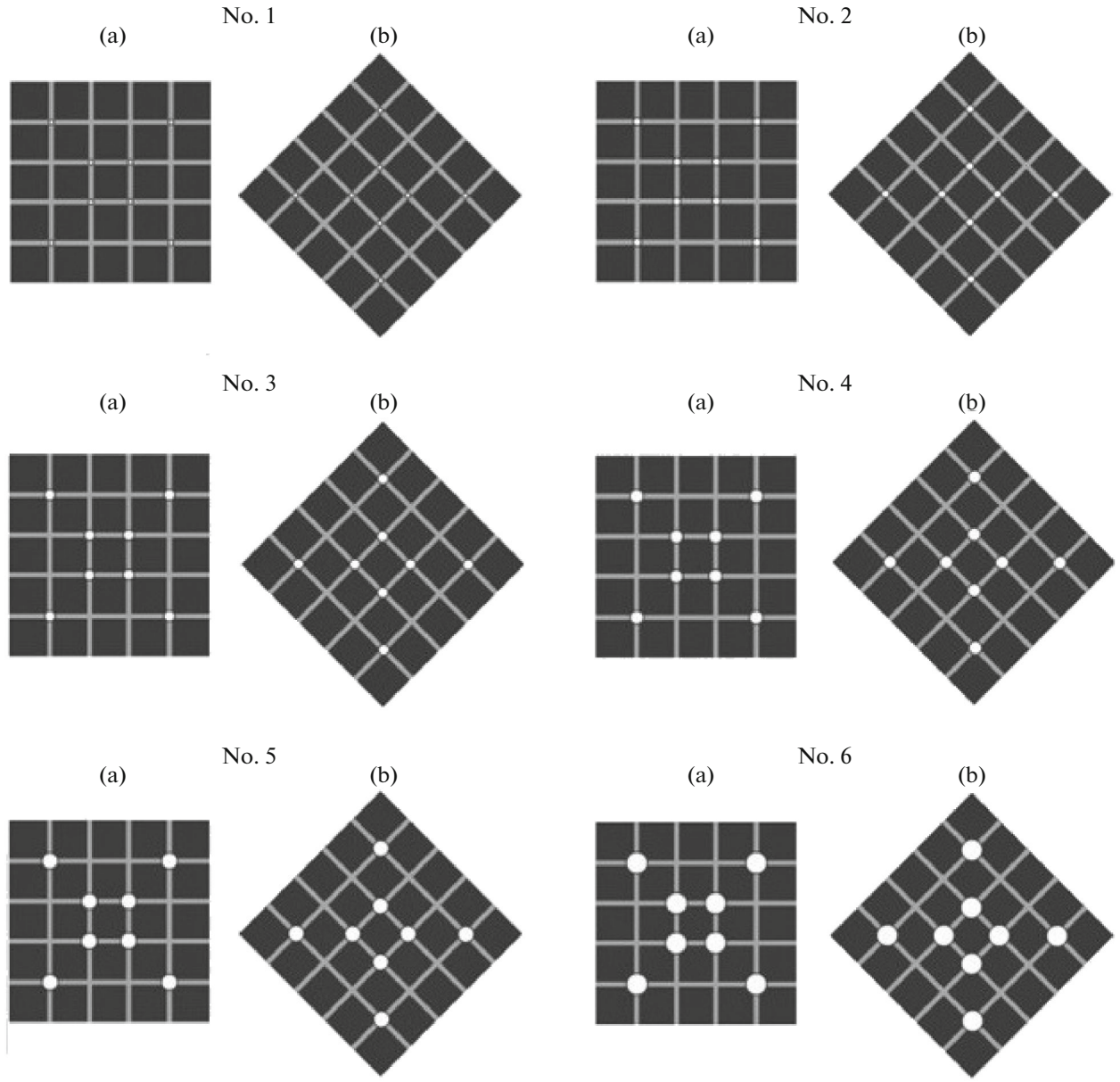

Fig. 2. Test images designed to study the manifestations of the scintillating grid illusion. Six test images are presented in classic versions (image Nos. 1a–6a) and variants of the same test images rotated by 45° (image Nos. 1b–6b). The figures contain disks of different diameters (DDs) and the ratio of the DD to the width of the intersecting gray stripes (DD/IGS) is: (1) 1.0; (2) 1.3; (3) 1.7; (4) 2.0; (5) 2.7; (6) 3.3.

only a qualitative, but also a quantitative assessment of its severity.

