UNIVERSITY OF LATVIA

Correlation between stereothreshold and quality of monocular stimuli

Gunta Krumina

Doctoral thesis

Riga
2004

Promotion work was accomplished in the University of Latvia in the Faculty of Physics and mathematics in the Department of Optometry and vision science in the period from year 2000-2004.

Type of work: set of scientific publications

Scientific supervisors:

Dr.habil.phys. **Māris Ozoliņš**

Dr.habil.phys. **Ivars Lācis**

Reviewers:

Dr.phys. **Raymond van Ee**

Dr.habil.phys. **Jānis Spīgulis**

Dr.psych. **Malgožata Raščevska**

Abstract

The aim of the present work was studies of correlation between the stereothreshold and the quality of eye stimuli in different eyes. To achieve this aim the following tasks have been set: assessment and comparison the characteristic values of stereovision in cases of real and induced cataract, amblyopia and uncorrected anisometropia as well as the comparison of the estimated stereothreshold values in cases of induced uncorrected myopic and hypermetropic anisometropia. It was supposed to develop a method for training the stereovision by determining the stereothresholds in cases of artificial amblyopia and cataract that could help people with lowered visual acuity in one eye to see the stereo images.

Three methods to determine the stereothreshold have been used in the present work: defocusing, monitor stimuli and eye occluder methods. The quality of the stimulus of one eye is being changed (blurring and contrast); the quality of the stimulus of the second eye remains all time constant. During the investigation positive and negative features of each method are stated to assess the application of these methods in order to induce different eye pathology conditions in laboratory. The subjects' stereothreshold was assessed simulating amblyopia, cataract and uncorrected anisometropia. To characterize the quality of the stimulus and to find ways to compare different stereostimuli spatial characteristics, three different methods have been used – the average of modulation amplitude, Fourier images spectral power density frequency distribution of stimuli and cross-correlation.

The developed methods are approved in stereothreshold studies: the defocusation method in cases of uncorrected anisometropia and amblyopia, the monitor stimuli method in cases of amblyopia and cataract, the eye occluder method as a good cataract simulation. The relationship between stimuli created by different method has been obtained allowing unambiguous their comparison with literature data.

The obtained results prove that the stereothreshold increases if the quality of visual stimulus is decreased in one eye. The determined threshold of stereovision are approximately the same comparing cases when decreasing of monocular visual acuity is simulated in laboratory with similar situation for real people with visual acuity lowering in one eye since childhood or due to the progress of cataract. The results of studies show, that in the case of hypermetropic anisometropia the stereothreshold is higher in comparison with myopic anisometropia under the same vision conditions. A method and conditions of vision perception are described to help people with a manifest difference of visual acuity between the eyes and weak binocular vision to see the latent image of random elements stereotests.

Keywords: stereovision, visual acuity, blurring, contrast, defocusation, monitor stimuli, eye occluder, PLZT and PDLC plates.

Publications in periodics and proceedings

The thesis is based on the following papers:

I. Papelba[*] G., Cipane I. & Ozolinsh M.
"Stereovision studies by disbalanced images." In: "*Advanced optical materials*" Ed. by J.Spigulis, J.Teteris, M.Ozolinsh, and A.Lusis, *Proc.SPIE* Vol.5123, pp.323-329, 2003

II. Papelba G., Ozolinsh M., Petrova J. & Cipane I.
"Stereoacuity determination at changing contrast of colored stereostimuli." In: "*Advanced optical materials*" Ed. by J.Spigulis, J.Teteris, M.Ozolinsh, and A.Lusis, *Proc.SPIE* Vol.5123, pp.330-338, 2003

III. Ozolinsh M., Papelba G. & Andersson G.
"Liquid crystal goggles for vision science application." In:"*19th Congress of the International Commission for Optics: Optics for the Quality of Life*" Ed. by A.Consortini and G.C.Righini, *Proc.SPIE* Vol.4829, pp. 1056-1058, 2003

IV. Papelba G., Ozolinsh M., Cipane I. & Petrova J.
"The effect of blurring degree, and chromatic contrast in one eye on stereovision." "*Perception*" Vol.31, supplement, p. 156, 2002

V. Krumina G. & Ozolinsh M.
"Clinical investigation of stereoacuity for patients having real or induced anisometropia and cataract." "*Optometry and Vision Science*" Vol.80 (12s), p.41, 2003

VI. Ozolinsh M. & Papelba G.
"Eye cataract simulation using polymer dispersed liquid crystal scattering obstacles." "*Ferroelectrics*" (in print 2004)

VII. Krumina G., Ozolinsh M. & Lyakhovetskii V.A.
"Stereovision by visual stimulus of different quality. " In. Proc. of the IV interregional seminar of Moscow Helmholtz Research Institute for Eye Diseases "*Ocular biomechanics 2004*", Ed. by E.N.Iomdina, I.N.Koshitz, pp.82-89, 2004

---

[*] surname at birth

Reports in conferences

I. Sixth International Meeting of American Academy of Optometry “Academy 2000” – Madrid, Spain, 7.-9. April 2000
    - Papelba G., Lacis I., Ozolinsh M. & Daae K.I.
      “Stereoresistance – a new characterisation of stereothreshold under external influence”

II. 99.Tagung der Deutsche Ophthalmologische Gesellschaft – Berlin, Germany, 29.September – 2.Oktober 2001
    - Papelba G. & Ozolinsh M.
      “Blurring effect to stereoscopic vision”

III. 3rd International Conference “Advanced Optical Materials and Devices – AOMD-3” – Riga, Latvia, 19.-22.August 2002
    - Ozolinsh M., Papelba G. & Andersson G.
      “Spatial and temporal transmittance of liquid crystal goggles used in vision tests”
    - Papelba G., Ozolinsh M. & Petrova J.
      “Method of determination of colour contrast to stereoacuity”
    - Papelba G., Ozolinsh M. & Cipane I.
      “Evaluation of image’s quality to stereovision acuity”

IV. The XXXV Nordic Congress of Ophthalmology – Tampere, Finland, 24.-27.August 2002
    - Papelba G., Cipane I. & Petrova J.
      “Stereovision acuity studies by disbalanced eye image quality”
    - Papelba G., Petrova J. & Cipane I.
      “The influence of blue-red colour’s contrast to stereoacuity”

V. 25th European Conference on Visual Perception – Glasgow, UK, 25.-29.August 2002
    - Papelba G., Ozolinsh M., Cipane I. & Petrova J.
      “The effect of one eye image blurring degree, luminance and chromatic contrast to stereovision”

VI. 3d International Conference “Television: Transmission and Processing of Images” – Sankt-Peterburg, Russia, 5.-6.june 2003
    - Lyakhovetskii V.A. & Papelba G.
      “Spectral composition description of images for objects in the perception of depth”

VII. Academy 2003 “The future in sight: Today’s Research, Tomorrow’s Practise” – Dallas, USA, 4.-7.December 2003
    - Krumina G. & Ozolinsh M.
      “Clinical investigation of stereoacuity for patients having real or induced anisometropia and cataract”

Abbreviations and key-terms

Amblyopia

Aniseikonia

Anisometropia

Cataract

D – dioptre

Disparity – difference between the locations of the two retinal projections of a given point in the space, relative to the corresponding points

Hypermetropia

LC shutters (goggles) – liquid crystal goggles

Myopia

PDLC plate – light scattering polymer dispersed liquid crystal cells plate that becomes transparent when voltage is applied

PLZT plate – $Pb_{0.905}$ $La_{0.095}$ $Zr_{0.35}$ $Ti_{0.65}$ O_3 ceramic plate with semitransparent gold electrodes that it becomes uniformly blurred when voltage is applied

Presbyopia

Stereoacuity – the lowest disparity value, measured in angle units, by which subjects perceive stereostimuli as a spatial image; this term is used more in clinics to evaluate the quality of stereovision

Stereogram

Stereothreshold, stereovision threshold – the lowest disparity value by which subjects perceive stereostimuli as a spatial image, a term having the opposite meaning to stereoacuity, by high stereoacuity the stereothreshold is low, both measured in angle units

Visual acuity

Contents

Appendix (publications PI - PVII and conference theses TI - TVIII)

Introduction

A human has two eyes with which he perceives 80% of information from the surrounding world. As our living environment is a three-dimension space the human's ability to orientate in the space can be called the highest phenomenon of visual perception. There have been endless attempts to explain the formation of spatial perception, and still there is a lot to do. Even the latest technologies do not allow us to study and understand our brain completely. New robots are being built the visual system of which is designed just like the human's spatial and visual perception. Recent neurological investigations (*Grossberg & Howe* 2003) based on the working principles of the animals' primary vision cortex cells (*Hubel & Wiesel* 1979, 1998) try to explain the formation of human's stereovision (*Cumming & DeAngelis* 2001). Other scientists try to use the same newly discovered algorithms in the formation and perfection of robots stereovision. How do the human's binocular vision and stereovision operate? What outer conditions and inner neurophysiologic factors can influence the formation of stereovision, its development and even its destruction? These questions have been important in the XX century and they have not lost their significance now. There are new technologies to investigate and to produce a similar visual system and to study it, but the question has not been answered: "How is the human's perception formed?"

The idea of the present investigation was to determine values of the stereothreshold under conditions when one eye sees a bad (or worse comparing with other eye) quality stimulus. To explain why a subject with weak binocular vision does not have a stereosense and does not see spatial tests – images by which most of the people are fascinated. Was it a coincidence or was it a desire to see stereo images by myself and to understand how stereovision is formed under conditions when the vision perception ability of one eye is reduced. But now I can be proud of the fact that three people feel happier as they have found themselves able to see the world as spatial. Nobody will ever say that they do not have stereovision. Using our method these people have been taught to see the complicated stereoscopic images produced on the basis of random element principle and recognized only when a subject possesses stereovision.

In its turn people who do not have stereovision do not feel worse because they can find their way to compensate it in the conditions of monocular stereovision such as perspective, the relative size of the image on the retina, light scattering in the atmosphere and others. However, a subject who has lost the ability to see with one eye feels what it means to perceive the world with one eye only. It is difficult and takes a long time to adapt to such conditions.

The aim of my work was to study and to determine values of the stereothreshold when the quality of the stimulus of one eye (blur and contrast) changes. Studies of factors influencing the stereothreshold using monocular stimuli of different quality for well seeing subjects allowed to develop a method to evoke and facilitate the formation of stereovision for the people with a real decrease of visual acuity in one eye, who have not previously had the stereovision.

In stereovision studies two classes of smart materials with controllable optical properties were applied to set up stimuli simulation experiments.

Experimental part

1. Aim and tasks of the study

The aim of the study is to investigate binocular vision and to determine values of the stereothreshold if stimuli of different quality are formed in subjects eyes. To fulfil the aim the following tasks have been set:

1) To assess binocular vision and to study the values of stereothreshold in cases of real and induced cataract, amblyopia and uncorrected anisometropia;
2) To compare the values of stereothreshold of uncorrected myopic and hypermetropic anisometropia;
3) To develop a method how to teach subjects with lowered visual acuity in one eye to perceive random elements stereotests.

Additionally it was necessary to perform tasks related with classification of stimuli and the application of different methods to create artificial conditions for subjects when the eyes receive images of different quality on the retina:

1) To characterize stimuli using the average of modulation depth, the frequency distribution of Fourier images and cross-correlation and to build scaling to compare the differently obtained stimuli during the studies of stereovision.
2) To evaluate the stereothreshold by simulating the eye pathologies by:
    a) defocusation method (with optical lenses) – in cases of uncorrected myopic and hypermetropic anisometropia and amblyopia:
    b) monitor stimuli method (using liquid crystal shutters and light filters) – in cases of amblyopia and cataract;
    c) one eye occluder method (with PLZT ceramics and PDLC plate) – in cases of cataract.

2. Subjects

Total 445 subjects – in each part the different number of subjects (see Figure 2.1) – participated in stereovision study. The age of subjects varied from 15 to 74 years (see Figure 2.2), with the average age 39±17 years. The major part of subjects is clinics patients that agreed voluntarily to participate in experiments. The second smallest part is students from Department of Optometry and Vision Science of University of Latvia. From more of 400 patients there were selected only 101, because some had not binocular vision or were very old with tingled hand and had difficulties to look very long time on stereotests. All selected subjects had a binocular vision determined with *Schober* and *Worth* tests, and a stereovision with TNO test.

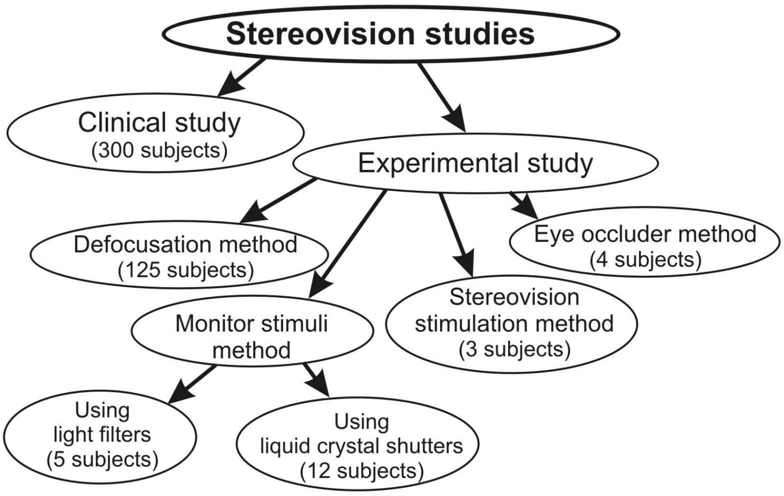


Figure 2.1. Subjects' distribution in different studies of stereovision.

All of them had full correction for the distance vision. Presbyopes had been corrected for a 40 cm distance although their most convenient working distance in the near was different. The good visual acuity was not the main condition to participate in experiments, and selected patients had decreased visual acuity from cataract or/and amblyopia. Subjects refractions were different – ever emmetropia, ever myopia, ever hyperopia. The dominant eye for all was determined in the distance by the *Dolman* method, in the near – by the *Crider* method. Assessment of stereovision using a TNO test was carried out for 300 optical patients out of whom 77 subjects had lowered visual acuity caused by amblyopia or cataract.

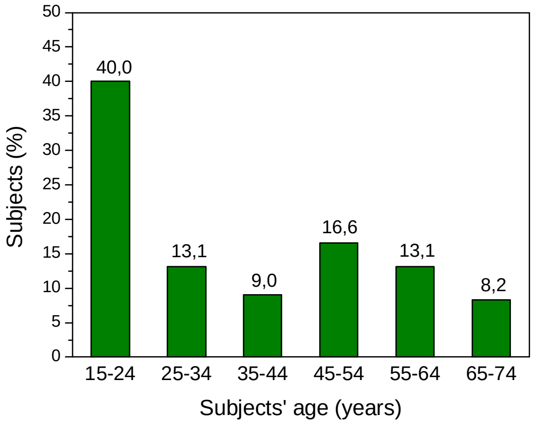


Figure 2.2. Distribution of all subjects that participated in stereovision studies.

3. Stimuli

In stereovision studies we used random dot stereotests. There is no monocular evidence about stereoscopic image in such tests, and subject could not predict the image location. In one part of the experiment the stereothreshold was assessed by the standard near TNO stereotest assigned for the distance of 40 cm. TNO test also is based on the random dot principle, in combination with the anaglyph method. Both eye stereostimuli are formed by scattered fine red and green elements printed on the TNO plate, and stimuli separation is achieved by red and green filters placed in front of the left and right eye, respectively. Trial case lenses with custom colour filters were used in experiments. Monocularly the subject perceives the red elements with one eye and the green elements with another one. If the subject looks simultaneously with both eyes, then in the case of binocularity a spatial image appears – a circle with a cut out sector (see Figure 3.1 A), and the perceived image looks greyish.

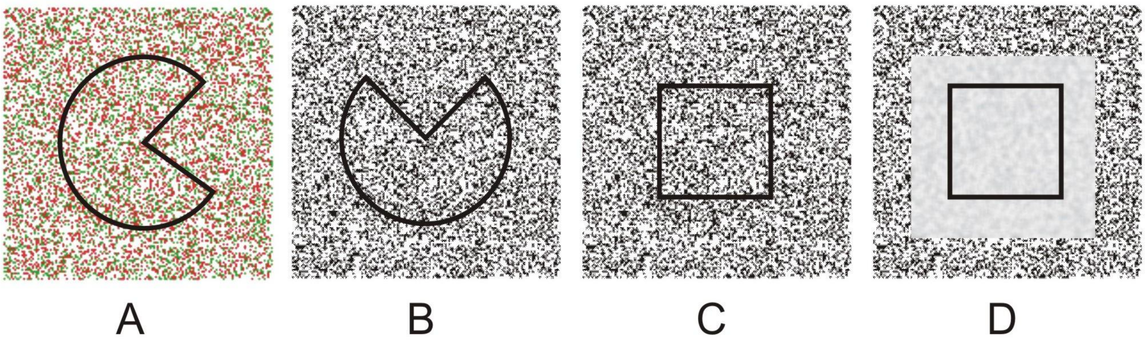


Figure 3.1. The stimuli of stereotests. A – standard TNO stereo image, B, C – stereo images on the computer screen for monitor stimuli method and eye occluder method. One eye had a constantly sharp image during the experiment, second eye had successive approximation image from sharp to blur and vice versa. D – one eye stereostimulus with an additional decrease of contrast in the centre of the field of vision.

In studies we created some computer programs that represented the random dot stereopair stimuli on PC screen with the blurring or contrast changes. Basically they represented an area comprising black and white or blue and red random dots. In the central part of the stimuli a smaller circle (a segment of which is cut-out) or a square is contoured (see Figure 3.1 B,C,D). The contoured area also is hidden by random dots, however in one eye stimulus the marked out region is displaced to the right or to the left by a small distance – the stereoscopic parallax. If an individual has developed stereovision he can see a three-dimensional object at the stimulus centre after two non-identical figures are fused in his brain. The stereopair images were merged by use of liquid crystal goggles. A special adapter was used doubling the frame frequency (see Figure 3.2). Thus the upper part of the frame (blurred stimulus) was displayed as whole even frames for one eye, and bottom part of the initial frame – as uneven frames displayed for other eye. The frame frequency was doubled from 60 to 120 Hz. The blur threshold at which the stereo sensation appeared was experimentally determined for one eye at different stereodisparities under the condition that the other eye saw a constant image of high contrast. The program fixed the number of the relevant blurring image (the radius of the blur effect).

In a case the coloured (red and blue) stereograms we used colour spectacles. Here each eye distinguishes its own stimulus since colour filters block the information assigned to the other eye. As well light filters as the liquid crystal goggles decrease the stimuli luminance and, correspondingly, the retinal illuminance. The controllable computer program created the stimuli for crossed and uncrossed disparity of stereosense.

In method with light scattering eye occluder (PLZT and PDLC plates) it is possible to estimate stereothreshold using standard TNO test and stereostimuli on PC screen. Additionally in all methods visual acuity was determined as criterion for comparing results about blurring and contrast influence to stereothreshold.