During the examination, the following parameters were evaluated:

(1) Visibility (perceptibility) of disks at the intersection of light lines. At the same time, the results were evaluated at points according to the following scale: disks are not visible at all—0 points, less than four disks are visible at the same time—1 point, four (usually central) disks are visible—2 points, most of the disks are visible at the same time—3 points, all disks are visible at the same time—4 points.

(2) The severity of the illusion, characterized by the appearance of dark spots (phosphenes) and the brightness of their flickering in the center of the disks. The result was also evaluated in points: 0 points —no phosphenes, 1 point—phosphenes are seen only in 1–2 peripheral discs, 2 points—phosphenes in all peripheral discs, 3 points—phosphenes are seen in all peripheral and 1–2 central discs, 4 points—phosphenes are

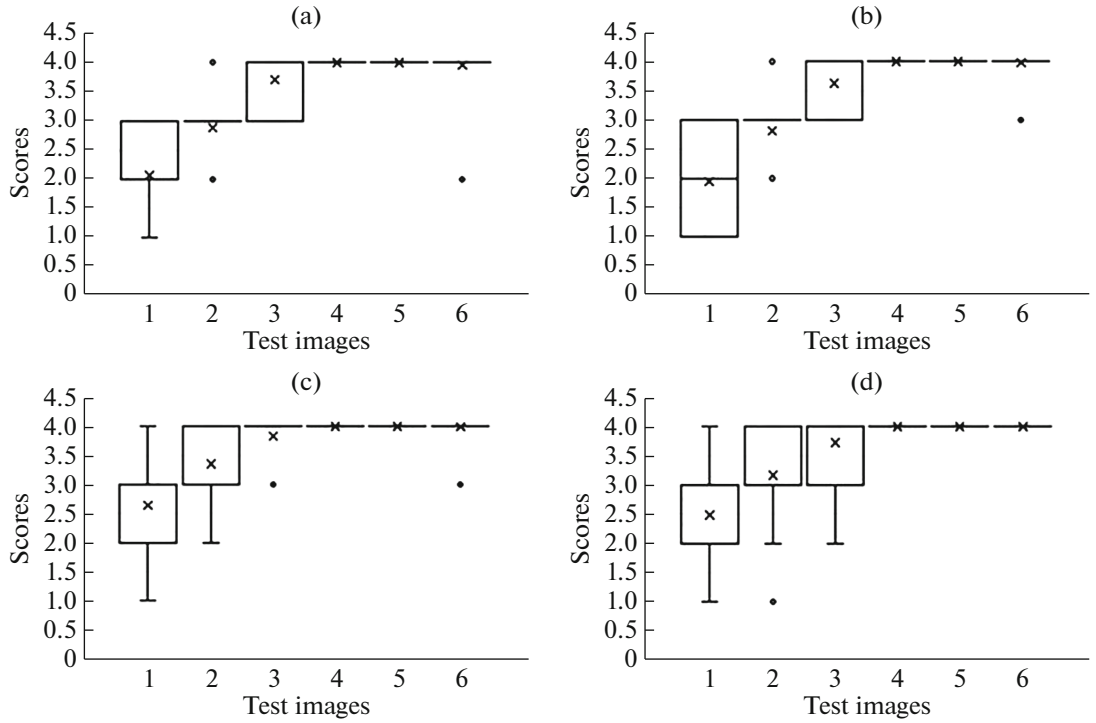

Fig. 3. Simultaneous visibility of disks at the intersections of light lines. (a) for the standard orientation of test images in children with amblyopia, (b) for test images rotated by 45° in children with amblyopia; (c) for the standard orientation of test images in children of the control group; (d) for test images rotated by 45° in children of the control group.

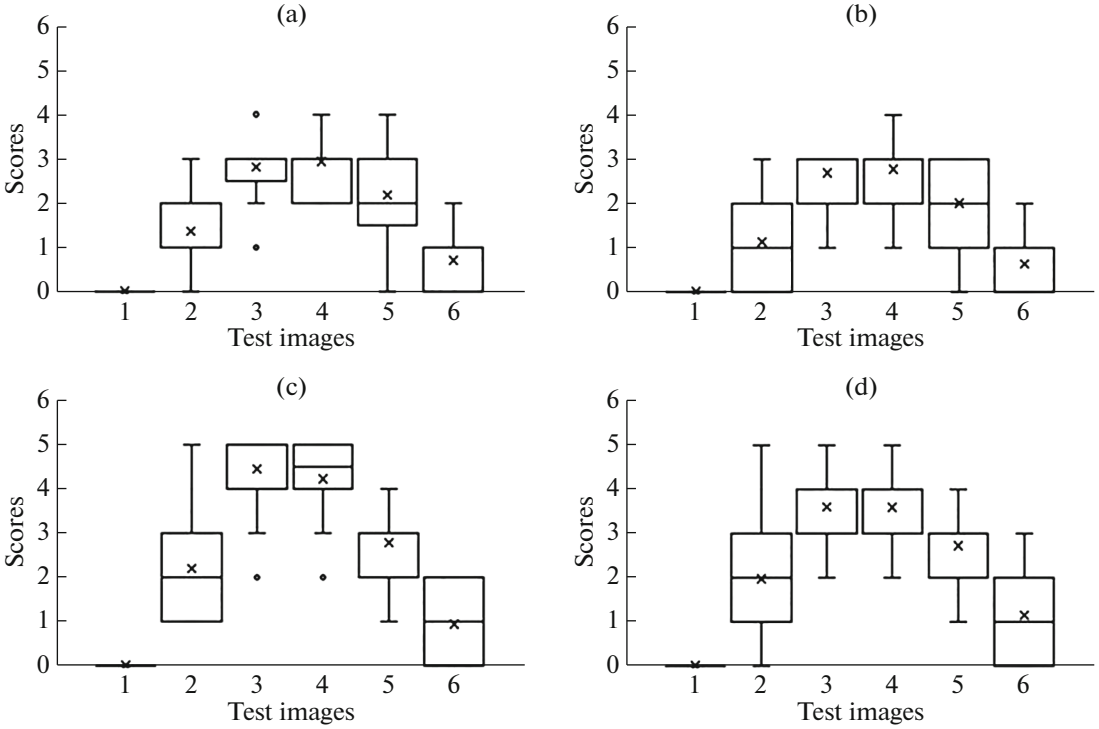

Fig. 4. The severity of the scintillating grid illusion. (a) for standard orientation of stimuli in children with amblyopia; (b) for 45° rotated stimuli in children with amblyopia; (c) for the standard orientation of stimuli in children of the control group; (d) for stimuli rotated by 45° in children of the control group.

Table 2. Statistical significance and significance differences in disk visibility and the severity of the scintillating grid illusion when using test images in their standard position (in the form of squares) in children with amblyopia and children in the control group

Incentives	Compared groups of children (amblyopia–control)	
	disk visibility in test images	the severity of the illusion
1	$U = 6511$ *df* 277, $p < 0.001$	Illusion is gone
2	$U = 5859$ *df* 277, $p < 0.001$	$U = 5436$ *df* 277, $p < 0.001$
3	$U = 8524$ *df* 277, $p = 0.16$	$U = 1704.5$ *df* 277, $p < 0.001$
4	$U = 9709$ *df* 277, $p = 1$	$U = 3001$ *df* 277, $p < 0.001$
5	$U = 9709$ *df* 277, $p = 1$	$U = 6680$ *df* 277, $p < 0.001$
6	$U = 9709$ *df* 277, $p = 1$	$U = 8248.5$ *df* 277, $p < 0.001$

U—Mann-Whitney test, *df*—degrees of freedom, *p*—the level of statistical significance.

observed in all discs, but pale, 5 points – bright phosphenes in all discs.