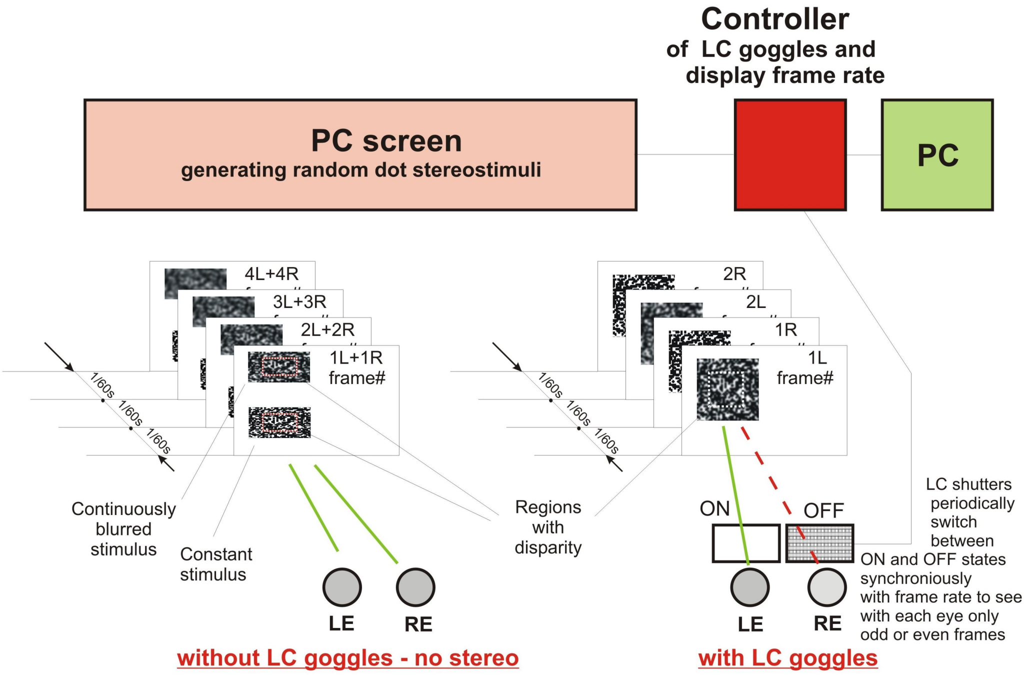


Figure 3.2. Experimental set-up to study stereovision with frame frequency doubling technique using LC goggles for random dot stereostimuli phase separation. The stimulus is demonstrated to each eye 60 times per second. Since relaxation of the human visual system is slower as compared to the stimuli delay demonstrated to each eye, the stimuli are superimposed by the brain and perceived “simultaneously.“

4. Assessment of the image quality

In the computer experiment the degree of blurring was scaled in terms of pixels (using Gaussian filter). In other methods (defocusation and eye occluder methods) the blurring degree was scaled with lens optical power or the value of voltage applied to the obstacle was used as the measure. To specify the degree of blurring it was necessary to find a measure independent of the way the stereo image is obtained. Such measure would describe the stereostimulus and qualify the stereovision itself if images are used as stereostimuli. Each image of the stereopair might be analyzed separately using:

- the average modulation amplitude,
- frequency analysis of stimuli Fourier images,
- cross-correlation.

In the computer experiments the stereothreshold was fixed as a function of the blurring radius in pixels for different values of the stereodisparity. In the TNO test the value of minimum resolvable stereothreshold was determined. One way to estimate blur was using a CCD camera (f = 18mm) as an eye model to take blurred and clear computer simulated random dot images, and further comparing images taken through light scattering PLZT ceramic plate with images blurred by optical lenses (in the latter case using for defocusing different positive and negative lenses placed in front of camera lenses).

As other criterion to measure blur we used the average modulation amplitude in the following way. One pixel wide line (in the centre of the square) of the blur images was selected to draw the sequence of RGB values. For each dip on the obtained graphs the modulation depth (MD) was estimated:

$$MD = 100 - \frac{I_{MIN} \times 100}{I_{MAX}} \qquad [1]$$

and, sequently, the average *MD* value characterizing the given image was calculated (see Figure 4.1).

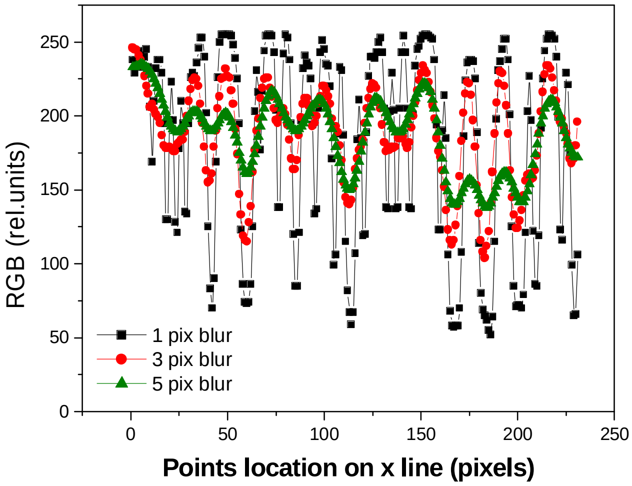


Figure 4.1. One version of the stimuli quality analysis. We have determined the modulation depth, which is an objective parameter that characterizes degree of blurring. Figure shows modulation depth for one pixel row.

Another method to describe stereostimuli was using fast Fourier transformation and analysed by high frequencies. The profiles representing functions of spatial frequency power density with respect to the spatial frequency obtained from 1 pixel wide lines in centres of Fourier patterns of the stereo images are shown in Figure 4.2.

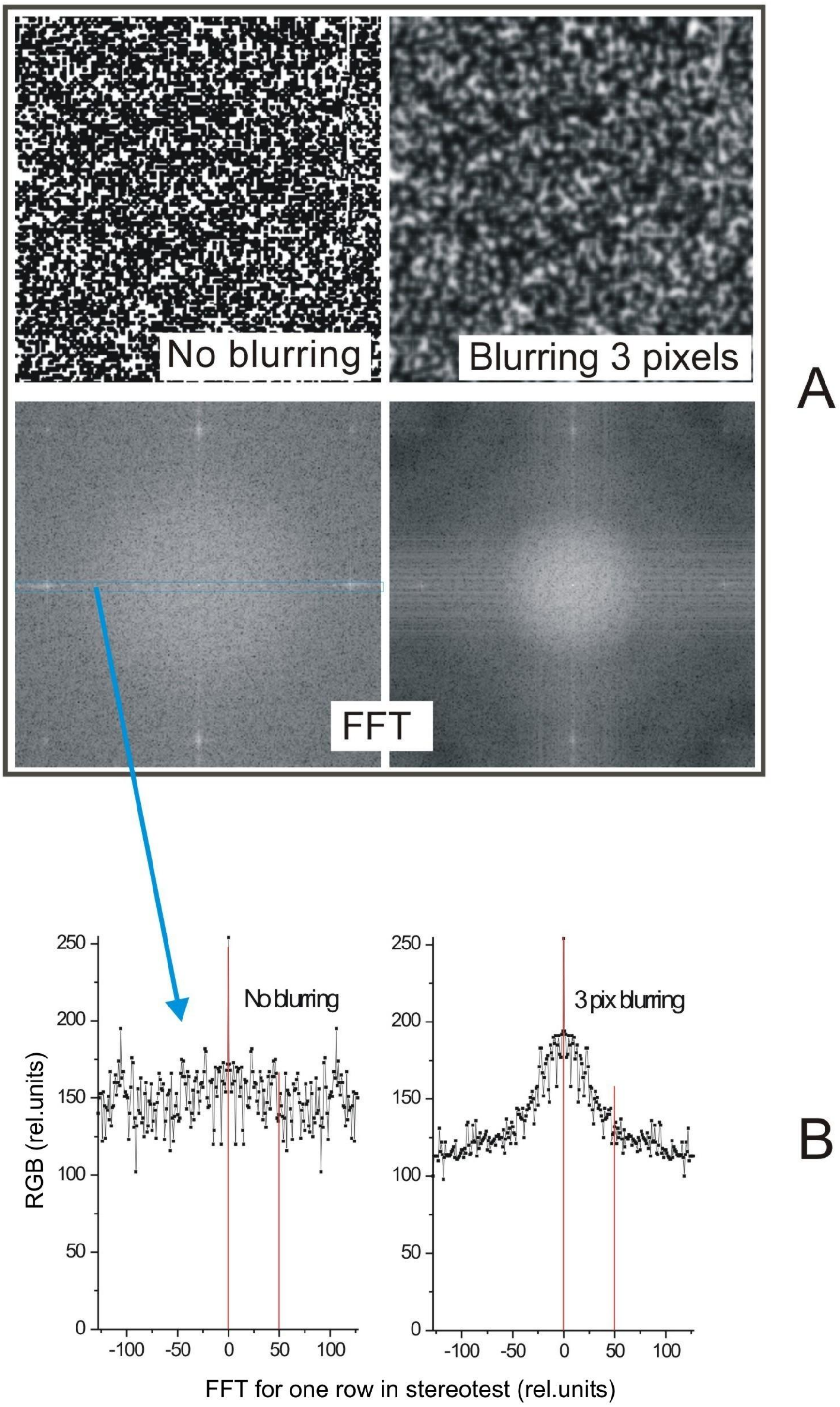


Figure 4.2. The blurred image quality can be analyzed with FFT (fast Fourier transformation). In figure A – the upper images are real stimuli, while in the bottom images – stimuli are analyzed with FFT. The corresponding profiles of FFT central part (1 pixel horizontal row) are shown in Figure B. The decreases of the integration’s area at high frequencies are used as an objective parameter.

The curve corresponding to a clear image has a gentle slope – a contribution of higher spatial frequencies as compared with spatial zero frequency at the centre is higher. The integral:

$$\int_0^{V_{0x}} I(V_x)\cdot\partial V_x = K_F(V_{0x}), \qquad [2]$$

where $I(V_x)$ is the spectral power density frequency distribution and V_{0x} – an arbitrary frequency, may be considered as a parameter specific to the image characteristics (pixel size of clear image, and eventually disparity if used for stereostimuli). If a small enough V_{0x} is chosen, then the more blurred the image, the bigger the corresponding integral [2].

The third method for comparing all stereostimuli should be cross-correlation. Cross-correlation was made to compare two images and to find the degree of similarity by looking for similar regions in both images (see Figure 4.3).

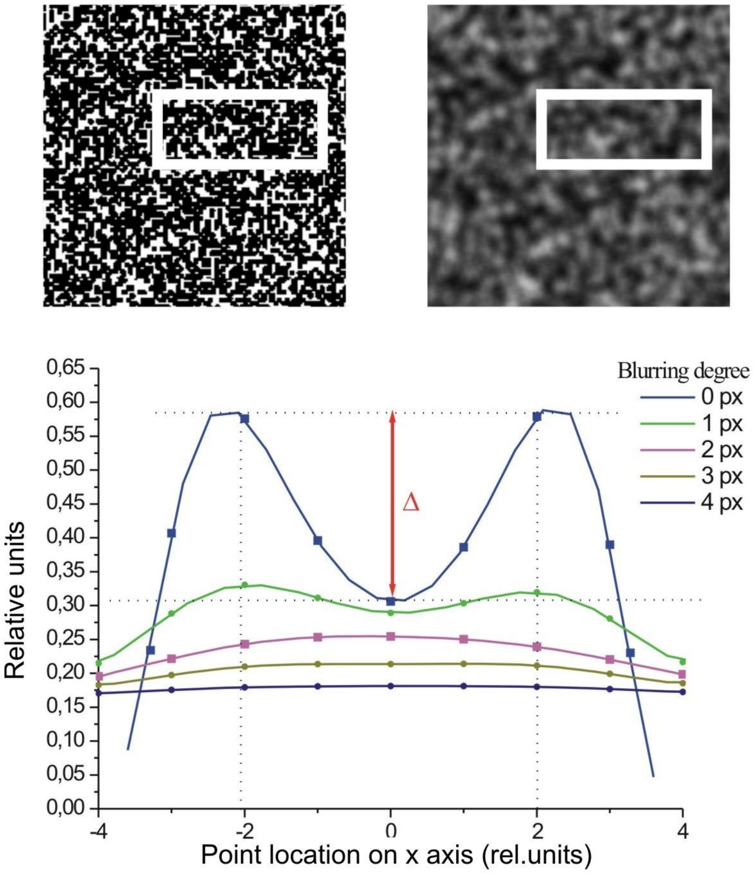


Figure 4.3. The figure shows cross-correlation results of stimuli. One stimulus is blurred with Gaussian distribution (A – left image). Such processing would be similar to neural signal processing in the human brain. B – the stereo image can be perceived at positive and close-to-zero values of DELTA.

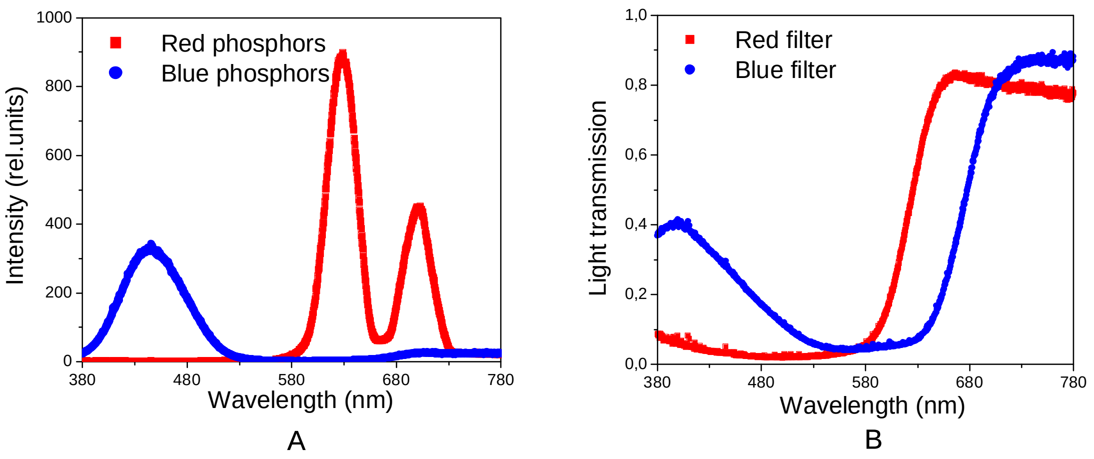
This way characterizes two correlated stimuli facility to evoke stereosense. The cross-correlation function Γ(a) was calculated within the stimuli areas needed to be fused in the human visual cortex. In the brain function similar to that is performed by “cross-correlation” neurons. Cross-correlation is performed for two stimuli – black-white random dot image S_1 with dot intensities $S_1(ij)$ either 0 or 255, and other stimuli S_2 obtained using continuously increased blurring $0<S_2(ij)<255$. Correlation $\Gamma(a)$ is calculated within an area including the contour of the disparity region symmetrically to the disparity region border:

$$\Gamma(a) = \frac{1}{i \times j \times 127^2} \Sigma_{i,j} \left[S_1(i-a, j) - 127\right] \times \left[S_2(i, j) - 127\right] \qquad [3]$$

Two maxima on cross-correlation function of two images S_1 and S_2 show a presence of correlated regions in both images separated horizontally by a parameter equal to disparity. The more manifest are these maxima the easier is the task for the visual cortex to fuse these parts and to evaluate the value of disparity – the depth of protrusion.

In vision experiments using computer monitors it is necessary to evaluate the physical parameters of the black-white and colour stimuli. Using the *OceanOptics S2000 Fiber Optics* spectrometer the transmission spectra of the light filters were measured as well the spectral distribution of the screen phosphors radiation to ensure that each of the subject eye would see a single colour stimulus in the colour stereotests (see Figure 4.4 A).

The spectral analysis of colour filters was made with data from transmission measured separately for the red and the blue filter, the results being normalised with respect to the spectrum of incident light (%). The light source was the natural daylight. There were accomplished 10 measurements with exposition time 150 msec. For spectral analysis of colour filters were accomplished through gotten out spectral part for colour and blue filters (see Figure 4.4 B).



A

B

Figure 4.4. PC screen’s red and blue phosphors emission spectra (A) and in experiments used filters transmission spectra (B)

In case the coloured spectacles are used, each eye distinguishes its own stimulus since colour filters block the information assigned to the other eye. In case of liquid crystal shutters unnoticeable occlusion in each eye is changed at the frequency of 120 Hz. Thus, the stimulus is demonstrated to each eye 60 times per second. Since relaxation of the human nervous system is slower as compared the stimuli delay demonstrated to each eye, stimuli are superimposed by the brain and perceived “simultaneously “.

The monitors used in experiments have 15 inch screens (0.27 mm/pix), The frame frequency in the experiment equals 85 Hz. The screen brightness as function of the RGB video signal values was obtained by means of a digital luxmeter LUX LD12Q-631. The photometric radiation characteristics of red, green, blue and composite white channels are shown in Figure 4.5. Determined data with luxmeter were calculated in the units of light brightness (cd/m^2).

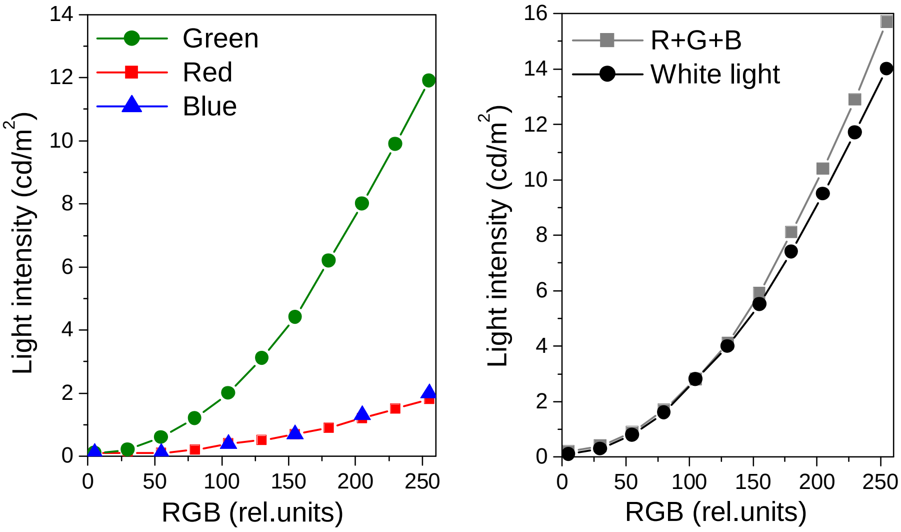


Figure 4.5. PC screen calibration's curves. Vertical axis – screen luminance (cd/m^2) measured by a luxmeter attached to the screen. Horizontal axis – monitor video signal in RGB units. R+G+B – summation of three phosphors luminance.

Additionally the values of visual activity are used as a subjective criterion. Values of visual acuity are obtained psychophysically, firstly, simulating the blurring in one eye by optical lenses and, secondly, by light scattering PLZT, PDLC plates. To compare all different kind of stimuli used in experiments, the visual acuity together with another criterion – objectively obtained mean modulation depth are used to create the scaling scheme of the stimuli created in different ways (see Table 4.1). Using the mean of modulation depth of the blur caused by optical lenses taking "retinal image" snapshots by artificial eye CCD camera, we can equalize the effect of optical blur with Gaussian filtering of stimulus demonstrated on the PC screen. The decrease of the visual acuity in its turn can be useful to equalize the effect of optical blur using the defocusing lenses with light scattering effect caused by PLZT or PDLC occluders.

Table 4.1.

Conversion table of stimuli

Lens power (D)	Modulation depth (%)	Blurring of monitor stimuli (pixels)	Visual acuity (decimal system)	PDLC blurring (V)	PLZT blurring (V)
-2.00	**27**	**2.1**	**0.23**	**-**	**1715**
-1.00	**58**	**0.7**	**0.48**	**15**	**1320**
0.00	**100**	**0.0**	**0.97**	**30**	**130**
+1.00	**68**	**0.5**	**0.82**	**20**	**925**
+2.00	**28**	**2.0**	**0.49**	**15**	**1320**

The table summarize the obtained results characterizing all the used stimuli. As we know the average of modulation depth of an optical lens and the determined average visual acuity when looking through the lens, we can find a similarly blurred monitor stimulus and in the same way the value of the eye occluder voltage characterizing the light scattering of the PDLC and PLZT plates.

5. Methods

To determine the stereothreshold three methods are used (defocusing, monitor stimulus and eye occluder) which simulate the changes in the quality of the stimulus in one eye. The fourth method describes the conditions when the formation of stereovision is stimulated for the people with lowered visual acuity in one eye to see the stereo images of the random elements test.

Defocusation method. In this part of the experiment the stereothreshold was assessed by the standard near TNO stereotest using defocusing optical lenses. TNO stereotest is also based on the random dot principle, in combination with the anaglyph method (see Figure 3.1 A). Red and green filters were placed in front of the eyes to separate stereostimuli. Far correction was provided for young subjects and near correction in case of presbyopia.

The TNO stereoscopic test was held at the distance of 40cm. The subject should recognize the orientation of the cut circle segment for stimuli with equal disparity. The test always began with the highest stereothreshold for all trials. There is possible to determine stereothreshold from 15 to 1000 arc sec using the TNO test.

After the stereothreshold was determined for the optimum correction, the refraction was changed for the right eye with a +2.50 D lens (the maximum positive overcorrection) and the stereothreshold was assessed for this +2.5D – the maximum value of the positive overcorrection. Further the power of lens was reduced by 0.50 D and with each step the last visible stereoscopic image was recorded. When the starting point had been reached (zero overcorrection), stereovision was tested once again making it clear, whether the subject distinguished the same as in the beginning. The same procedure was repeated with the left eye.

The method was also used for both eyes with a negative overcorrection. In the beginning the stereothreshold was stated without overcorrection. Then, again a negative 2.50 D lens was placed in the front of the right eye and further overcorrection was diminished by a step of 0.50 D to determine the stereothreshold dependence on overcorrection. The presentation time of each stimulus was limited – it was no longer than 30 sec for each lens overcorrection. If within 30 sec time subjects could not recognize the cut-out of the stereoscopic image, then the disparity of the previous correctly named stereo image was the one that counts. For elder subjects that needed correction in the near, visual acuity were additionally monocularly tested with the near table (which corresponds to a 40 cm distance) beginning with +0.50 D up to +2.50 D by step 0.50 D. For younger people it wasn’t necessary to determine visual acuity monocularly because having good facility of accommodation, these patients had visual acuity at the distance of 40cm also with negative lenses. However with positive lenses, looking at a distance 40cm accommodation relaxed and the finest test text could still be seen with +2.50 D overcorrection.

This method simulates artificially uncorrected anisometropia of myopia and hyperopia that sometimes is the main reason for development of amblyopia or should arise for subject with increasing of unilateral cataract. The investigators (*Lovasik & Szymkiw* 1985) showed that a stereoacuity of 40 arc sec was possible with 20% aniseikonia, and 50-100 arc sec with 30% aniseikonia in conditions if stimuli were clear. The highest aniseikonia in my experiments was 7% from optical lenses, thus the stereoacuity was influenced by blurring as well by aniso-accommodation.

Monitor stimuli method. A random dot stereopair was displayed on the monitor screen (see Figure 3.1 B,C,D). Separation can be realized by colour filters or applying so called phase separation technique with liquid crystal (LC) goggles. The blurring intensity, contrast and colour were possible to change for stimuli. There used two psychometric methods to measure stereovision – method of limits and method of constant stimuli. Each image of the pair was a square with a smaller square or circle (a segment of which is cut-out) with in its centre. The latter, imperceptible at monocular observation, appeared as a three-dimensional object out of the plane of reference at superposition of the images. The top image was constant during the experiment – it was clear with 50% black and 50% white random dots, the smallest of which was 1 pixel. The bottom image varied from blurred to clear. The program performed 40 series of measurements and the central square in a series was randomly shifted to right or left by 1 to 4 pixels. Within one series each blur image was displayed for 1 sec. The size of the square stereopairs was 7±0.1 cm. The size of central squares was 3.5±0.1 cm.

The blurred stimuli were formed with the help of *Corel Photo Paint* program using the Gaussian distribution of radius half-width value. The size of the half-width of blurred band changed from 0.1 (the less blurred image No.1) up to 5.0 (the most blurred image No.50) with a step 0.1. Some examples of the blur are shown in Figure 5.1.

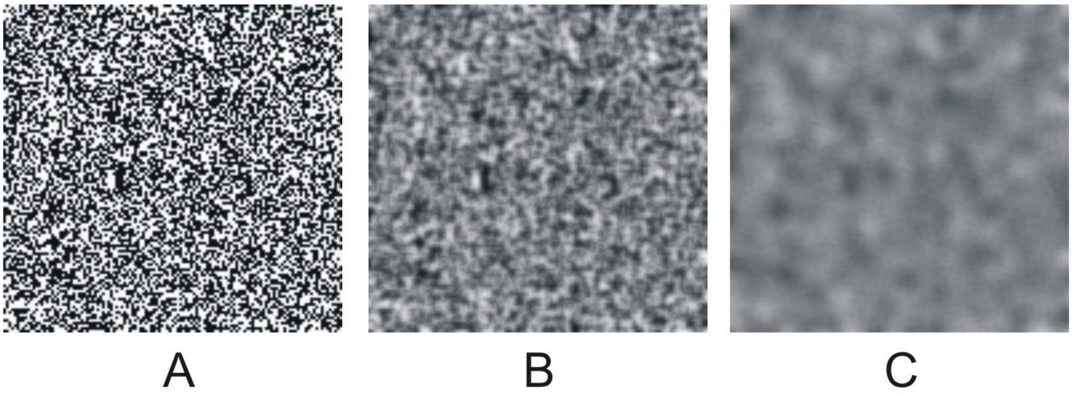


Figure 5.1. The stimuli of stereotests. A – one eye had sharp image, B, C – the second eye had a successive approximation image from sharp to blur and vice versa. B – 1 pixel blurring, C – 3 pixels blurring with Gaussian filter.

The stereopair images were merged by use of liquid crystal goggles, where one eye sees clear image and second eye bad quality image. In the computerized experiment was used a 15 inch monitor. The measurements were made at artificial illumination of 200 – 400 lx. It has been reported (*Lovasik & Szymkiw* 1985, *Yap et al.* 1994) that such oscillations of illumination do not affect the stereovision. Subject's head was fixed during experiment.

The blur threshold at which the stereo sensation appeared was experimentally determined for one eye at different stereodisparities under the condition that the other eye saw a constant image of high contrast. The program fixed the number of the relevant blurring image (the radius of the blur effect). The magnitude of stereovision ω (in radians) was calculated from the formula:

$$w = \frac{PD \times \Delta l}{l^2}, \qquad \Delta l = \frac{l \times y_p}{PD \pm y_p}, \qquad [4]$$

where ω is the stereothreshold value (rad), y_p – the stereo parallax or displacement of images (or disparity) (m), l – the distance of the fixed point to eyes (m), PD – the pupil distance (m).

Before the tests the essence of the experiments is explained to subjects and operation of programs is demonstrated. At least five minutes are allowed for a training experiment. Subjects are seated at a distance of 60±1cm from the monitor and provided with liquid crystal shutters or colour filter goggles. As soon as the stereo sensation is experienced the subject takes part in test cycles. He specifies the corresponding forced choice. At a given distance 40 measurements are made in each cycle. The measurements taking about 60 minutes include twelve different disparities: six crossed and six uncrossed.

As different optical materials are used in the studies: light filters, PLZT ceramics, PDLC plate and liquid crystal glasses, it is very important to know the optical properties of each material in the visible part of the spectrum. Light filters are used both in the standard TNO test and in the experiment where the stimuli are shown on the monitor. The transparency of light filters must be the same throughout so, that the intensities of stimuli of the neural signal that reaches the primary visual cortex are also the same. Using the method where people with lowered visual acuity in one eye are trained for stereovision light filters with different transparency are specially chosen. Thus an effect is reached when for the well-seeing eye the intensity of the stereostimulus is reduced. The transparency of the light filter for the well-seeing eye is at least three times smaller.

In the experiment of coloured monitor stimuli it is important to adjust the filters so, that one eye sees only the stimulus of one colour while the other eye sees the stimulus of different colour. If isoluminant red and blue stimuli are formed on the monitor our brains have to perceive them as the stimuli of equal intensity. In standard tests red and green light is used but the green light emitted by the monitor is of very high luminance (see Figure 4.5). Thus it is not adequate to use them in the experiments where it is important to observe the changes in the colour contrast at the formation of stereovision. Another, a more complicated variant is to calibrate and to modify the green light forming an algorithm, where the alteration of the contrast of green light for each intensity of the stimulus is estimated corresponding to the intensity of the stimulus of the other colour. The calibration has its disadvantages, as there remain fewer possibilities to change the contrast of the green light in a wide range. Simpler method uses two monitors and a system of mirrors. Here the monitor luminance can be altered accordingly to preliminary calibration and it is possible to adjust all the contrasts to the light intensities of stimuli.

In monitor stimuli experiments eye separation can be realized by liquid crystal (LC) goggles applying so called phase separation technique, when stimuli for both eyes are displayed periodically for a short while only for the left or right eye. In most cases stimuli are simulated by computer and showed on the PC screen and synchronised by switching LC goggles. LC goggles used in such experiments can be of different quality – the best ones based on ferroelectric liquid crystals. Besides these expensive goggles, one can find in market other kind of LC goggles. They have a lower switching speed, a lower contrast ratio. However due to the great popularity of various virtual reality, mass production of such glasses sharply has decreased their price. The spectral and switching characteristics for LC goggles of different origin are very important in stereovision experiments. If the liquid crystal goggle cell of each eye does not close fully, while the cell of the other eye is already opening, then we can face a situation when both the eyes see the motion parallax of the stimulus. This can help the subject to see the location of the stimulus and other mechanisms will switch on in the brains (the depth perceived from the motion) producing the stereo sensation. Two types of liquid crystal shutters were compared during the investigation: "ELSA" and the shutters of the Institute of Cinematography, Moscow (CPRI). The spectral transparency as well as was the opening-closing velocity controlled by the voltage were assessed for these shutters (see Figure 5.2).

Eye occluder method. The situation of cataract is very well simulated in this experiment by using the eye occluders. It is not easy to realize this on the monitor because then we have to produce both the blur and the changes in contrast. The PLZT plate (*Ozolinsh et al.* 1999) becomes less transparent steadily (see Figure 5.3) if the applied voltage is increased. The plate does not produce precisely the same conditions as with the real cataract because as we know cataract can develop both in the periphery of the eye lens and in the central part of the eye lens. In the first case the central vision remains quite good while in the second case it has a great influence on visual acuity. However the light scattering characteristics of such plate is similar as for the people with a blurred eye lens, i.e. the short waves are scattered more and visual acuity decreases in the range of short waves the same way as it does for a subject with a cataract (see Figure 5.4). Visual acuity is determined by optotypes in different colours to assess the visual acuity if a blue colour stimulus is seen on the monitor and the same stimulus is observed through the PLZT or PDLC plates. It is seen in Figure 5.4 that looking through the PLZT plate even without the blur the visual acuity has decreased for the blue optotype. People with real cataract present the same situation.

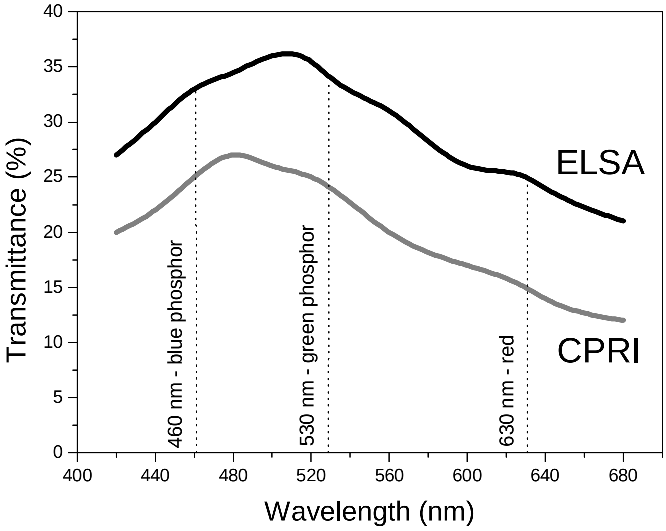


Figure 5.2. Open state transmission spectra of two tested nematic liquid crystal goggles ELSA and CPRI. Display phosphor emission maxima are at 460, 530 and 630 nm.

The blue image of the stereopair was chosen as a stimulus with changing contrast partially due to the greater scattering of the blue light present in a cataract case. We have used a test (by displaying Landolt **C** figures with only **R**, **G** or **B** monitor phosphors) to determine visual acuity for three primary colours. The dependence of visual acuity on the light scattering (caused by a special PLZT plate, allowing continuously increase the light scattering depending on the voltage applied to the plate) is shown in Figure 5.4.

The scattered light of PDLC plate is strongly wavelength dependent in visible spectral range. Figure 5.5 shows the spectral dependencies of attenuation of the directly transmitted light. As such plate are used detecting visual stimuli demonstrated on colour CRT, the emission wavelengths of the red **R**, green **G** and blue **B** phosphors are depicted in the same graph. Comparing transparent PLZT ceramics with PDLC plate, the effective scattering coefficient of PDLC is much higher (up to $3x10^3$ cm^{-1} for blue light), however the active PDLC layer thickness is much less than the scattering PLZT ceramics plate thickness 1.5mm.

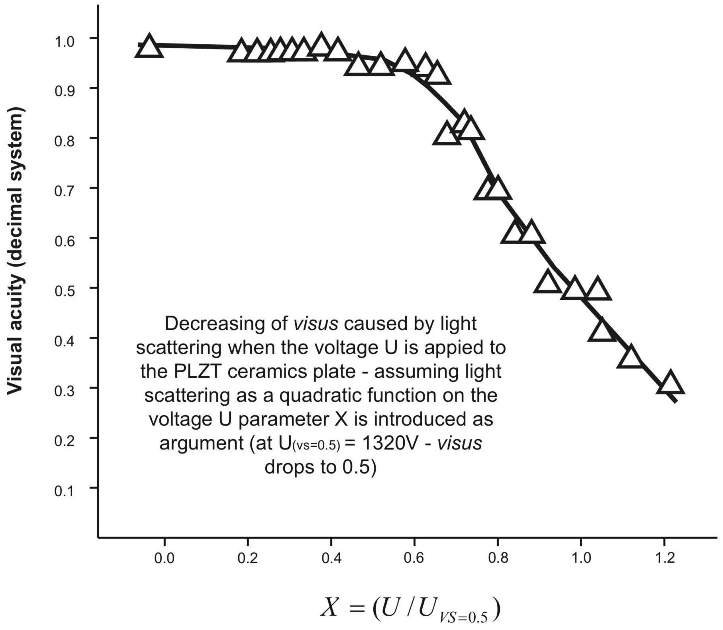


Figure 5.3. Visual acuity changes by applying voltage to PLZT ceramic plate.

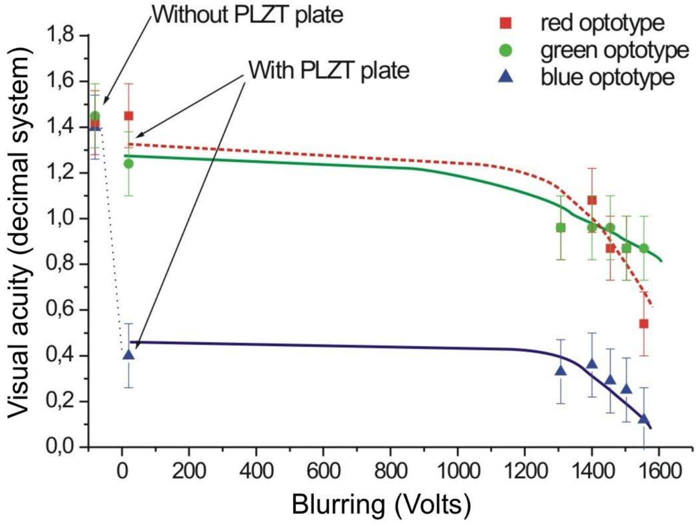


Figure 5.4. Visual acuity determined with three primary colours. Without PLZT plate visual acuity are approximately similar, with PLZT (but without voltage) visual acuity for blue colour to come down with a run.

Visual acuity at different degrees of the induced light scattering was determined from psychometric function using constant stimuli method. In this method subject was forced to choose one of four available orientation of the standard Landolt **C** demonstrated on PC screen in series with random size and orientation. Scattering has remarkable wavelength dependence, thus we used the following stimuli: high contrast black on white background, black-blue, white-yellow, and white-grey with luminance contrast similar to those of white-yellow stimuli. An eye of humans has a complicated structure of retinal photoreceptors and receptive fields. In the eye central part (*fovea*), responsible of the visual acuity, the density of red (long wavelength **L**) and green (middle - **M**) cones is much higher and intermediate distance much shorter as for blue (short - **S**) cones (*Roorda & Williams* 1999).

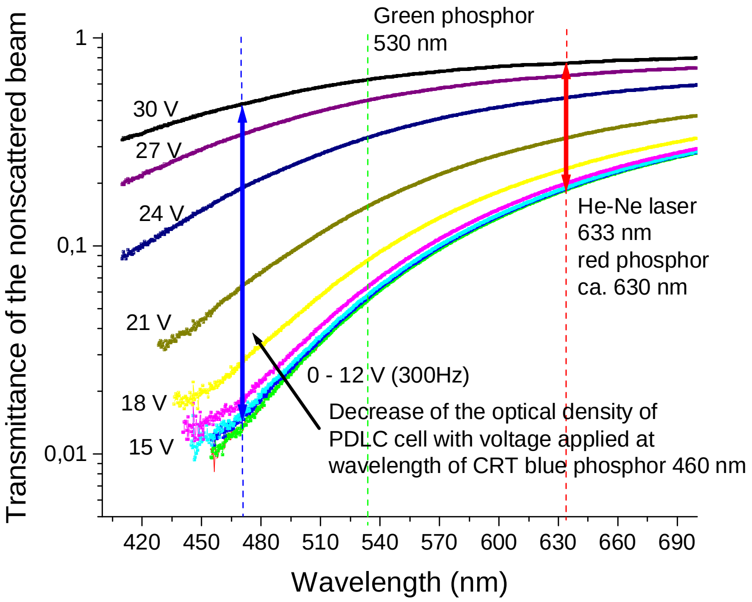


Figure 5.5. Spectral dependencies of transmittance of PDLC for directly transmitted light at different voltages applied to the cell. CRT phosphor emission maxima wavelength at 460 (blue), 530 (green) and 630 nm (red) are marked with dashed lines.

Figure 5.6 shows results of three subjects visual acuity obtained in a subjective way. The most drastic decrease of the visual acuity is observed for black-blue (display RGB values – 0,0,0 for black and – 0,0,255 for blue) and for white-yellow (255,255,255 – for white and 255,255,0 – for yellow) Landolt **C** stimuli. In both of these cases the only colour channel participating in stimuli recognition is the most scattered **B** channel. Comparing results for the white-yellow and white-grey stimuli with the same luminance contrast, a lower specific contribution of the **B** channel in white-grey case determined much less decrease of the visual acuity comparing to the white-yellow stimuli.

Method of stimulation of stereovision. From the previously determined values of the stereothreshold we have obtained knowledge about the size of horizontal disparity for the stereotests shown to the people with lowered visual acuity in one eye to stimulate the formation of stereovision. The stimulus of the well-seeing eye is also blurred by the Gaussian filter using the conversion table (see Table 4.1), which shows the relationship between the quality of the stimulus and the optical power of the lens, visual acuity and the blur in pixels. The stereodisparity is chosen a little larger than the determined values of stereothreshold in cases of induced amblyopia or cataract. To stimulate the stereovision applying the liquid crystal shutters uses a method of phase shifting. If the stereovision is obtained by this method then the stereothreshold is determined once again using the clinical TNO stereotest at first allowing to hold the test plate nearer than 40 cm and look for so long until the stereo image is seen. To specify the stereothreshold the test is placed at a correct distance and stereovision checked one more time.

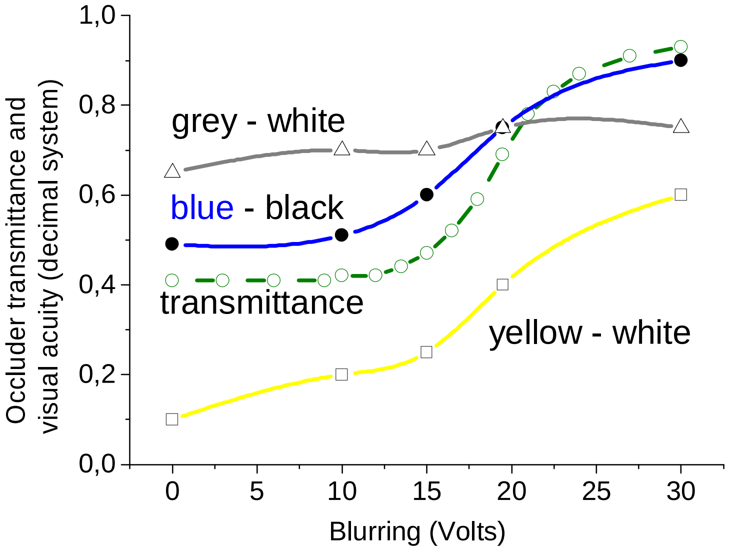


Figure 5.6. Occluder transmittance and visual acuity *vs.* voltage applied to PDLC cell. Stimuli: high contrast blue on black background, low contrast (10%) white on grey and white on yellow background.

To simulate the lowering of visual acuity in one eye and to assess the formation of stereovision in a real situation caused by amblyopia, cataract or uncorrected anisometropia three different methods were used. Using the method of defocusing the vergence of image in one eye is altered by optical lenses thus simulating the uncorrected anisometropia. In this method it is not possible to eliminate aniseikonia of the images produced by optical lenses the number of which does not exceed 7% in this study and according to references (*Lovasik & Szymkiw* 1985) it is of no great importance.