RESULTS

The results of the study of the visibility of the discs obtained upon presentation of test images in a standard position (in the form of squares) and rotated by 45° (in the form of rhombuses) are shown in the diagrams (Fig. 3).

Analyzing the presented data, it should be noted that in test images with the smallest used DD—1.5 mm (DD/NR = 1), their visibility was minimal in both groups of children (no more than four central discs were visible at the same time). The observed phenomenon, in the opinion of the authors of this article, can characterize the phenomenon of the disappearance of the perception of peripheral (not fixed by the eye) disks. In test images with larger discs, their simultaneous visibility improved in both groups of children. Comparison of the results of disk visibility in children with amblyopia and in the control group shows significantly lower indicators in amblyopia for test images Nos. 1–2 ($p < 0.001$ according to the Mann–Whitney test). A possible explanation for this may be the influence of the processes of inhibition of the analysis of incoming information in the central section of the visual analyzer. For test images Nos. 3–6, the results were comparable.

When using variants of test images rotated by 45° (in the form of rhombuses), the simultaneous visibility of the discs also significantly improved as the DD increased both in the children of the control group and in the amblyopes. Comparing the disk visibility estimates in the test images in the form of squares and in in the form of rhombuses in the control group of children, a significant (according to Wilcoxon test) deterioration in the visibility of disks in rotated images No. 1 ($z = -2.65$ *df* 145, $p = 0.008$), No. 2 ($z = -4.84$ *df* 145, $p < 0.001$), no. 3 ($z = -3.42$ *df* 145, $p = 0.001$). In the amblyopes group, the visibility of disks in rhombuses was also significantly lower according to the Wilcoxon test than in squares of test images No. 2 ($z = -3.0$ *df* 132, $p = 0.003$), and no. 3 ($z = -3.32$ *df* 132, $p = 0.001$). For the rest of the test images, the difference was not detected.

The results of the study of the severity of the scintillating grid illusion with test images in a standard position (in the form of squares) and rotated by 45° (in the form of rhombuses) in children with amblyopia and children in the control group are also presented in the diagrams (Fig. 4).

According to the presented data, when examining test images with a DD of 1.5 mm (DD/NR = 1), the scintillating grid illusion did not arise in any of the examined children.

The maximum values of the power of illusion in amblyopia and in the control were noted for test images Nos. 3 and 4. In the control group, they were for test image No. 3 $Me = 5.0$ [$Q_1 = 4.0$; $Q_3 = 5.0$], for No. 4 $Me = 4.5$ [$Q_1 = 4.0$; $Q_3 = 5.0$]. In the group of children with amblyopia – for test image No. 3 $Me = 3.0$ [$Q_1 = 2.5$; Q_3=3.0], for number 4 $Me = 3.0$ [$Q_1 = 2.0$; $Q_3 = 3.0$], which was significantly lower than in the control group ($p < 0.001$). The indicators of the severity of the illusion for other test images (except for No. 1, which did not cause an illusion in any of the children) in amblyopes were also significantly lower than in the control group (Table 2).

When the test images were rotated by 45°, the severity of the illusion in the control group was lower for test images Nos. 4 and 5 ($p < 0.001$) and No. 6 ($p < 0.05$). In the group of amblyopes, no significant difference was found in the severity of the illusion for the test images in the form of squares and in the form of rhombuses.

Pearson's correlation analysis of the severity of this illusion from the age of children did not reveal a significant correlation in both study groups ($p > 0.05$).

DISCUSSION

One of the first proposed physiological explanations for the appearance of the scintillating grid illusion, based on ideas about the antagonistic central-peripheral organization of retinal ganglion cells, was proposed by G. Baumgartner in 1960 [11]. In his opinion, dark spots may appear due to the fact that the activation of retinal ganglion cells with on-centers of receptive fields gives a less pronounced response than activation of ganglion cells by non-intersecting sections of lines [12].