In the method of monitor stimuli the contrast or blur is being changed. By this method better comfort is achieved for the subject because lenses create a little chaos in the process of accommodation for a short period of time. Using this method it is not possible to simulate the optical differences of the eye but the blur simulates the lowering of visual acuity in one eye. In the third method to worsen the quality of stimulus the eye occluders are set between the eye and the stimulus (PLZT and PDLC plates). Thus the progress of cataract is simulated in one eye and the values of stereothreshold are estimated for a stimulus of bad quality. By this method we can well observe that visual acuity decreases more rapidly in the range of short waves (blue stimulus) that is characteristic for a blur of the lens in the case of cataract. The changes of visual acuity in one eye that influence the stereothreshold are shown in Figure 5.4 and 5.6.

Statistical analysis including correlation coefficient (probability r^2), t-test of all results were performed with personal computer programs *MS Excel* and *Microcal Origin*.

6. Results

In the method of monitor stimulus different methods to induce the stereosense (light filters and use of liquid crystal glasses) and wide choice of different stimuli (squares and circles with a cut-out) were used. The colour contrast threshold of stereovision experimentally determined by method of limits using light filters for stimuli separation are higher than using the liquid crystal glasses. The transparency of glasses is comparatively larger than that of light filters (see Figure 6.1). This is a serious condition when studying the threshold of colour stereovision.

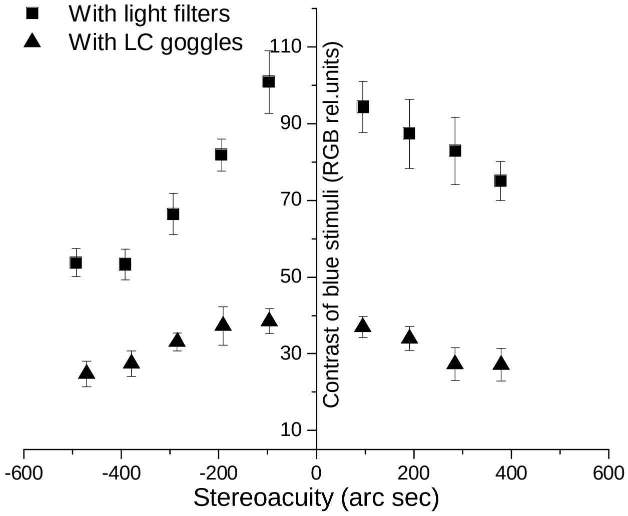


Figure 6.1. Colour contrast threshold values were determined by changing blue colour contrast and stereodisparities, and stereosense was stimulated using colour filters and LC shutters.

Concerning first results of studies of the colour contrast effect on stereothreshold, here the best of all is to use liquid crystal glasses. It was concluded also during the study that the choice of objects for the test gives little diversity. Statistically it is of no importance ($p>0.1$) whether the stimulus to be shown is chosen as a simple object (square) or more complicated (circle with cut-out). The obtained results with stereo images of different stimuli type are given in Figure 6.2. After control experiments of the testing equipment and the initial inspection, experiments have been carried out to determine the threshold values of colour contrast at fixed stereodisparity with one colour (blue) stimuli contrast change.

In the first test series the contrast of the stimulus was changed continuously – the threshold was determined by method of limits with stimuli being separated by colour filters. Results obtained for five subjects at repeated tests with square stimuli are shown in Figure 6.2 (black square). In the second test series the hidden stereo image was the circle with sector cut-out. The blue colour contrast changed continuously, and subject should respond if he could catch direction of cutting circle sector. The results using circle stimuli are showed in Figure 6.2 (open circle). With respect to dispersion, results obtained using constant stimuli method with circle stimulus are not much different from the square stimulus test with colour filters. A lasting attention is required from subjects during experiments when approaching the contrast threshold of stereovision gradually (method of limits). Besides, due to binocular rivalry, – the dominating tint of the perceived binocularly colour stimulus periodically varies. This “pumping” of colours is one of the factors causing a rather wide dispersion of results since the subject has difficulties to concentrate.

Afterwards the values of the threshold of colour contrast at different stereodisparities for subjects were determined at variable blue stimulus contrast by determining the threshold values using the method of constant stimulus. At great disparities about 500 arc seconds the psychometric functions are steep (see Figure 6.3) and the determined blue colour contrast threshold is with lesser dispersion. The disparity being decreased the psychometric curves are sloping, and the obtained values of the threshold have less credibility. Also in this series of experiments the results obtained with the circle stimulus are of little difference from the quadratic stimulus test using coloured light filters.

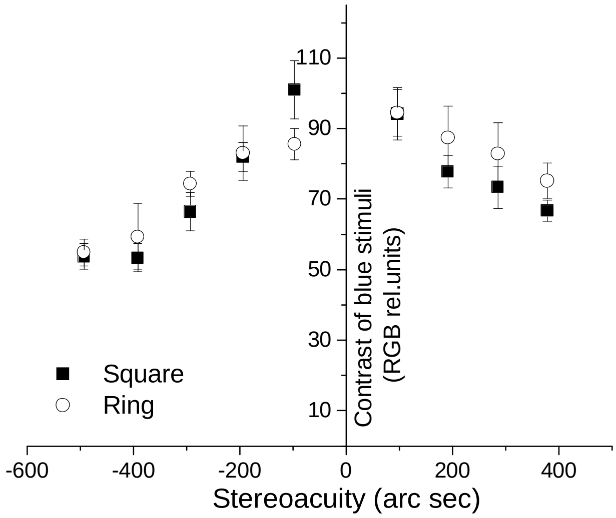


Figure 6.2. Using method of limits colour contrast thresholds for colour stimuli are determined with different type stimuli (square and circle with cut-out sector) at different stereodisparities. Results obtained with circle stimuli are not much different from the square stimuli test (p>0,1).

Using liquid crystal shutters it was possible to soften the effect of binocular rivalry on the perception and on results of the experiment, and we partly succeeded. The comfort of observing improved, and dispersion of results, compared with demonstration of similar stimuli separated by colour filters, decreased (see Figure 6.1).

The stereogram disparity is one of parameters affecting the contrast threshold of stereovision. The value of the stereothreshold ω [4] (stereodisparity given in angular units) calculated from the pupil distance (*PD*) and the distance of subject from the screen is small. By changing the *PD* from 55 mm to 70 mm the corresponding change of the stereothreshold is less than 1% within a fixed viewing distance between 45 cm and 180 cm. A more effective factor is the monitor pixel size – the change of the dot size on the screen from 0.28 mm to 0.27 mm gives a difference ≈4%. Subject head was fixed in range ±1cm that gives 3-4% error. For the screen stereo parallax measured in pixels (if the monitor horizontal and vertical scanning are calibrated correctly) the corresponding crossed and uncrossed stereodisparities for different operating distances are given in Table 6.1.

In most studies of effects of monocular contrast on stereovision (*Wilcox & Hess* 1998; *Rohaly & Wilson* 1999) relation between the contrast and stereodisparity threshold is described by a power function and data are analyzed in the logarithmic scale. As in our experiments a comparatively narrow range of disparities was analyzed it was assumed that the connection between the stereothreshold and the blur or contrast of the stimulus in this district could be called linear. Thus I could do the analysis in linear coordinates. In Figure 6.4 we can see the average values of the contrast threshold (alterations of black-white and blue contrast) of the monocular image for all 11 subjects averaged at each demonstrated stereostimuli disparity.

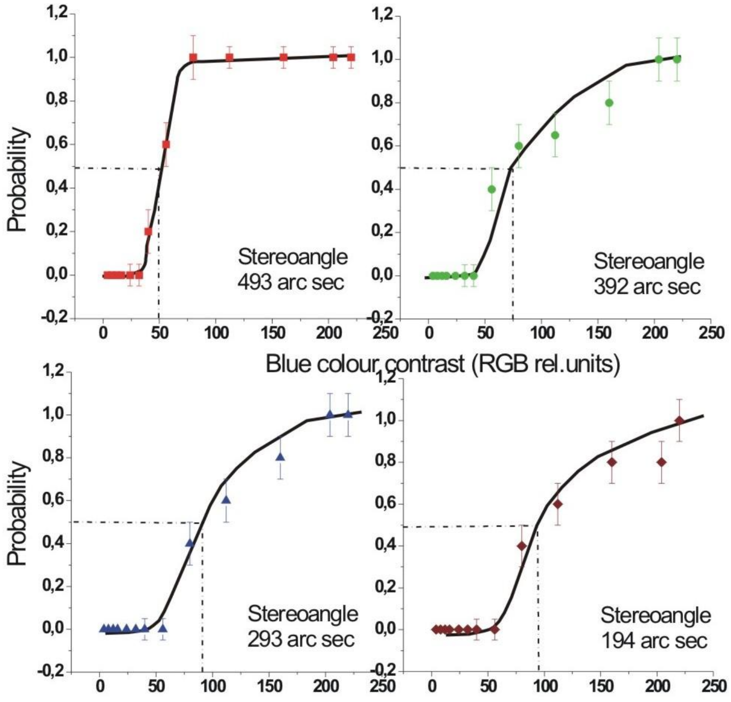


Figure 6.3. Psychometrical measurements with constant stimuli. Colour contrast thresholds are showed with dashed lines.

6.1.Table

Dependence of stereothreshold value on distance to monitor and disparity type

Distance between monitor and subject	Image deviation in pixels									
	Uncrossed disparity					Crossed disparity				
	5	4	3	2	1	1	2	3	4	5
0.45 m	606"	487"	367"	246"	123"	124"	250"	376"	504"	633"
0.60 m	454"	365"	275"	184"	92"	93"	187"	282"	378"	475"
0.80 m	341"	274"	206"	138"	69"	70"	141"	212"	284"	356"
1.20 m	227"	183"	138"	92"	46"	47"	94"	141"	189"	237"
1.80 m	151"	122"	92"	61"	31"	31"	62"	94"	126"	158"

Average values of stereothreshold in cases of crossed and uncrossed disparities. Stereothreshold values are calculated for the condition that the distance between the pupils (PD) is 62 mm and the values of monitor pixels are 0.27 mm. All working distances used during the stereotests are given in the Table.

The technique used in our experiments allows to assess both the coarse and fine stereovision both for crossed and uncrossed disparity. Random-dot stereograms exclude any indications where the stereo image is going to form when looking only with one eye.

Using this method it is possible to create artificial conditions for amblyopia and cataract where the degree of blur of the stimulus changes on the monitor. It is concluded in the investigation that the stereothreshold increases both in the case of crossed and uncrossed disparity if the intensity of blur of the stimulus increases in one eye (see Figure 6.5).

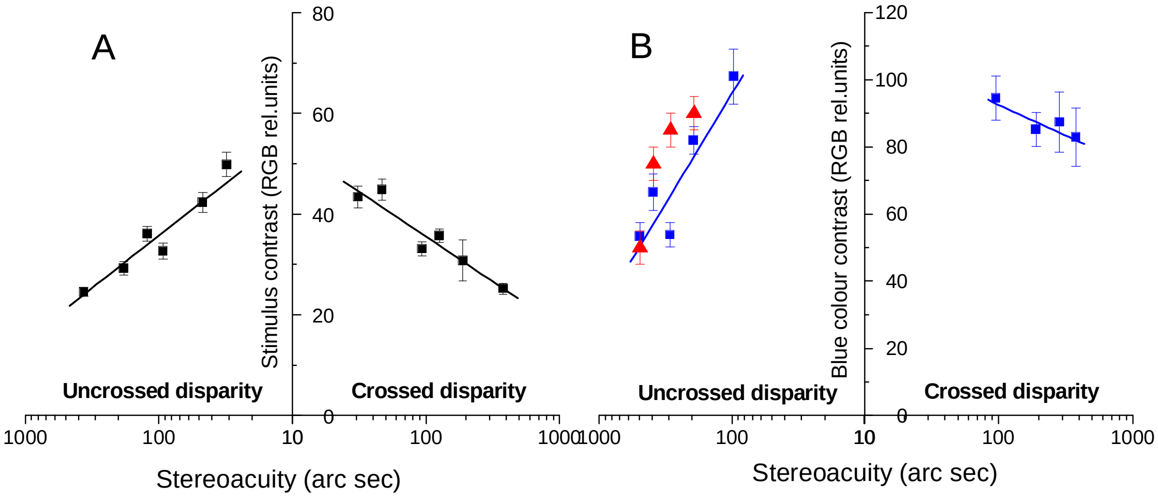


Figure 6.4. One eye stereostimuli contrast thresholds at different stimuli stereodisparities were determined using method of limits. A – greyscale stereotest results; B – red-blue stereotest results. Colour contrast was measured in RGB relative units (colour coding system units from 0 to 255). The red triangles (in B) show the blue colour stimuli contrast thresholds that are appreciated with the constant stimuli method.

In other experiment part we have assessed also the decrease of visual acuity applying overcorrection with additional lenses for elder patients. Younger people have large facility of accommodation; they can compensate the effect of negative lenses. To avoid this one need to apply cycloplegia to block eye accommodation. Results of applying of overcorrection on monocular visual acuity are shown in Figure 6.6. It is seen that applying the negative overcorrection causes stronger decrease of the visual acuity as compared with positive overcorrection. That occurs in spite of that values the average of modulation depth of the blurred images are equal if blurring is performed either by positive or negative lenses – blurring degree is similar (see conversation 4.1 Table). However positive lenses little increase the size of retinal image comparing with action of negative lenses and the spatial resolution of eye stays higher for stimuli blurred by positive lenses.

In the next part of the investigation the stereothreshold was assessed under the conditions of artificially produced uncorrected anisometropia and the obtained results compared with the data obtained for the clinics patients in the situations of real amblyopia and cataract. Uncorrected anisometropia can be the cause of amblyopia and facilitates the progressing of cataract in one eye.

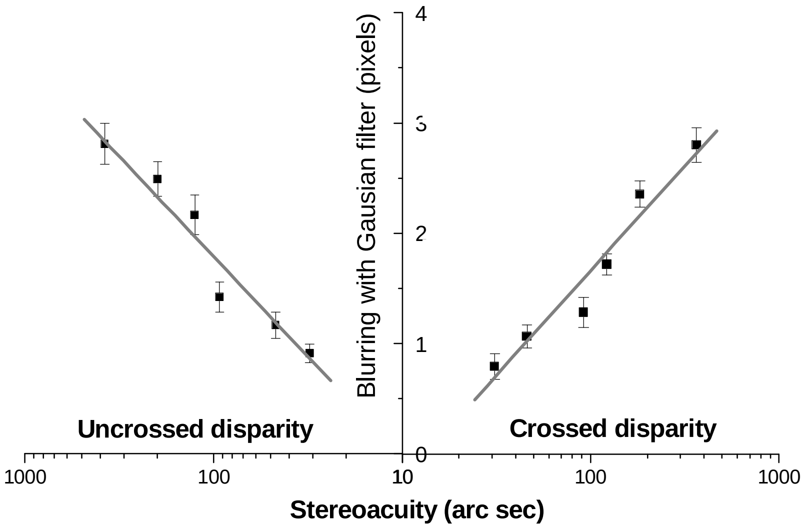


Figure 6.5. Relationship between stereothreshold and stereodisparity values when one of the stereopair image demonstrated on PC screen is blurred using Gauss filter for two kinds of stereodisparities – crossed (right side of graph) and uncrossed (left side of the graph) disparities.

Considering the obtained results for more than one hundred subjects on the influence of artificial amblyopia on the quality of stereovision one can see a pronounced diminishing of the stereoacuity on difference in the both eye visual acuity (close to linear in the reference frame log(stereothreshold) *vs.* difference in visual acuity). For the visual acuity difference ΔVS=0.8 (decimal) the stereothreshold value is 360±50 arc sec. For patients with real amblyopia and cataract the stereothreshold value at ΔVS=0.8 equals to 330±90 arc sec (see Figure 6.7). Though there are subjects whose stereothreshold under conditions of real amblyopia or cataract can be even lower than in cases of induced amblyopia or cataract. This is clearly seen in the graph (see Figure 6.7 B) that in real cases the dispersion of values is bigger than at the lowering of induced visual acuity of one eye.

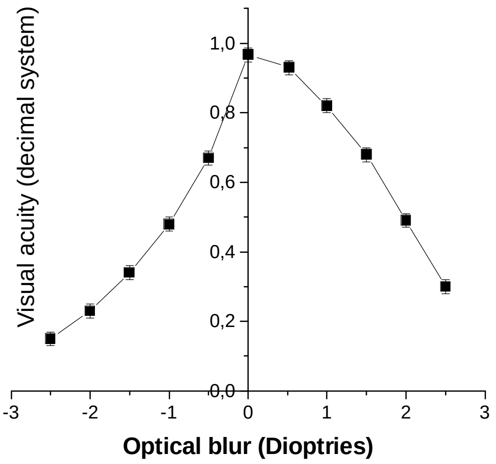


Figure 6.6. Dependences of visual acuity on optical blur using monocular overcorrection.

At induced anisometropia we have observed a tendency that the decrease of stereoacuity depends on the eye refraction (hypermetropia, myopia) (see Figure 6.8). If there is emmetropia in one eye and hypermetropia in other then for the difference of eye refraction 2.5 diopters the stereothreshold is very low – about 530±35 arc sec. The artificial simulation of hypermetropia is carried out using negative optical lenses, which form a sharp image behind the retina and a dim image – on the retina. Contrary, if the individual has emmetropia in one eye and myopia in another, then the stereothreshold at same 2.5 diopters refraction difference equals to 214±21 arc sec (see Figure 6.8).

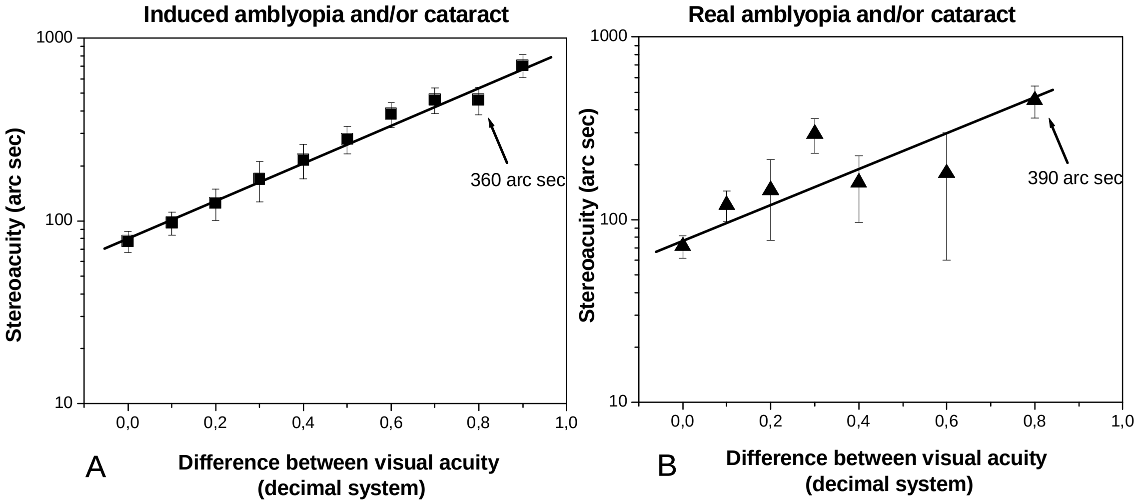


Figure 6.7. Dependence of stereothreshold – minimum resolved stereodisparity in arc sec on difference between the left and right eye visual acuities: A – for subjects without eye pathologies when amblyopia was induced by blurring one eye retinal image using positive and negative lenses, B – for subjects with real amblyopia and cataract.

It means that in cases when the difference of the left and right eye visual acuities is very big we could predict that an approximate stereothreshold is comparatively high and tests and trainings of stereovision is reasonable to begin at high stereothreshold. For such patient having the primary binocular level determined by *Schober* and *Worth* tests we would still predict the presence of the coarse stereovision.

In order to diminish the great eye dominance of amblyopic subjects we have used stereostimuli phase separation. It was accomplished alternately switching stimuli for the left and the right eye with the liquid crystal goggles. Here even PC frame sequence displays stimuli for stimulating the right eye and the odd sequence – for stimulating the left eye. The alteration of sequences is sequential and quick in order not to destroy the perception mechanism of binocular vision. Such separating of stereo images forms compulsory conditions so that both images – the clear and the blurred one reach the brain and possibly are not suppressed at once.

Three subjects with a high degree of amblyopia were involved in the experiment stimulating the stereovision. The cause of amblyopia is hypermetropic anisometropia. The difference in both eye refraction for all the subjects is in the range 2.0-2.5 D. Three subjects have low binocular vision, and in the beginning of experiments stereovision using the clinical TNO stereotest was not diagnosed. Then the subjects were asked to look at the monitor at the displayed stereotest using liquid crystal glasses. The images had a great horizontal stereodisparity (1000-2000 arc sec). The procedure of teaching subjects with amblyopia to recognize stereo images had several stages. At first subjects looked at these tests for a long time (40-60 seconds) trying to catch sight of the hidden depth object. The initial stereodisparity of the random-dot stimuli was within the range of 1000-2000 arc sec. The following actions was taken in further steps: a) the stimulus for the well seeing eye was blurred, and subjects should to look for a long time at the stereotest; b) the stimuli for both eyes were blurred. When the stereosense was eventually provoked, it was checked once again with the clinical TNO test. Besides a neutral filter was applied in the front of the well seeing eye. Bringing the test plates closer to the eyes continuously enlarged the stereodisparity, and that could be more to stimulate stereovision. Afterwards the plates were held at the correct distance and the stereoacuity was assessed repeatedly. Results for three subjects are given in Table 6.2. Besides the steps of the procedure outlined above, the well seeing eye was deliberately covered with a lens blurring the stimulus. Placing in the front of the better seeing eye a filter reducing the stimulus luminance much below the bad seeing eye stimulus luminance turns out as contributory means. Such action diminished neural activity flowing out of the non-amblyopic eye, and similarly the dominance of this eye could be depressed for the reasons described above.

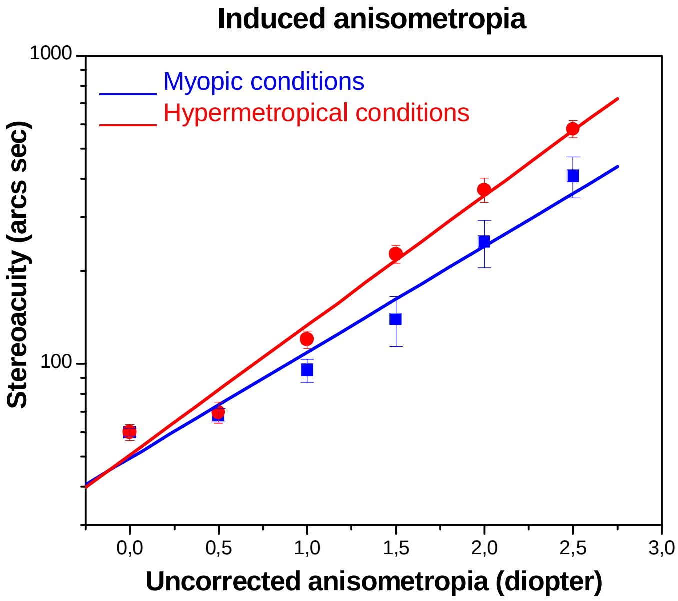


Figure 6.8. Stereothreshold dependences on induced anisometropia by positive lenses (myopic conditions) and by negative lenses (hypermetropic conditions) placed in front of one eye. One can see that in induced hyperopic anisometropia stereothreshold increases more rapidly as in conditions of induced myopic anisometropia ($p<0,05$).

In the clinical study when assessing the stereothreshold 223 subjects were tested, divided into three age groups. The visual acuity for all was not less than 0.9 (decimal system). Each subject had an individual minimal stereothreshold at which he could distinguish the depth effect and see the details in the image. From the graph (see Figure 6.9 A) it can be concluded that a subject in the advanced age has a higher stereothreshold than young subjects. However, the visual acuity 1.0 does not mean that subjects will have a very good stereothreshold (see Figure 6.9 B). It can be seen from the obtained data that the most frequent value of the stereothreshold for participated subjects lies within 60 to 120 arc sec.

Using the method of defocusing with 125 subjects under study it was concluded that in 50 % of cases the stereothreshold lowers after the experiment (it lasted *ca.* 20 minutes), i.e. the procedure of the experiment works like a stereovision training improving stereoacuity. During this time the subject learns to concentrate and to distinguish the finest details of the stereo image (the cut in a circle).

Table 6.2.

Obtained results in method of stimulation of stereovision

	Stereovision with TNO test before experiment	**Stereovision with new method**	**Stereovision with TNO test after the experiment**
Subject 1	Not found	Forms in 5-10 minutes	Sees 480”-240”
Subject 2	Not found	Forms in 5-10 minutes	Sees 480”
Subject 3	Not found	Forms in 20-25 minutes	Sees 480”-800”

The obtained values of the stereothreshold for three subjects after the method of stimulation of stereovision.

Data from blurring degree and contrast changes of one eye are presented in a semilog graph. Averaged data lie along a straight-line for positive as well for negative lenses, for applied voltage or for values of pixel with a slope coefficient *k*:

$$k = \frac{\Delta \log y}{\Delta x}, \qquad [5]$$

where *y* – stereothreshold (arc sec), *x* – parameter that characterizing the degree of stereostimuli blurring or contrast decreases, *k* – the coefficient. Parameter *k* can be defined the sensitivity coefficient of stereovision, which characterizes the fastness of change of the stereothreshold according to the intensity of contrast or blur. Analysing the obtained values of the sensitivity coefficient of stereovision it can be concluded that it depends on the subject’s age, initial stereoacuity (at zero overcorrection) and on other factors.

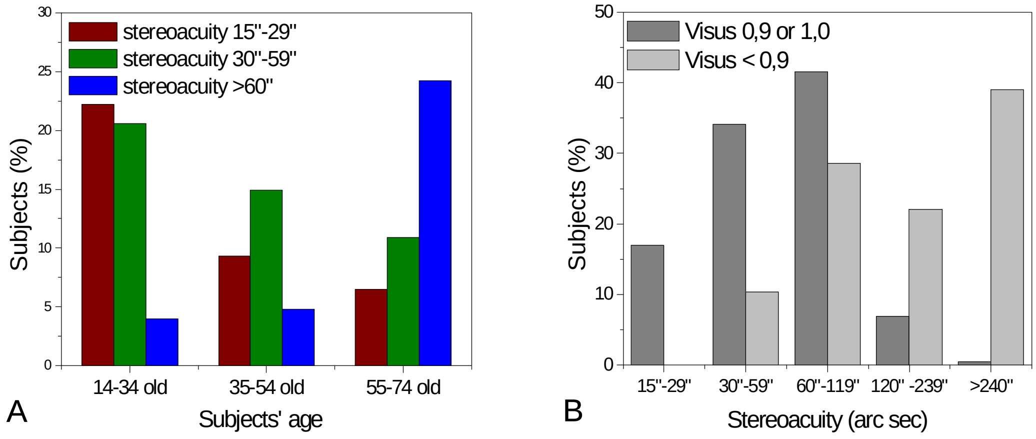


Figure 6.9. A – stereothreshold values for all subjects participated in our studies. B – stereothreshold of 300 patients. Data reveals that a good visual acuity not always is a satisfactory demand for well developed stereovision. One interpretation of that would be insufficient vision training, due to the lack of need for high vision stereoacuity in everyday conditions.

This sensitivity coefficient of stereovision *k* depends on the initial minimal value of stereothreshold under other factors. For example, if the subject’s initial stereothreshold is 30 arc sec, then in this case the coefficient will be larger, i.e. the line characterizing the process will be steeper (see Figure 6.10 A). Using this coefficient we can easily characterize the alterations of the stereothreshold under other factors. For example, how does the blur in the dominant eye change the stereothreshold in comparison with the monocular blur in the non-dominant eye. Similarly using this coefficient it can be stated how much hypermetropic anisometropia influences the stereothreshold in comparison with the myopic uncorrected anisometropia (see the calculated sensitivity coefficients of stereovision) if the blur is placed in front of the dominant eye or the non-dominant eye (see Figure 6.10 B). Experimentally we obtained that doing monocular overcorrection the eye dominance played role, there is statistically significant ($p<0.05$) difference in the values of the stereovision sensitivity coefficients if blur is applied to the dominant or non-dominant eye.

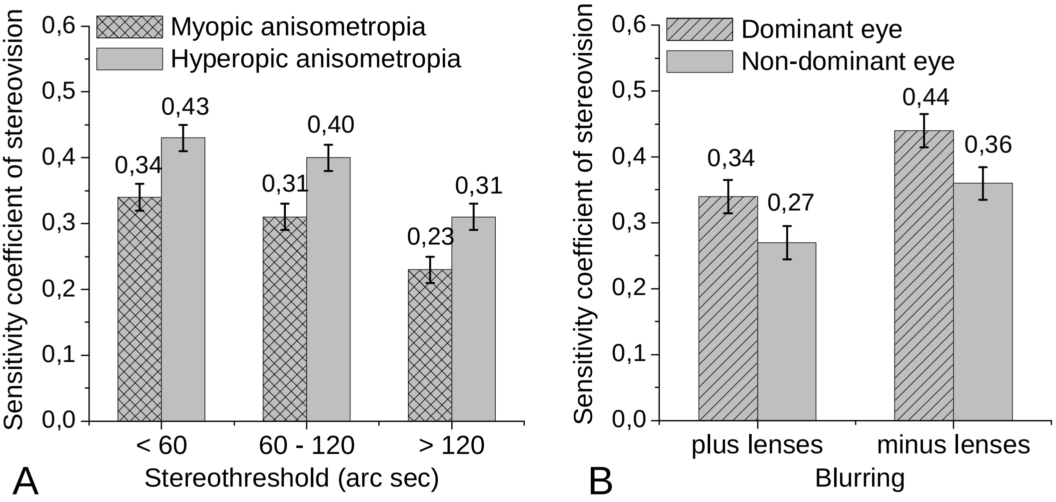


Figure 6.10. The sensitivity coefficients of stereovision in myopic and hypermetropic anisometropia conditions (A) and of monocular overcorrection of the dominant and non-dominant eye (B). It is seen that stereovision is more sensitive to overcorrection of the dominant eye as of the non-dominant eye; statistically significant values ($p<0.05$).

In Figure 6.11 there is a summary for all the methods applied to assess the value of stereothreshold performing different blur conditions. We can conclude that the highest stereothreshold is assessed blurring with eye occluder that simulate the cataract (see Figure 6.11 – squares). In this graph the unifying value is the distinction in visual acuity. From here it follows that for people with cataract the stereothreshold increases due to combination of the blur and reduced contrast. However, using the method of defocusing the value of stereothreshold changes only under the influence of blur. Thus we can calculate the value of the influence of contrast between two curves in the case of cataract.

Considering the determined values of the stereothreshold at different blur using the method of monitor stimuli and taking into account that one group of subjects of the experiment were with very good stereothreshold (about 30 arc sec), one can observed a tendency that the stereothreshold for these subjects due to blurring increases faster than for subjects whose average stereothreshold at zero overcorrection is about 60-80 arc sec. Thus also the sensitivity coefficients of stereovision calculated for these two groups have different values. Comparing values of the stereothreshold obtained in our studies with quoted in references, and particularly for data obtained by TNO test with colour stimuli and colour filter separation, one should always take into account differences in threshold values obtained using colour filters and liquid crystal glasses (see Figure 6.1). Here the assessed stereothresholds with colour filters are almost greater than those with liquid crystal glasses.

Thus the values of stereothresholds obtained by TNO test are greater as prospective for the case when they would be assessed with equivalent black-white test in conditions of uncorrected anisometropia (see Figure 6.11 – the dashed line shows the approximate stereothreshold if TNO test would be substituted with an equivalent black-white test).

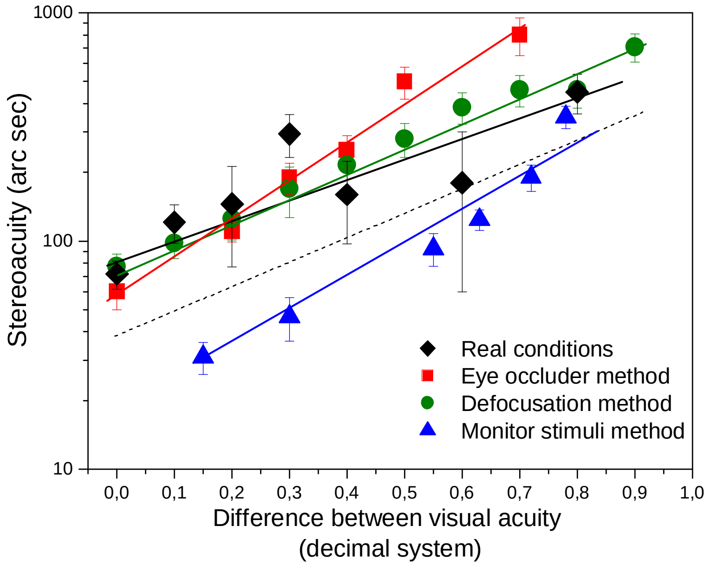


Figure 6.11. Stereothreshold values assessed using techniques of the present studies. Diamonds – for subjects with real diminished visual acuity of one eye, squares – thresholds using light scattering eye occluders, having the highest values, circles – using defocusing with optical lenses, triangles – using monitor stimuli method. Dash line shows prospective stereothresholds values for TNO test if red-green test would be substituted with black-white test.

So all the methods on equal conditions would produce the same results, which coincide with real stereothresholds for the subjects with amblyopia and/or cataract. It should be noted that the method of eye occluder could be very well used to simulate cataract and to study vision functions.

7. Discussion

The aim of the study was to assess the values of the stereothreshold if the visual system is stimulated by the stimuli of different quality in each eye and the quality of the stimulus in one eye is altered. To realize this it was necessary to study the applications of different methods in the assessment of the stereothreshold. The different methods used during the research to determine the values of stereothreshold gave the possibility to obtain a wide field of information.

In addition of disturbances of mechanisms, which underlay stereopsis, stereoacuity can be reduced by optical, sensory and motor aberrations, which degrade the stimulus for stereoscopic depth discrimination. Optical factors such as cataract, ametropia and aniseikonia produced measurable loss of stereoacuity. The main criterion in such situations is visual acuity. If cataract is formed up in the centre of eye lens than visual acuity decreased very quickly and stereoacuity is lost or very poor (*Scarpatetti* 1983; *Katsumi et al.* 1992; *Kwapiszeski et al.* 1996; *Sucker et al.* 2000). The difference between both eyes optical system (anisometropia) could be produced aniseikonia on the retina. Aniseikonia is another factor that initiates interocular suppression and a loss of stereovision sensitivity in the central visual field (*Lovasik & Szymkiw* 1985; *Jimenez et al.* 2002; *Holopigian et al.* 1986).

Using the defocusing method the uncorrected conditions of anisometropia can be well simulated that is impossible to create on the monitor screen. Very small optical differences between the eyes can cause the process of aniso-accomodation, which is mentioned as a positive contribution to development of the fine stereovision (*Marran & Schor* 1998), especially if the observable object lies nearer than 40cm, when then the aniso-accomodation is more pronounced (*Marran & Schor* 1999). However a subject looking with one eye through an additional optical lens still has a slight feeling of discomfort because aniseikonia has been formed all of a sudden. It is not great, in these studies the greatest reaches 7% but for a moment it gives unpleasant feelings. This feeling can be well avoided with the method of monitor stimuli where the stimuli have equal linear size. Here the intensity of blur or contrast of one image changes. As an unpleasant side effect in this method is switching of frames not seen by a human's eye, however existing in neural signal flow. There are subjects who have had a feeling of discomfort using the liquid crystal glasses for a long time. Consequently the duration of the experiment was shortened reducing the number of measurements introducing greater scatterings of results.

Using the occluder method the situation of cataract is easily simulated and we could not study only the formation of stereovision but also other visual functions. It should only be remembered that in real life the manifestation of cataract could be very different. Cataract can be with blurs in the periphery, which do not influence the central visual acuity and stereovision. If the cataract has formed in the central part of the lens then the visual acuity decreases fast and stereovision also changes. The authors measured aniseikonia and stereoacuity in patients with both bilateral and unilateral posterior chamber intraocular lenses and have concluded that average stereoacuity evaluated with *Titmus* test was less than or equal to 100 arc sec (*Scarpatetti* 1983; *Katsumi et al.* 1992), but it depends on the lens implant and on the success of positive results cataract operation.

Scarpatetti (1983) quoted the mean stereothreshold values after successful cataract surgery equalled to 480 arc sec detected with TNO test. If the cataract develops in one eye and its visual acuity decreases down to 0.5-0.1, then it is an indication to have an operation though the visual acuity of the well seeing eye is 1.0. Comparing the data before and after the operation *Kwapiszeski et al.* (1996) and *Sucker et al.* (2000) concluded that the stereoacuity improved for most of subjects as well the second operation need to be done if the first was not successful (*Elliott et al.* 2000).

Larson (1988) investigated that local stereoacuity was reduced when red-green TNO anaglyph glasses were worn. Such reduction ranged from 2 to 34 arc sec. Stereoacuity has been reported decreasing significantly in the seventh decade of life. Results of *Lovasik & Szymkiw* (1985) and *Yap et al.* (1994) suggest that the reduced retinal illuminance resulting from normal ageing is not a cause of the decreased stereoacuity found with ageing.

From literature data (*Hofstetter & Bertsch* 1976; *Coutant & Westheimer* 1993; *Brown et al.* 1993) it is known that stereovision in age range 8 to 50 is very good, subjects are able to see a depth difference at horizontal disparities of 2 arc min or smaller and in the age range 20-25 stereoacuity is achieving a maximal sensitivity. In studies *Brown et al.* 1993 and *Schneck et al.* 2000 was found that stereoacuity declines for subjects with age over 50-60 years. This loss of stereoacuity after age 60 could be due to a decrease in the optical quality of the retinal images (*Brunette et al.* 2003). The decline in the modulation transfer function (MTF) of the optics of the eye takes place for subjects between ages of 20 to 70 years. Wave aberrations of the eye increase with age and this increase is consistent with the loss of contrastvision sensitivity for subjects' age from 61 to 82 years (*Guirao et al.* 1999; *McLellan et al.* 2001). The relative contributions of optical and neural factors to the decrease in visual function with aging were investigated by *Greene & Madden* (1987), *Schneck et al.* (2000), *Scialfa et al.* (2002) and *Pardhan* (2004). Authors have detected some loss of contrast sensitivity due to changes in the central nervous system for subjects elder as 60 years. A decrease in stereoscopic vision performance, particularly in people over 60 years of age, has been described as degenerative changes of the visual pathways – the visual cortex loses its cells. The cells, which remain have fewer synapses and fewer receptor sites (*Marshall* 1987).

In many studies researchers have used various stereotests and their results differed each from other. However experimentally it is detected that for selected subjects under the best conditions, stereoacuity lies within the range 2 to 6 arc sec (*Westheimer & McKee* 1978; *Bach et al.* 2001). Most of human population has stereoacuity 120 arc sec or better – about 97% of adults, and 80% of them have a stereoacuity of 30 arc sec. But that is very important to consider which methods are used by authors estimating the stereovision of adults and children, because diverse methods give different results (*Lovasik & Szymkiw* 1985; *Goodwin & Romano* 1985; *Broadbent & Westall* 1990; *Hatch & Rickman* 1994; *Schmidt* 1994; *Ciner et al.* 1996).

It is mentioned in literature that a higher stereothreshold is detected in the case of uncrossed disparity in comparison with the stereothreshold level formed by the crossed disparity (*Woo & Sillanpaa* 1979; *Landers & Cormack* 1997), because stereoacuity of crossed disparity develops earlier (*Birch & Gwiazda* 1982) but at approximately the same rate as stereoacuity of uncrossed disparity. *Richards* (1970, 1971) estimated that about 30% of the population have a stereoanomaly. Stereoanomalous subjects have stereovision either at only crossed or only at uncrossed disparities. Revealing of stereoanomaly is possible only with special tests (*Larson* 1990; *Van Ee & Richards* 2002; *Van Ee* 2003), but all clinical tests are based on crossed disparity stereovision. However also stereoanomalous subjects can see these stereotests. They still can compensate one disparity type with other, however it takes longer time to see stereotests. Other explanation (*Becker et al.* 1999) is that differences between crossed and uncrossed disparity is from effects related to occlusion. *Lam et al.* (2002) showed results that suggest stereoacuity can be effect by heterophoria. Subjects with ortophoria have the best stereoacuity, followed by subjects with exophoria and esophoria. Exophoric subjects have a better crossed than uncrossed stereoacuity. For esophoric subjects it is not yet known which stereodisparity crossed or uncrossed can be better perceived. In my opinion the stability of bifocal fixation and the mechanism providing it are of great importance.