However, further research has shown that this explanation is not exhaustive. For example, it was shown that when the position of intersecting lines changes (lattice curvature), the severity of the illusion decreases significantly, despite the fact that theoretically, differences in the severity of the response of ganglion cells should not be observed in this case [13, 14].

In this regard, a theory was proposed, according to which the existence of the scintillating grid illusion can be explained by the peculiarities of the work of simple S1 neurons of the visual cortex (zone V1), which have orientational selectivity. It has been established that these cells usually have elongated receptive fields of different sizes. In this regard, it is possible that S1 neurons with receptive fields corresponding to intersections of image lines give a smaller response than S1 cells with receptive fields corresponding to non-intersecting sections of lines [14].

The results obtained by us in the control group and the group with amblyopia demonstrate that the scintillating grid illusion is most pronounced when the DD is approximately 1.5–2 times larger than the line width, which is also consistent with the results of J. Ninio and K.A. Stevens obtained from healthy adults [15].

Analyzing our observations, we can assume that the phenomenon of the disappearance of the perception of disks that are not fixed by the eye at the intersections of lines, especially disks with a small diameter of 1.5 mm (equal to the width of light stripes in test images), is a manifestation of the lateral inhibition mechanism in the central regions of the visual analyzer. This phenomenon has been called the illusion of disappearance (Extinction illusion) by Ninio and Stevens [15–17]. Decreased visibility of discs when rotating the standard variant of the test image (square) by 45°, especially in children in the control group, is also consistent with the results of Ninio and Stevens conducted on healthy adult subjects [15]. The results obtained by these researchers showed a decrease in the strength of the scintillating grid illusion and an increase in the disappearing illusion when the test image was positioned in a rhombus pattern. Presumably, this phenomenon is associated with the predominance in the primary visual cortex (zone V1) of simple S1 neurons with horizontal and vertical directional sensitivity compared to the number of S1 neurons with diagonal directional sensitivity [18–25].

At the same time, our results, demonstrating that the indicators of the simultaneous visibility of disks and the strength of the scintillating grid illusion are significantly lower in amblyopia compared to the control, can be explained by the processes of inhibition of perception and processing of visual information in amblyopes at the level of the central part of the visual analyzer.

CONCLUSIONS

1. The phenomenon of disappearing illusion is more pronounced, and the indicators of the strength of the scintillating grid illusion are significantly lower in children with amblyopia compared to children without ophthalmopathology.

2. When the test images are rotated by 45°, an increase in the phenomenon of disappearing illusion is observed both in children with amblyopia and in children of the control group.

3. The severity of the scintillating grid illusion in children with amblyopia is significantly lower than in children without ophthalmopathology.

COMPLIANCE WITH ETHICAL STANDARDS

All studies were carried out in accordance with the principles of biomedical ethics, formulated in the Declaration of Helsinki of 1964 and its subsequent updates, and approved by the local bioethical committee of the Institute for Information Transmission Problems (Moscow).

Informed consent. Each study participant provided a voluntary written informed consent signed by him or his legal representative (for minors) after explaining the potential risks and benefits, as well as the nature of the upcoming study.

CONFLICT OF INTEREST

The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

REFERENCES

1. Rozhkova, G.I., Tokareva, V.S., Ognivov, V.V., and Bastakov, V.A., Geometric visual illusions and mechanisms of size perception constancy in children, *Sens. Sist.*, 2005, vol. 19, no. 1, p. 26.
2. Menshikova, G., An investigation of 3D images of the simultaneous-lightness-contrast illusion using a virtual reality technique, *Psychol. Rus.*, 2013, vol. 6, no. 3, p. 49.
3. Rabichev, I.E. and Kotov, A.V., Visual illusions and virtual visual images: comparative aspects, *Teor. Eksp. Psikhol.*, 2013, vol. 6, no. 2, p. 94.