In the studies of stereovision the subjects had to look at stereotests for a very long time in order to assess the stereothreshold. Both the accommodation of the eye and eye movement muscles participate in the formation of spatial perception. That is how we can explain the weariness of eyes continuously looking at the stereo images (*Fisher & Ciuffreda* 1988; *Koh & Charman* 1998; *Takeda et al.* 1999). Using the light filters the subjects experience additional binocular colour rivalry (*Boynton & Wisowaty* 1984; *Erkelens & Van Ee* 2002; *Van Lier & De Weert* 2003), i.e. occasionally the image turns in one colour, then in another. That can influence the stereothreshold in the experiments of the colour contrast because the subject has to exert hard himself to concentrate. In its turn comparing the test results with different stimuli shape – a circle or a square then here we do not have any differences. Using the liquid crystal glasses we can reduce the effect of colour "pumping" and the obtained stereothresholds are also lower.

Livingstone & Hubel (1987) and *Simmons & Kingdom* (1997, 1998, 2002) try to explain how the chromatic contrast influences stereoscopic judgments. One way – the influence of colour contrast is artifactual. Second way – chromatic- and luminance-contrast-sensitivity mechanisms summate linearly before stereoscopic judgments are made. The third is that chromatic and luminance mechanisms summate nonlinearly before stereoscopic judgments. The fourth way – there are separate mechanisms for chromatic and luminance stereopsis that influence each other only by virtue of probability summation. It could be one reason of great deviations in perceiving of colour stereotests. Subject needs to be more concentrated as in greyscale stereotests.

The liquid crystal glasses are more transparent comparing with colour filters, sequently, the loss of intensity of the stimulus also decreases. The obtained types of stimuli and responses also differ. If the subject has to choose between the preferences whether he sees something or not, then in this case the subject can notice something and press the keyboard button at once. But if the task is made more complicated then the subject has to state whether the image is inwards or outwards or to state the direction of the circle cut-out sector. Thus more precise values of the stereothreshold are determined.

When doing the colour stereotest the subject experienced unpleasant feelings created by binocular rivalry, the colour of the image changed – first blue, then red. Thus the subject could not do the experiment for more than twenty minutes at a time. Considering the anatomical structure (formation) of the retina it is known that cones perceive only colour. **L** cones sensitive at the long wave range perceive pulses at highest degree if the stimulus is in the red wave range of the visible light. **S** cones sensitive at the short wave range react only if the stimulus is within the blue light wave range. The **S** cones in blue are less in number on the retina (*Roorda & Williams* 1999), and a hypothesis is being considered that while looking at colour stereotests only some disparate fields forming the stereovision participate in the perception of the stimuli. If the subject looks at black and white stereotests then in this situation all the disparate fields of cones creating the stereovision participate. Thus the determined contrast threshold for the black-white stimuli decreases more than for colour stimuli when one stimuli contrast is changed. *Kingdom & Simmons* (1996) obtained that stereothreshold is higher for chromatic stimuli as compared with isohromatic stimuli

If stereoacuity is determined with a colour test then the obtained stereothresholds are higher, i.e. stereovision is worse. Thus the stereoscopic colour test should be applied less frequently, but with this test it is possible to determine the adaptation of stereovision to colours. The maximum transparency of the red and green light filters in the visible light spectrum is very close. It would be interesting to observe the adaptation of stereovision to colours with greater difference of maximum spectral light transparency.

The obtained and calculated data consistently show that the quality of stereovision is changing if we manipulate with the optical overcorrection. One of the experiment aims was to observe the changes in stereopsis values without cycloplegia (without blocking of accommodation), i.e., under natural conditions. The experiments mentioned in references were carried out under conditions of cycloplegia when the process of accommodation is blocked. The optical overcorrection (*Lovasik & Szymkiw* 1985; *Goodwin & Romano* 1985; *Schmidt* 1994) was performed at binocular cycloplegia with the near tests – *Random-dot* and *Titmus* to study the influence of visual acuity and aniseikonia on the stereoacuity.

The influence of artificially produced aniseikonia (from 1.2% to 32.3%) on the stereovision was studied by *Lovasik & Szymkiw* (1985), *Lubkin et al.* (1999) and *Jimenez et al.* (2002). The stereothreshold values were measured with *Titmus* and *Random-dot* tests using special afocal magnifiers placed in front of the leading eye. Similar experiments were done increasing overcorrection by step of 0.5 D up to the moment when either monocular suppression or diplopia switched on, or it was not more possible to recognize stereostimuli. The stereoacuity decreases with increasing of aniseikonia. *Lovasik & Szymkiw* (1985) suggest that a stereoacuity 40 arc sec was possible with 20% aniseikonia, and 50-100 arc sec with 30% aniseikonia. *Lovasik & Szymkiw* (1985) had determined that +1.50 D overcorrection, resulting in magnification of only 4%, caused the same decreases of stereovision as 8% pure aniseikonia. On the basis of experimental data it can be proved that the low visual acuity is not the most decisive factor causing the reduction of stereovision.

Our studies results showed that induced anisometropia decreased visual acuity and stereoacuity. However in practice I have met different contradictious cases of the real life. Humans with high visual acuity sometimes do not manifest good stereovision (see Figure 6.9 B), eventually due to non-optimum correspondence of the both eye corresponding receptive fields (that are not anatomically equal). A mechanism is adopted to the brain and adjusted to definite living conditions during the first years of life. Now it is destroyed and the quality of stereovision is reduced.

Lovasik & Szymkiw (1985), *Goodwin & Romano* (1985), *Schmidt* (1994) and *Lam et al.* (1996) carried out similar experiments. They had a goal to investigate the influence of artificially produced amblyopia on stereovision. Authors used cycloplegia for both subject eyes. After that the vision near correction was applied resulting in difference of the eye visual acuities – 20/20 for one eye and 20/200 for other eye. Within a half of hour the stereothreshold was measured vs. difference of the eye visual acuity till both eyes had equal 20/20 acuity. The second experiment was done with an artificially produced binocular amblyopia. Due to the applied positive overcorrection the visual acuity of both eyes was 20/200 in the start of experiment, afterwards it gradually improved up to 20/20. The stereoacuity was determined by *Titmus* test. Authors observed 2-3 times worsening of stereovision threshold while visual acuity due to overcorrection decreased by a half. Using a spectacle magnification formula it can be shown that a +4.00 D lens creates an aniseikonia of approximately 11%. The strongest lens used in my experiments is 2.50 D that creates the highest aniseikonia 7%. *Lovasik & Szymkiw* (1985) observed if visual acuity decreased by a half, the stereovision threshold increases 2-3 times. In our experiment the same relation is observed for elder subjects, who need the near correction.

Goodwin & Romano (1985) have found that good visual acuity only does not prove the existence of stereopsis or the quality of stereovision. I have observed in my practice cases when visual acuity in one eye was decreased for three or four decimal visual acuity lines together with good visual acuity for another eye, however subjects still had good stereoscopic vision. In opposite, in 0.8% cases out of 793 optical patients we found good visual acuity and binocular vision but no stereoscopic vision was tested with standard clinical tests.

Donzis et al. (1983), *Lovasik & Szymkiw* (1985), *Goodwin & Romano* (1985) *Schmidt* (1994) and *Lam et al.* (1996) concluded the influence of relative monocular blurring (loss of monocular visual acuity) on stereovision. The authors represent different outlooks, presented experimental data differ – eventually as a result of different research methods and initial conditions. A quantitative comparison of data on stereoacuity as a function of induced aniseikonia or monocular blur indicates that stereoacuity decreases approximately 1.8 times faster by ***Titmus*** test than by the ***Randot*** test for identical levels of aniseikonia or blur (*Lovasik & Szymkiw* 1985). Authors would suggest to use *Titmus* test for detecting ocular abnormalities compromising binocular function. Consequently, it would be the test of choice for detecting binocular abnormalities in children.

In standard clinical tests stereo images are separated using colour filters or polarizators, and both eyes perceive images simultaneously**.** In such case the eye that sees a clear image becomes the leading eye. The blurred image from the eye not seeing well can be suppressed (*Simpson* 1991, *Schmidt* 1994) due to competition of the brain activities. Due to that the images from the both eyes are not fussed together, and the subject does not see the stereotests.

In order to diminish the great eye dominance of amblyopic subjects I have used stereostimuli phase separation. It was accomplished alternately switching stimuli for the left and the right eye with the liquid crystal goggles – controllable light shutters switching in time with the display frame rate. The even PC frame sequence displays stimuli for stimulating the right eye and the odd sequence – for stimulating the left eye. The alteration of sequences is sequential and quick in order not to destroy the perception mechanism of binocular vision. Such stereo image separation forms compulsory conditions so that both images – the clear and the blurred one reach the brain and possibly are not suppressed at once.

During tests of the binocular vision for individuals who have a reduced visual acuity (amblyopia or cataract), the lack of stereovision very often is diagnosed because it is not found using the clinical tests. Clinical tests also have different ways of determining the stereothreshold in range from 15 to 500 arc sec. In the *Titmus* test the image of the fly is produced with about 3000 arc sec disparity, but using this test we cannot obtain reliable results about the existence of stereovision as there are people who do not understand the test correctly. Usually the stereotests are used to determine amblyopia, anisometropia or aniseikonia, which can destroy the binocular functions of vision, including stereopsis. However, the methods used to determine and distinguish the optical and neural causes of the destruction of perception are not found yet. Researchers try to determine the criteria for aniseikonia destroying the stereovision and reducing the stereoacuity. The relations between the degrees of monocular or binocular amblyopia and the changes in the quality of stereovision are looked for.

In our stereovision study stereotests the random-dot stereopair was demonstrated on the computer screen. The left and right eye stereostimuli were separated using liquid crystal goggles synchronized with the even and odd PC screen frame sequence. It gives a possibility to demonstrate a clear stimulus for the amblyopic eye that project a blurred image to our brain. For the eye with good vision the stimulus is blurred already on the PC screen. Thus stimuli, when they reach the brain, are equally blurred and eventually they might create at least coarse stereovision for an amblyopic subject.

At induced anisometropia I have observed tendency that the decrease of stereoacuity depends on the eye refraction (hypermetropia, myopia). One reason of such difference could be the loss of accommodation process in hypermetropic eye to create clear image on the retina. In the mild myopic anisometropia, the more myopic eye can sometimes be used for near work and the less myopic eye for distance, either eye having a clear retinal image. In myopic anisometropia subject do not use accommodation, and our brain always chooses the easier way to see something.

Rutstein & Corliss (1999) showed results that higher degrees of anisometropia generally cause deeper amblyopia and poorer levels of binocularity for hyperopes, but not for myopes. The retina of the more ametropic eye in hypermetropic anisometropia rarely receives a clear image. If the difference between the optical powers of eyes is +2.7D (hypermetropic conditions) and –6.2D (myopic conditions) than it would be big risks to develop amblyopia in childhood.

Another explanation of these cases could be found in the retina of the eye. *Cheng et al.* (2003) have investigated different types of aberration and sizes in myopic, emmetropic and hypermetropic eyes. The obtained results show that the numerical value of all the aberrations is equal at high degree of myopia (above 6.00 D) and hypermetropia (up to 3.00 D). Considering the obtained data on the stimuli average of modulation depth for blurring with optical lenses (see Table 4.1), then here we do not see great changes which could possibly influence the stereothreshold. The main criteria to form the stereovision is the quality of image on the retina and how this stimulus is sent along the vision canals to the brain where it is further processed and, sequently, the stereosense is or is not formed.

Stereovision is the highest level in the hierarchy of binocular vision. The formation of stereosense occurs in the primary vision cortex. And how that happens, - we have only guesses, explanations, algorithms and models – cooperative disparity model, phase and energy disparity models (*Julesz* 1974; *Marr & Poggio* 1976; *Poggio & Poggio* 1984; *Ohzawa et al.* 1997; *Cumming & DeAngelis* 2001; *Grossberg & Howe* 2003). What can influence the stereovision? First, these are factors, which destroy the primary levels of binocular vision: concerning the eye – anisometropia, aniseikonia, squinting, congenital cataract and glaucoma, pathologies of the retina. Binocular vision functions at anisometropia, squint and amblyopia are most widely studied. As the main reasons the following are mentioned: visual acuity, the contrastsensitivity, the anomalous retinal correspondence, which is most often formed in the case of squint (*Lovasik & Szymkiw* 1985; *Goodwin & Romano* 1985; *Holopigian et al.* 1986; *Stathacopoulos et al.* 1993; *Brooks et al.* 1996; *Rutstein & Corliss* 1999; *Lubkin et al.* 1999; *Lee & Isenberg* 2003; *Harwerth et al.* 2003). Second, the changes could happen in stereovision system, called stereoblindness. *Richards* (1970, 1971) concluded that perceived depth depends on the pooling of inputs from three classes of tuned disparity detectors. One class is tuned to crossed disparities, one to uncrossed disparities, and one to zero disparities. He also concluded that some people lack either the crossed or uncrossed disparity detectors and consequently fail to detect either crossed or uncrossed disparities.

In clinics doctor devotes usually no more than 1-2 minutes to assess stereovision. If the subject does not recognize various stereostimuli during this period of time the test is interrupted. In clinics such procedure is considered to be sufficient to prove the presence or absence of stereovision. Actually the negative test according to such procedure leaves over the answer. Most likely subjects do have stereovision that can be revealed under special conditions helping them to identify stereostimuli. In the case of amblyopia this time mostly is not enough to make sure conclusions about the presence of stereovision. Ophthalmologists and optometrists prescribe a number of exercises for treatments of amblyopia in childhood. Also liquid crystal goggles are applied in vision practice for children with disturbances of binocular vision to stabilize and develop it (*Bahn et al.* 2001). If no practicing was done in childhood or it was ineffective, the visual acuity does not improve and remains unchanged for the rest of life.

One aim of my research was to investigate the influence of induced anisometropia on the quality of stereovision and to assess the prognosis to obtain the coarse stereovision at high degrees of anisometropic amblyopia. Further we liked to create conditions to facilitate provoking of stereovision for individuals with amblyopia, and for those failed in diagnosis of stereovision with the clinical stereotests.

Possibly also amblyopic subjects have stereovision, however they yet cannot give an affirmative answer looking on stereostimuli of the standard clinical tests due to the lack of experience and the restricted test time. A special test developed by us displaying random-dot stereostimuli on a computer screen, first of all allowed to produce a blurred stimulus also for the well seeing eye. Thus two blurred images of the same size reach the brain, and perhaps they are perceived in our brain as more similar thus diminishing one eye dominance. Using the liquid crystal shutters it is possible to stimulate the amblyopic eye at least for some moment, i.e. eye alone sees the stimulus and this information reach the primary visual cortex. Such conditions could make the brain to receive both eye images and to fuse them without suppression to form stereo sensation. A patient with amblyopia needs a longer time to “control” the sensor fusion mechanism in the process of stereovision, however thereafter he is capable to see the hidden depth image. Going on with looking at the stereostimuli even with great disparities subjects needed long adaptation time (at least 20-30 seconds) until they saw the stereo image. A difference in the ease to recognize stereostimuli exists also for normal subjects. Thus time needed to see crossed disparity images is shorter as compared with uncrossed disparity stimuli (*Birch & Gwiazda* 1982; *Landers & Cormack* 1997; *Lam et al.* 2002). Authors also have mentioned that comparing stereoacuity for such cases, the stereoacuity by crossed disparity was better as compared with uncrossed disparity.

After the amblyopic patients for the first time affirmed their depth sense while applying the random-dot stereotest as described above, the stereovision was assessed also by clinical tests. To ease at the beginning the clinical stereotest – we held the TNO test much closer to eyes than it is prescribed (increasing the disparity values). Besides the longer adaptation period than during the clinical vision test was needed.

It was found out in the additional study that for three subjects with amblyopia the stereovision was obtained and the stereothreshold decreased if the well seeing eye is covered with a light filter of three times smaller light transparency. In case of real amblyopia the stereothreshold is higher if colour filters are with equal light transparency.

The developed equipment should be allowed to help subjects having a manifest difference in both eye visual acuities to see at first the random dot stereograms and to train them afterwards. The only requirement – the subject should have at least weak binocular vision. Unification of both eye stimuli responses through blurring of the good eye stimulus or decreasing of the neural response by higher optical density filters in front of the better seeing eye turn out to be factors to facilitate inducing of stereopsis.

It is found out experimentally that it is possible to train even in a considerably short time period (20-30 minutes while the experiment goes on) and to improve stereovision.

Sometimes we met problems with the subjects facing these types of tests for the first time. Such subjects failed to see the stereo image at once and had difficulties with the idea of the test, which could influence the results of the experiment – to raise the stereothreshold and to increase the dispersion of results. As another disadvantage of the experiment we could mention the long time period needed – a series of 40 measurements took about 20 minutes – the time period when the subject had to concentrate on the computer monitor.

Similar to the colour contrast tests it is important to add that advantages and disadvantages of each method must be known. In this case it is stated that using light filters the colour contrast threshold at different stereodisparities can be determined at much higher values than using liquid crystal glasses. However using light filters the range of certain colour can be distinguished more precisely. This cannot be achieved on the monitor. If the formation of stereovision at different changes of colour contrast is further studied, then the intensity of phosphors for each colour must be well established and balanced with the intensity of the other colour so that the brain could receive the light stimuli of the same luminance but the question about the perception of different colours at the formation of stereovision remains current.

The measured values of the threshold for each subject were individual. Besides for some subjects the dispersion of the determined thresholds is very high and the values can differ up to three times, using the method of constant stimuli and method of limits. Also summing up the results of all subjects no essential differences are found between the types of disparity. In our experiments no looking limits were introduced in the test thus the subject could compensate one type of disparity with another disparity.

With the present methods we can determine the values of thresholds using two different psycho-physical methods – the method of limits and the method of constant stimulus. The obtained colour contrast thresholds at different stereodisparities differ in the case of the black white stereotest and the blue red test. It can be explained with the displacement of colour receptors on the retina and separate colour and disparity canals existing in the brains. How does it really analyze the disparity of colour tests? Most probably it is the black and white contrast channel (luminance) in which the colours are transformed greyscale level. Then such a contrast will be like the black one and the thresholds of stereovision will be larger.

At the end I remind about an interesting discovery that would be important in practice. If the subject's stereothreshold is assessed using the TNO test in the near for patients trying to apply monocularly +0.50 D and sequently -0.50 D overcorrection looking for changes of the stereothreshold. We have discovered in our experiments that for a half of subjects that decreased the stereothreshold. Perhaps it is because stereo images are observed for about half an hour and actually that it was a short training, which improved the quality of stereovision.

At the end I would like to conclude that the three developed methods could be used in the studies of stereovision and binocular vision simulating the cataract, amblyopia and uncorrected anisometropia. It can be seen from the experimental results that in the case of uncorrected hypermetropic anisometropia the stereothreshold is lower than in the case of uncorrected myopic anisometropia. Also for people with uncorrected hypermetropic anisometropia amblyopia is more often observed than for those with uncorrected myopic anisometropia. During studies a tendency was observed that at induced cataract and/or amblyopia the stereothreshold increases faster if the vision conditions are made worse for the leading eye.

Conclusions

- The techniques are developed for the estimation of stereothreshold in conditions when one eye retinal image quality is artificially decreased:
    - using monocular defocus to simulate uncorrected anisometropia together with the inducing of small aniseikonia, aniso-accommodation and blurring;
    - one eye occluding with controllable light scattering obstacles to investigate stereovision in induced cataract conditions (PLZT ceramics and polymer dispersive liquid crystals PDLC have been found as good smart materials to build optical phantoms to simulate different cataract stages);
    - direct blurring of stimuli on PC screen for stereostimuli separation using liquid crystal shutters, allowing to study stereovision's (as well for achromatic as for chromatic stimuli) characteristics for induced amblyopia and cataract, thus avoiding anisometropia and aniseikonia contribution to determine stereothreshold changes;
    - the last technique proves to be worthwhile for the formation of the stereosense and training of stereovision;
    - the conversion table is created for comparison of stimuli features in the different methods of stereothreshold detection.
- Experimental results showed that estimated stereothreshold in conditions of induced uncorrected hyperopic anisometropia is higher as the stereothreshold measured in conditions of the induced myopic anisometropia. It is established that blurring is the main factor for the changes of stereothreshold for subjects with real amblyopia in hyperopic anisometropia.
- In cases when the quality of one eye retinal image is artificially lowered, the stereothreshold increase follows the linear relationship $k = \frac{\Delta \log y}{\Delta x}$, where y – stereothreshold (arc sec), x – parameter that characterizing the degree of stimuli blurring or contrast decreases, k – the sensitivity coefficient of stereovision (depending on subject's age, initial stereovision threshold, a.o. factors).
- It is determined that dependences of stereothreshold for subjects with amblyopia or cataract and with difference in both eye visual acuity are on the same level as that measured for another subjects for whom approximately same difference if amblyopia, cataract and uncorrected anisometropia were induced artificially.
- In the experiment the developed equipment should be allowed to help subjects having a manifest difference in both eye visual acuities to see at first the random dot stereograms and to train them afterwards. Unification of both eye stimuli responses through blurring of the good eye stimulus or decreasing of the neural response by higher optical density filters in front of the better seeing eye turn out to be factors to facilitate inducing of stereopsis.
- In this stereovision studies *ca.* 50% of subjects manifest the decrease of stereothreshold after longer stereovision assessment and together with small monocular overcorrection.