4. Grishin, S.N., Ionenko, S.I., Dautova, R.V., and Morozov, O.G., *Zritel'nye illyuzii* (Visual Illusions), Kazan': Kazan. Fed. Univ., 2015.
5. Hermann, L., Eine Erscheinung simultanen Kontrastes, *Pflügers Arch.*, 1970, vol. 3, no. 1, p. 13.
6. Bergen, J.R., Hermann's grid: new and improved, *Invest. Ophthalmol. Vision Sci.*, 1985, vol. 26, suppl., p. 280.
7. Schrauf, M., Lingelbach, B., and Wist, E.R., The scintillation grid illusion, *Vision Res.*, 1997, vol. 37, no. 8, p. 1033.
8. Matsuno, T., Scintillating grid illusion without the grid, *i-Perception*, 2020, vol. 11, no. 4, p. 2041669520944418.
9. Sun, E.D. and Dekel, R., ImageNet-trained deep neural networks exhibit illusion-like response to the scintillating grid, *J. Vision*, 2021, vol. 21, no. 11, p. 15.
10. Rychkova, S.I., Sandimirov, R.I., and Kosobutskaya, L.V., The study of phosphene illusion in students with partial atrophy of the optic nerve and normal fundus, *Hum. Physiol.*, 2019, vol. 45, no. 5, p. 507. https://doi.org/10.1134/S0362119719050165
11. Baumgartner, G., Indirekt Grössenbestimmung der rezeptiven Felder der Retina beim Menschen mittels der Hermannschen Gittertäuschung, *Pflügers Arch.*, 1960, vol. 272, p. 21.
12. Hubel, D.H. and Wiesel, T.N., *Brain and Visual Perception: the Story of a 25-Year Collaboration*, New York: Oxford University Press, 2005.
13. Levine, M.W. and McAnany, J.J., The effects of curvature on the grid illusions, *Perception*, 2008, vol. 37, no. 2, p. 171.
14. Schiller, P.H. and Tehovnik, E.J., *Vision and the Visual System*, New York: Oxford University Press, 2015.
15. Ninio, J. and Stevens, K.A., Variations on the Hermann grid: an extinction illusion, *Perception*, 2000, vol. 29, no. 10, p. 1209.
16. McAnany, J.J. and Levine, M.W., The blanking phenomenon: a novel form of visual disappearance, *Vision Res.*, 2004, vol. 44, no. 10, p. 993.
17. Araragi, Y. and Kitaoka, A., Increment of the extinction illusion by long stimulation, *Perception*, 2011, vol. 40, no. 5, p. 608.
18. Lafuente, V. and Ruiz, O., The orientation dependence of the Hermann grid illusion, *Exp. Brain Res.*, 2004, vol. 154, no. 2, p. 255.
19. Bertamini, M., Herzog, M.H., and Bruno, N., The honeycomb illusion: uniform textures not perceived as such, *i-Perception*, 2016, vol. 7, no. 4, p. 2041669516660727.
20. Schrauf, M. and Spillmann, L., The scintillating grid illusion in stereo-depth, *Vision Res.*, 2000, vol. 40, no. 7, p. 717.
21. Qian, K., Yamada, Y., Kawabe, T., and Kayo, M., The scintillating grid illusion: influence of size, shape and orientation of the luminance patches, *Perception*, 2009, vol. 38, no. 8, p. 1172.
22. Zhuang, J., Stoelzel, C.R., Bereshpolova, Y., et al., Layer 4 in primary visual cortex of the awake rabbit: contrasting properties of simple cells and putative feedforward inhibitory interneurons, *J. Neurosci.*, 2013, vol. 33, no. 28, p. 11372.
23. Yu, Y. and Choe, Y., A neural model of the scintillating grid illusion: disinhibition and self-inhibition in early vision, *Neural Comput.*, 2006, vol. 18, no. 3, p. 521.
24. Read, J-C.A., Robson, J.H., Smith, C.L., and Lucas, A.D., The scintillating grid illusion is enhanced by binocular viewing, *i-Perception*, 2012, vol. 3, no. 10, p. 820.
25. Qian, K., Kawabe, T., Yamada, Y., and Kayo, M., The role of orientation processing in the scintillating grid illusion, *Atten. Percept. Psychophys.*, 2012, vol. 74, no. 5, p. 1020.