Acknowledgements

Stereovision is a very complicated neurological process, which can be influenced very differently by both the inner and outer conditions. It is not possible to understand everything yet as the human's brains are very difficult to reach from inside. During the studies I had the possibility to obtain new knowledge about the formation of stereovision and the most wonderful moment was when at last I could see the complicated stereograms of random elements.

To conclude with my most sincere thanks go to my scientific advisers Professor *Maris Ozolinsh* and Professor *Ivars Lacis* who helped me with advice both on publications and the summary of doctoral thesis during the whole process of writing my doctor's theses. Owing to the useful discussions I have added much to my knowledge in the field of vision science as well as optics, I have seen the world of science from a different side.

I am very grateful to *my husband* who helped to manage the new technologies and I am much obliged to my parents for their moral assistance.

Also I would like to thank my students *Inara Cipane* and *Jelena Petrova* who helped me with the experimental data as well as my English language teachers *Mara Kreicberga* and *Inta Augustane* for teaching me the third foreign language and the translation of the present work.

My thanks go to all the people for their patience and responsiveness while taking part into the experiments of stereovision.

References

B

Bach M., Schmitt C., Kromeier M., Kommerell G. “The Freiburg Stereoacuity Test: automatic measurement of stereo threshold.” *Graefes Arch Clin Exp Ophthalmol*, 239(8), pp.562-566 (2001).

Bahn Jieun, Choi Yong-Jin, Son Jung-Young, Kodratiev N.V., Elkhov V.A.,. Ovechkis Y.N., Chung Chan-sup. “A device for diagnosis and treatment of impairments on binocular vision and stereopsis.” *Proc.SPIE “Stereoscopic Displays and Virtual Reality Systems VIII”*, Edit. A.J. Woods, M.T. Bolas, J.O. Merritt, and S.A. Benton, 4297, pp.127-131 (2001).

Becker S., Bowd C., Shorter S., King K., Patterson R. “Occlusion contributes to temporal processing differences between crossed and uncrossed stereopsis in random-dot displays.” *Vision Res*, 39(2), pp.331-339 (1999).

Birch E.E., Gwiazda J., Held R. “Stereoacuity development for crossed and uncrossed disparities in human infants.” *Vision Res*, 22(5), pp.507-513 (1982).

Boynton R.M., Wisowaty J.J. “Selective color effects in dichoptic masking.” *Vision Res*, 24(7), pp.667-675 (1984).

Broadbent H., Westall C. “An evaluation of techniques for measuring stereopsis in infants and young children.” *Ophthalmic Physiol Opt*, 10(1), pp.3-7 (1990).

Brooks S.E., Johnson D., Fischer N. “Anisometropia and binocularity.” *Ophthalmology*, 103(7), pp.1139-1143 (1996).

Brown B., Yap M.K., Fan W.C. “Decrease in stereoacuity in the seventh decade of life.” *Ophthalmic Physiol Opt*, 13(2), pp.138-142 (1993).

Brunette I., Bueno J.M., Parent M., Hamam H., Simonet P. “Monochromatic aberrations as a function of age, from childhood to advanced age.” *Invest Ophthalmol Vis Sci*, 44(12), pp.5438-5446 (2003).

C

Cheng X., Bradley A., Hong X., Thibos L.N. “Relationship between refractive error and monochromatic aberrations of the eye.” *Optom Vis Sci*, 80(1), pp.43-49 (2003).

Ciner E.B., Schanel-Klitsch E., Herzberg C. “Stereoacuity development: 6 months to 5 years. A new tool for testing and screening.” *Optom Vis Sci*, 73(1), pp.43-48 (1996).

Coutant B.E., Westheimer G. “Population distribution of stereoscopic ability.” *Ophthalmic Physiol Opt*, 13(1), pp.3-7 (1993).

Cumming B.G., DeAngelis G.C. “The physiology of stereopsis.” *Annu Rev Neurosci*, 24, pp.203-238 (2001).

D

Donzis P.B., Rappazzo J.A., Burde R.M., Gordon M. “Effect of binocular variations of Snellen's visual acuity on Titmus stereoacuity.” *Arch Ophthalmol*, 101(6), pp.930-932 (1983).

E

Elliott D.B., Patla A.E., Furniss M., Adkin A. “Improvements in clinical and functional vision and quality of life after second eye cataract surgery.” *Optom Vis Sci*, 77(1), pp.13-24 (2000).

Erkelens C.J., Van Ee R. “Multi-coloured stereograms unveil two binocular colour mechanisms in human vision.” *Vision Res*, 42(9), pp.1103-1112 (2002).

F

Fisher S.K., Ciuffreda K.J. “Accommodation and apparent distance.” *Perception*, 17(5), pp.609-621 (1988).

G

Goodwin R.T., Romano P.E. “Stereoacuity degradation by experimental and real monocular and binocular amblyopia.” *Invest Ophthalmol Vis Sci*, 26(7), pp.917-923 (1985).

Greene H.A., Madden D.J. “Adult age differences in visual acuity, stereopsis and contrast sensitivity.” *Am J Optom Physiol Opt*, 64(10), pp.749-753 (1987).

Grossberg S., Howe P.D. ”A laminar cortical model of stereopsis and three-dimensional surface perception.” *Vision Res*, 43(7), pp.801-829 (2003).

Guirao A., Gonzalez C., Redondo M., Geraghty E., Norrby S., Artal P. “Average optical performance of the human eye as a function of age in a normal population” *Invest Ophthalmol Vis Sci*, 40(1), pp.203-213 (1999).

H

Harwerth R.S., Fredenburg P.M., Smith E.L. 3rd. “Temporal integration for stereoscopic vision.” *Vision Res*, 43(5), pp.505-517 (2003).

Hatch S.W., Rickman J.E. “Stereopsis testing without polarized glasses: a comparison study on five new stereoacuity tests.” *J Am Optom Assoc*, 65(9), pp.637-641 (1994).

Hofstetter H.W., Bertsch J.D. “Does stereopsis change with age?” *Am J Optom Physiol Opt*, 53(10), pp.664-667 (1976).

Holopigian K., Blake R., Greenwald M.J. “Selective losses in binocular vision in anisometropic amblyopes.” *Vision Res*, 26(4), pp.621-630 (1986).

Hubel D.H., Wiesel T.N. “Brain mechanisms of vision.” *Sci Am*, 241(3), pp.150-162 (1979).

Hubel D.H., Wiesel T.N. “Early exploration of the visual cortex. Review.” *Neuron*, 20(3), pp.401-412 (1998).

J

Jimenez J.R., Ponce A., Del Barco L.J., Diaz J.A., Perez-Ocon F. “Impact of induced aniseikonia on stereopsis with random-dot stereogram.” *Optom Vis Sci*, 79(2), pp.121-125 (2002).

Julesz B. “Cooperative phenomena in binocular depth perception.” *Am Sci*, 62(1), pp.32-43 (1974).

K

Katsumi O., Miyajima H., Ogawa T., Hirose T. “Aniseikonia and stereoacuity in pseudophakic patients. Unilateral and bilateral cases.” *Ophthalmology*, 99(8), pp.1270-1277 (1992).

Kingdom F.AA., Simmons D.R. “Stereoacuity and colour contrast.” *Vision Res,* 36(9), pp.1311-1319 (1996).

Koh L.H., Charman W.N. “Accommodation to perceived depth in stereotests.” *Ophthalmic Physiol Opt*, 18(3), pp.279-284 (1998).

Kwapiszeski B.R., Gallagher C.C., Holmes J.M. “Improved stereoacuity: an indication for unilateral cataract surgery.” *J Cataract Refract Surg*, 22(4), pp.441-445 (1996).

L

Lam A.K., Chau A.S., Lam W.Y., Leung G.Y., Man B.S. “Effect of naturally occurring visual acuity differences between two eyes in stereoacuity.” *Ophthalmic Physiol Opt*, 16(3), pp.189-95 (1996).

Lam A.K., Tse P., Choy E., Chung M.. “Crossed and uncrossed stereoacuity at distance and the effect from heterophoria.” *Ophthalmic Physiol Opt*, 22(3), pp.189-193 (2002).

Landers D.D., Cormack L.K. “Asymmetries and errors in perception of depth from disparity suggest a multicomponent model of disparity processing.” *Percept Psychophys*, 59(2), pp.219-231 (1997).

Larson W.L. “An investigation of the difference in stereoacuity between crossed and uncrossed disparities using Frisby and TNO tests.” *Optom Vis Sci*, 67(3), pp.157-161 (1990).

Larson W.L. “Effect of TNO red-green glasses on local stereoacuity.” *Am J Optom Physiol Opt*, 65(12), pp.946-50 (1988).

Lee S.Y., Isenberg S.J. “The relationship between stereopsis and visual acuity after occlusion therapy for amblyopia.” *Ophthalmology*, 110(11), pp.2088-2092 (2003).

Livingstone M.S., Hubel D.H. “Psychophysical evidence for separate channels for the perception of form, color, movement, and depth.” *J Neurosci*, 7(11), pp.3416-3468 (1987).

Lovasik J.V., Szymkiw M. “Effects of aniseikonia, anisometropia, accommodation, retinal illuminance, and pupil size on stereopsis.” *Invest Ophthalmol Vis Sci*, 26(5), pp.741-750 (1985).

Lubkin V., Kramer P., Meininger D., Shippman S., Bennett G., Visintainer P. ”Aniseikonia in relation to strabismus, anisometropia and amblyopia.” *Binocul Vis Strabismus Q*, 14(3), pp.203-207 (1999).

M

Marr D., Poggio T. “Cooperative computation of stereo disparity.” *Science*, 194(4262), pp.283-287 (1976).

Marran L., Schor C.M. “Lens induced aniso–accommodation.” *Vision Res*, 38(22), pp.3601-3619 (1998).

Marran L., Schor C.M. “The effect of target proximity on the anosi-accommodative response.” *Ophthalmic Physiol Opt*, 19(5), pp.376-92 (1999).

Marshall J. “The ageing retina: physiology or pathology.” *Eye*, 1, pp.282-295 (1987).

McLellan J.S., Marcos S., Burns S.A. “Age-Related Changes in Monochromatic Wave Aberrations of the Human Eye.” *Invest Ophthalmol Vis Sci*, 42(6), pp.1390-1395 (2001).

O

Ohzawa I., DeAngelis G.C., Freeman R.D. “The neural coding of stereoscopic depth.” *Neuroreport*, 10;8(3), pp.3-12 (1997).

Ozolinsh M., Daae K.I., Bruenech D., Lacis I. “Time response of the vision binocularity by use of dynamic suppression of retinal images.” In: “*International Conference on Biomedical Optics*” Eds. Qingming Luo, Britton Chance, Lihong V. Wang, Steven L. Jacques, *Proc.SPIE*, 3863, pp.214-218 (1999).

P

Pardhan S. “Contrast sensitivity loss with aging: sampling efficiency and equivalent noise at different spatial frequencies.” *J Opt Soc Am A Opt Image Sci Vis*, 21(2), pp.169-75 (2004).

Poggio G.F., Poggio T. “The analysis of stereopsis.” *Annu Rev Neurosci*, 7, pp.379-412 (1984).

R

Richards W. “Anomalous stereoscopic depth perception.” *J Opt Soc Am*, 61(3), pp.410-414 (1971).

Richards W. “Stereopsis and stereoblindness.” *Exp Brain Res*, 10(4), pp.380-388 (1970).

Rohaly A.M., Wilson H.R. “The effects of contrast on perceived depth and depth discrimination.” *Vision Res*, 39(1), pp.9-18 (1999).

Roorda A., Williams D.R. “The arrangement of the three cone classes in the living human eye.” *Nature*, 397, pp.520-522 (1999).

Rutstein R.P., Corliss D. “Relationship between anisometropia, amblyopia, and binocularity.” *Optom Vis Sci*, 76(4), pp.229-233 (1999).

S

Scarpatetti A. “Binocular vision after lens implantation.” *Acta Ophthalmol*, 61(5), pp.844-850 (1983).

Schmidt P.P. “Sensitivity of random dot stereoacuity and snellen acuity to optical blur.” *Optom Vis Sci*, 71(7), pp.466-471 (1994).

Schneck M.E., Haegerstrom-Portnoy G., Lott L.A., Brabyn J.A. “Ocular contributions to age-related loss in coarse stereopsis.” *Optom Vis Sci*, 77(10), pp.531-536 (2000).

Scialfa C.T., Kline D.W., Wood P.K. “Structiral modeling of contrast sensititvity in adulthood.” *J Opt Soc Am A Opt Image Sci Vis*, 19(1), pp.158-65 (2002).

Simmons D.R., Kingdom F.A.A. “Interactions between chromatic- and luminance-contrast-sensitive stereopsis mechanisms.” *Vision Res*, 42(12), pp.1535-1545 (2002).

Simmons D.R., Kingdom F.A.A. “On the binocular summation of chromatic contrast.” *Vision Res*, 38(8), pp.1063-1071 (1998).

Simmons D.R., Kingdom F.A.A. “On the independence of chromatic and achromatic stereopsis mechanisms.” *Vision Res*, 37(10), pp.1271-1280 (1997).

Simpson T. “The suppression effect of simulated anisometropia.” *Ophthalmic Physiol Opt*, 11(4), pp.350-358 (1991).

Stathacopoulos R.A., Rosenbaum A.L., Zanoni D., Stager D.R., McCall L.C., Ziffer A.J., Everett M. “Distance stereoacuity. Assessing control in intermittent exotropia.” *Ophthalmology*, 100(4), pp.495-500 (1993).

Sucker J., Zvizdic M., Vogten H. “Stereosehen vor und nach Kataraktextraktion mit Kunststofflinsenimplantation.” *Ophthalmologe*, 97(10), pp.676-681 (2000).

T

Takeda T., Hashimoto K., Hiruma N., Fukui Y. “Characteristics of accommodation toward apparent depth.” *Vision Res*, 39(12), pp.2087-2097 (1999).

V

Van Ee R. “Correlation between stereoanomaly and perceived depth when disparity and motion interact in binocular matching.” *Perception*, 32(1), pp.67-84 (2003).

Van Ee R., Richards W. “A planar and a volumetric test for stereoanomaly.” *Perception*, 31(1), pp.51-64 (2002).

Van Lier R., de Weert C.M. “Intra- and interocular colour-specific activation during dichoptic suppression.” *Vision Res*, 43(10), pp.1111-1116 (2003).

W

Westheimer G., McKee S.P. “Steroscopic acuity for moving retinal images.” *J Opt Soc Am*, 68(4), pp.450-455 (1978).

Wilcox L.M., Hess R.F. “When stereopsis does not improve with increasing contrast.” *Vision Res*, 38(23), pp.3671-3679 (1998).

Woo GC, Sillanpaa V. “Absolute stereoscopic thresholds as measured by crossed and uncrossed disparities.” *Am J Optom Physiol Opt*, 56(6), pp.350-355 (1979).

Y

Yap M., Brown B., Clarke J. “Reduction in stereoacuity with age and reduced retinal illuminance.” *Ophthlamic Physiol Opt*, 14(3), pp.298-301 (1994).

P I

Stereovision studies by disbalanced images

Gunta Papelba*, Inara Cipane, and Maris Ozolinsh
Department of Optometry and Vision Science, University of Latvia, Riga, Latvia

ABSTRACT

Studies are focused on design and appraisal of an objective test of the quality of stereovision depending on optical stimuli blurring and detecting of the stereovision threshold at various stimuli blur degree. The method is based on the principles of grayscale and color random dot stereotests[1] (B.Julesz 1974). Experiments may be divided with respect to the principle of demonstration: 1) the blur is modeled by defocusing an optical lens – the strength of the optical system is varied at a constant quality of the stimulus, or 2) the blur is simulated on the computer screen – here the quality of the stimulus varies. To obtain an independent description and to measure blurring the experimentally demonstrated images are analyzed with regard to modulation depth, Fourier frequencies and by cross-correlation.

Keywords: stereovision, random dot stereo test, blur, stereovision threshold, modulation depth, Fourier filtering, cross-correlation.

1. INTRODUCTION

Stereovision is a functional part of vision that provides a more comprehensive representation of the surrounding reality. Stereovision is founded on a complicated mechanism of psychomotoric function. Depending on location the image is being formed, a distinction is made between the fine and the coarse stereovision.

The eyes are strongly interrelated. They compare and exchange information to complete the task impossible for a single eye – measuring of the relative distance to an object. The system of vision is capable of combining the two slightly different images of a three-dimensional object forming in each eye. That is stereovision – the ability to assess the relative distance to an object by means of binocular vision exclusively. It is possible due to and dependent on, a very small disparity, if there is a small displacement between images of the object on the retinas in both eyes.

Stereovision is sensitive to the set of spatial frequencies of the stimulus. The blur obscuring stimuli can be simulated by means of positive lenses or light scattering media. The blurring produced by lenses reduces (diminishes the energy of) the higher spatial frequencies of the image and changes its size. Usually the higher spatial frequencies are more important for perception of three-dimensional objects[2,3].

As in the case of a reduced contrast, the stereo threshold is more disturbed by monocular rather than binocular blurring. Compared with contact lenses, blurring caused by conventional glasses created a stronger disturbance of stereovision[4]. Light scattering media reduces the contrast without affecting the size of the image. They change the distribution of spatial frequencies but the analysis of that is complicated by other factor[3].

Since stereovision is based on binocular information, its quality is essentially affected by the difference between the images emerging in each eye. Images of different quality on the retina may arise because of uncorrected anisometropia, cataract, amblyopia, and damage of the optical system of the eye. The situations are modeled and studied by static blurring produced by light filters, light scatters, and hypercorrection suppressing reaction of accommodation in the healthy eye[5-7].

---

* papelba@tiger.cfi.lu.lv; fax 00371 7260796; Department of Optometry and Vision Science, University of Latvia, Kengaraga str 8., LV-1063, Riga, LATVIA

Advanced Optical Devices, Technologies, and Medical Applications, Janis Spigulis,
Janis Teteris, Maris Ozolinsh, Andrejs Lusis, Editors, Proceedings of SPIE Vol.5123 (2003)

Stereovision measurements are important in screening and diagnostics of different anomalies of binocular vision; tests are assigned as one of the screening procedures to detect amblyopia, anisometropia, or aniseikonia. The number of modern professions that require normal stereovision is growing.

The objective of the present studies is to develop a method for assessment of stereovision that examines the effects of monocular stereoimage quality on stereovision. The tasks have been:

- To design computer-controlled stereo tests where a blur image is seen by one eye while a clear and sharp one – by the other. Blurring of one stimulus is simulated on the computer screen.
- To perform measurements for computer simulated blurred stereostimuli (*method 1*) and for standard TNO stereo tests with a monocular blur produced by a positive lens (*method 2*) that examines the relationship between the stereovision acuity and the blurring of the monocular image that still does not upset the stereovision and to compare both techniques.
- To find an independent way to assess the quality of stereo stimuli that measures and analyzes stereovision.

2. METHOD 1

A random dot stereopair was displayed on the monitor screen (Fig. 1). Each image of the pair was a square with a smaller square in its center. The latter, imperceptible at monocular observation, appeared as a three-dimensional object out of the plane of reference at superposition of the images. The top image was constant during the experiment – it was clear with black and white random dots, the smallest of which was 1 pixel. The bottom image varied from blurred to clear. The program performed 40 series of measurements and the central square in a series was randomly shifted to right or left by 1 to 4 pixels. Within one series each blur image was displayed for 1 sec. The size of the square stereo pairs was 7±0.1 cm. The size of central squares was 3.5±0.1 cm.

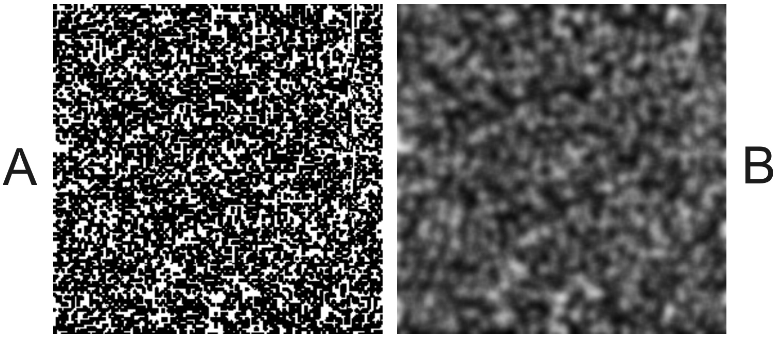


Figure 1: The stimuli of stereotest. A – one eye had sharp image, B – the second eye had a successive approximation image from sharp to blur and vice versa.

The blur images of the stereopairs were produced by ***Corel Photo Paint*** blur effect using Gaussian filter. The radii of blur effect in one series varied 0.1 to 5 pixels by steps of 0.1 pixel.

The stereopair images were merged by use of liquid crystal goggles[8]. A special adapter was used doubling the frame frequency. Thus the upper part of the frame (blurred stimulus) was displayed as whole even frames for one eye, and bottom part of the initial frame – as uneven frames displayed for other eye. The frame frequency was doubled from 60 to 120 Hz. The blur threshold at which the stereosensation appeared was experimentally determined for one eye at different stereo disparities under the condition that the other eye saw a constant image of high contrast. The program fixed the number of the relevant blurring image (the radius of the blur effect).

3. METHOD 2

In the other part of the experiment the stereo threshold was assessed by the standard near TNO stereo test assigned for the distance of 40 cm. It was also based on the random dot principle, in combination with the anaglyph method. The

TNO test plates contained small red and green elements as in Method 1. Red and green filters were placed in front of the eyes providing far correction for a young subject or near correction in case of presbyopia. In case of binocularity (the subject used both eyes simultaneously) a spatial image appeared – a circle in which a sector is cut out, thus stereoacuity threshold is determined.

After that refraction of the right eye was changed by a –2.50 *D* or +2.50 *D* lens and the stereovision threshold detected by starting demonstration from images with greater disparity. Further the strength of the lens was decreased by 0.50 *D*, and the last visible stereoscopic image was fixed at each step. After returning to the original setting (no additional lenses), stereovision was tested again to see if the subject discriminates images at the same level as in the beginning. The same procedure was repeated for the left eye.

4. ASSESSMENT OF THE IMAGE QUALITY

In the computer experiment the stereo threshold was fixed in terms (for combination) of the blurring radius in pixels and the disparity (disparity is a partial dissociation of two eyes). In the TNO test the value of minimum resolvable stereoangle was determined.

One way to compare blur was using a CCD camera (f = 18mm) as an eye model to take blurred and clear computer simulated random dot pictures (the latter besides are additionally defocused using corresponding positive lenses taking pictures). Depicted images were a subject of Fourier analyses.

To specify the degree of blurring it was necessary to find a measure independent of the way the stereo image is obtained. The measure would describe the stereo stimulus and qualify the stereovision itself if images are used as stereostimuli. Each image of the stereopair might be analyzed separately using:

- the average modulation amplitude,
- frequency analysis of stimuli Fourier images,
- cross-correlation.

We have used the average modulation amplitude in the following way. One pixel wide line (in the center of the square) of the blur images was selected to draw the RGB values (Fig. 2).

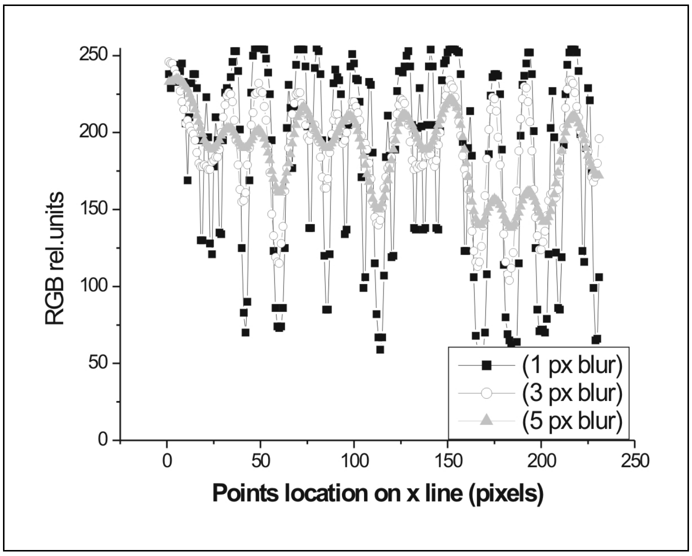


Figure 2: One version of the stimuli quality analysis. We have determined the modulation depth, which is an objective parameter that characterizes degree of blurring. Figure shows modulation depth for one pixel row.

For each dip on the obtained graphs the modulation depth (MD):

$$MD = \frac{I_{MIN} \times 100}{I_{MAX}} \quad (1),$$

and the average value characterizing the given image was calculated (Fig. 3).

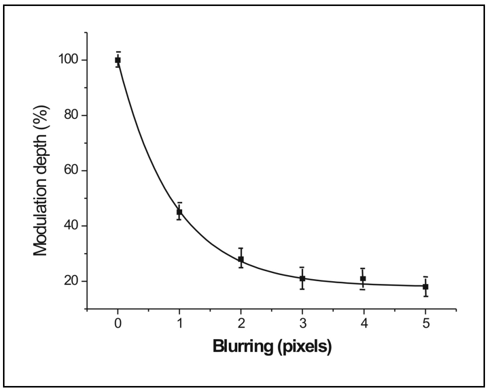


Figure 3: The average value of modulation depth for one pixel row.

Since the human vision system is more sensitive to variation of higher frequencies[5], it is reasonable to analyze changes of only the higher frequencies in the blur images.

The profiles representing functions of frequency distribution with respect to the spatial frequency (proportional to number of oscillations per pixel) obtained from 1 pixel wide lines in centers of Fourier patterns of the stereo images are shown in Fig. 4.

The curve corresponding to a clear image has a gentle slope – a contribution of higher spatial frequencies as compared with spatial zero frequency at the center is higher. The integral:

$$\int_{0}^{n_0 x} I \cdot \partial V_x = K_F(V_{0x}) \quad (2),$$

where *I* is the maximum of the frequency distribution and V_{ox} – an arbitrary frequency, may be considered as a parameter specific to the image characteristics (pixel size of clear image, and eventually disparity if used for stereostimuli). If a small enough V_{ox} is chosen, then the more blurred the image, the bigger the corresponding integral (Fig. 4. B).

Cross-correlation were made to compare two images and to find the degree of similarity by looking for similar regions in both images (Fig. 5). The experimentally obtained relationships were as expected – within the examined disparity interval dependence of the blurring threshold of a monocular image on the degree of stereovision could be described by a linear function.

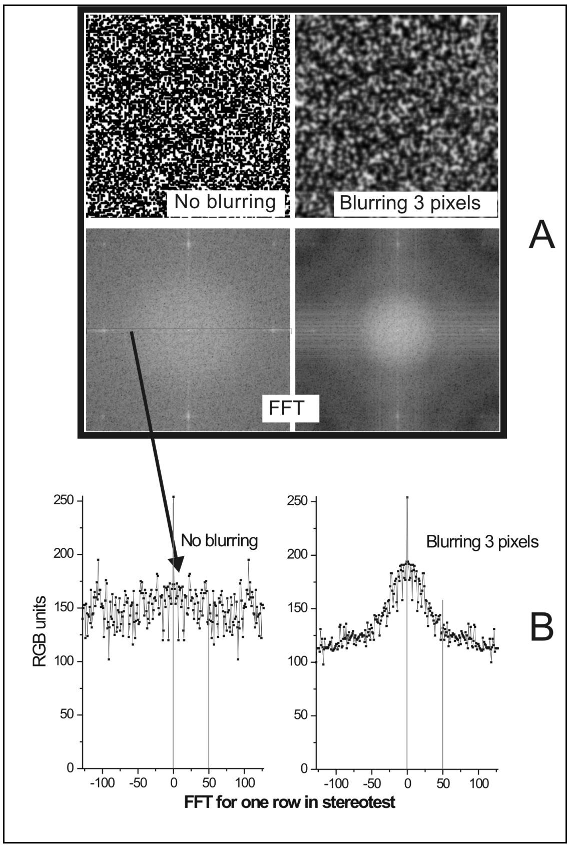


Figure 4: The blurred image quality can be analyzed with FFT. In figure A – the upper images are real stimuli, while in the bottom images – stimuli is analyzed with FFT. The corresponding profiles of FFT central part (1 pixel horizontal row) are shown in Figure B. The decrease of the integration's area at high frequencies are used as an objective parameter.

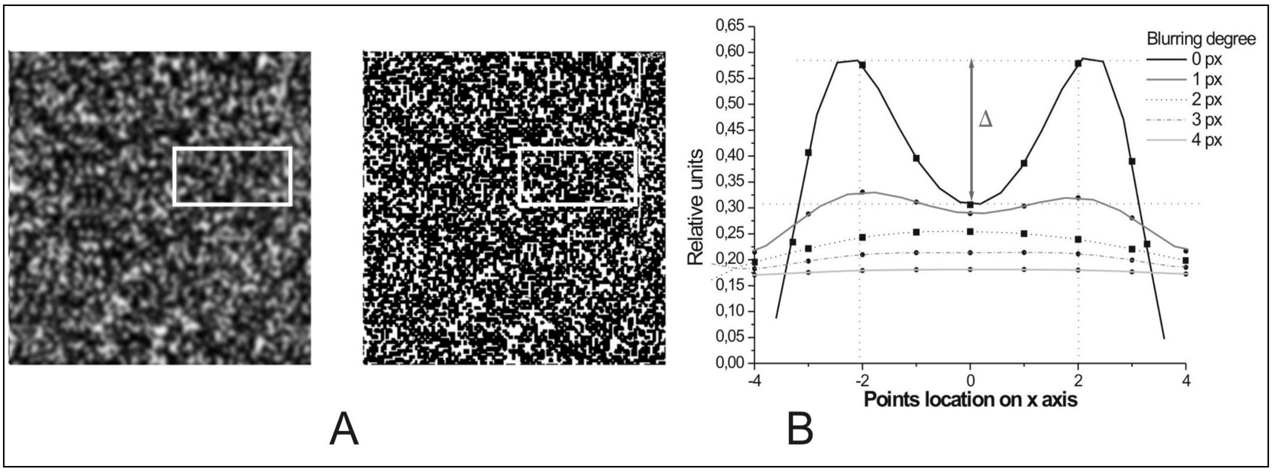


Figure 5: The figure shows cross-correlation results of stimuli. One stimulus is blurred with Gaussian distribution (A – left image). Such processing would be similar to neural signal processing in the human brain. B – the stereoimage can be perceived at positive and close-to-zero values of DELTA.

Cross-correlation is one more method of image analysis. The mechanism by which the images are compared and stereovision forms in the brain may be very similar. In this case a good image of zero displacement should be compared with a good image, the central figure of which is displaced by one to four pixels. After that a good image should be compared with the blurred image.

5. SUBJECTS

In the computerized experiment a 15 inch monitor was used to appraise the method on 11 subjects, ages 21-23. All of the subjects had a good visual acuity: monocular *Visus* = 1.0 – 1.2 in far and in near. Eight subjects were emmetrops, three had myopia and astigmatism (they employed their individual corrections during the experiment). Stereoacuity of the subjects tested by the standard *Titmus* test were within the limits 40-60", the pupil distance – from 57 to 68 mm.

100 subjects were examined using method 2: TNO stereotest inducing monocular blur with positive lenses and negative lenses (Fig. 6). Complete near and far distance corrections were determined and functions of binocular vision estimated. If necessary, the corrections in near were made to provide binocular vision acuity at least a 0.9 or 1.0 the distance of 40 cm.

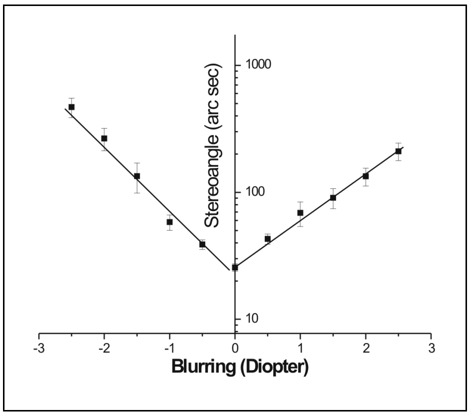


Figure 6: Subjects' stereoacuity threshold. The Stereoangle was measured with constant stimuli methods and standard TNO test.

The selected subjects had neither eye traumas, nor serious eye diseases, nor amblyopia. The measurements were made at artificial illumination of 200 – 400 lx. It has been reported[9] that such oscillations of illumination do not affect stereovision.

6. RESULTS

The magnitude of stereovision ω in radians was calculated from the formula:

$$w = \frac{PD \times \Delta l}{l^2}, \text{ and } \Delta l = \frac{l \times y_p}{PD \pm y_p} \tag{3}$$

where ω is the stereoangle (rad), y_p - the stereoparallax or displacement of images (or disparity) (m), l – the distance of the fixed point to eyes (m), PD – the pupil distance (m).

In most studies of effects of monocular contrast on stereovision relation between the magnitudes is described by a power function $y = a \times x^b$ and data are analyzed in the logarithmic scale (Fig. 7).

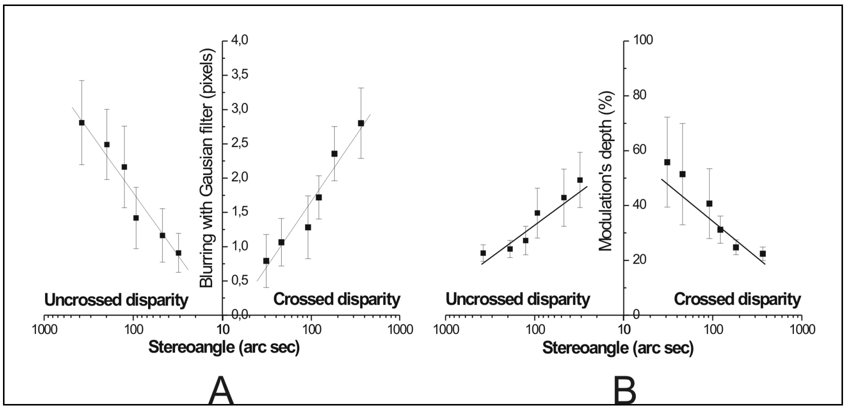


Figure 7: Blurring effect of one eye stimuli on stereoacuity. A - blurring was measured in pixels. B - modulation's depth of blurring, blurring effect was made with Gaussian filter.

Since the present experiments refer to a rather narrow disparity interval, relation between stereovision and blurring of the image was assumed to be linear and analyzed in linear co-ordinates, the same relation correlated equally well with a linear function in linear co-ordinates and with a power function in logarithmic co-ordinates. The average values of the blur threshold of monocular image for all the subjects at each of the considered disparities are shown in Fig. 7.

7. CONCLUSIONS

The described computer-controlled method allows measuring the minimum resolvable stereoangle and its change with the intensity of blurring while the blur effect can be simulated on the computer screen. Within a narrow disparity interval the effect of blur (the average modulation depth, Fourier frequencies or image cross-correlation) on stereovision may be described by a linear function.

REFERENCES

1. B. Julesz, "Cooperative phenomena in binocular depth perception," *Am. Sci.* **62**, pp. 32-43, 1974.
2. D. L. Halpern and R. R. Blake, "How contrast affects stereoacuity," *Perception* **17**, pp. 483-495, 1988.
3. L. M. Wilcox, J. H. Elder, and R. F. Hess, "The effect of blur and size on monocular and stereoscopic localization," *Vision Res.* **40**, pp. 3575-3584, 2000.
4. P. P. Schmidt, "Sensitivity of random dot stereoacuity and Snellen acuity to optical blur," *Optom. Vis. Sci.* **71**, pp. 466-471, 1994.
5. G. Papelba and M. Ozolinsh, "Blurring effect to stereoscopic vision," 99.Tagung der Deutsche Ophthalmologische Gesellschaft, Berlin, report, 2001.
6. H. Oguz and V. Oguz, "The effects of experimentally induced anisometropia on stereopsis," *J. Pediatr. Opthalmol. Strabismus* **37**, pp. 214-218, 2000.
7. W. L. Larson and M. Bolduc, "Effect of induced blur on visual acuity and stereoacuity," *Optom. Vis. Sci.* **68**, pp. 294-298, 1991.
1. Ji-eun Bahn, Yong-jin Choi, Jung-young Son, N. Kondratiev, V. Elkhov, Yu. N. Ovechkis, and Chan-sup Chung, "A device for diagnosis and treatment of impairments on binocular vision and stereopsis," *Proc.SPIE "Stereoscopic Displays and Virtual Reality Systems VIII"*, Edit. A.J. Woods, M.T. Bolas, J.O. Merritt, and S.A. Benton, **4297**, pp.127-131, 2001.
8. J. V. Lovasik and M. Szymkiw, "Effects of aniseikonia, anisometropia, accommodation, retinal illuminance, and pupil size on stereopsis," *Invest. Opthalmol. Vis. Sci.* **26**, pp. 741-750, 1985.

P II

Stereoacuity determination at changing contrast of colored stereostimuli

Gunta Papelba*, Maris Ozolinsh, Jelena Petrova, and Inara Cipane
Department of Optometry and Vision Science, University of Latvia, Riga, Latvia

ABSTRACT

Studies are focused on design and appraisal of an objective test for assessment of the stereovision quality in unfavorable conditions. Stereostimuli of different colors are used while the contrast of one of the stimulus being varied. Tests are based on principles of black-and-white and two primary color random dot stereotests[1] (B.Julesz 1974). Experiments are divided by the method of stimuli display and separation: 1) stereoeffect is obtained haploscopically – by use of spectacles with color filters (blue and red) or prisms, 2) stimuli separation is obtained by liquid crystal shutters when both eye stimuli are demonstrated with a different delay. The stereovision threshold is determined at different stimuli disparities simulating the random dot stereotests on a computer monitor with a variable contrast of one-color stimuli. The applied tests differ by stimuli geometry, separation of vision channels, and by data processing. Tests have been appraised and may be used in stereovision studies.

Keywords: stereovision, random dot stereotest, color stereotest, color contrast threshold, stereoacuity.

1. INTRODUCTION

Stereovision is a functional part of vision providing a more comprehensive representation of the surrounding reality. Stereovision is founded on a complicated mechanism of the psychophysiological function. Depending on image location on retina distinction is made between the fine and the coarse stereovision[2].

That is hard to imagine a colorless everyday life. Colors mean enjoyment and are signs of attention, enrichment and apprehension of life. Perception of colors is provided by three types of photoreceptors, which makes one to suppose that processing of color information should be complicated to provide the ability of discriminating more colors and tints.

Stereovision and color perception are important constituents of visual conception inseparable from life. Eyes are strongly interrelated. They compare and exchange information to complete the task impossible for a single eye – measuring of the relative distance between objects. The visual system is capable of combining two slightly different images of a three-dimensional object forming in each eye. That is stereovision – the ability to assess the relative distance to an object by means of binocular vision exclusively. That is possible due to and is dependent on a very small disparity if there is a small displacement between corresponding parts of the object images on retinas in both eyes.

Measurements of stereovision are important in a number of diagnostic anomalies of binocular vision to detect amblyopia, anisometropia or aniseikonia.

Progressing cataract changes the eye optical and transparent media deteriorating contrast vision. At the same time cataract either in the dominant or non-dominant eye has an effect on the individual's perception of surroundings and his/her feeling of comfort. Most often feeling of discomfort accompanies the development of cataract in the dominant eye. It is not clear, however, if the dissatisfaction is related to the loss of visual acuity or to destruction of the function of binocular vision as well.

---

* papelba@tiger.cfi.lu.lv; fax 00371 7260796; Department of Optometry and Vision Science, University of Latvia, Kengaraga str 8., LV-1063, Riga, LATVIA

Advanced Optical Devices, Technologies, and Medical Applications, Janis Spigulis,
Janis Teteris, Maris Ozolinsh, Andrejs Lusis, Editors, Proceedings of SPIE Vol.5123 (2003)

Since stereovision is founded on binoculary obtained information the quality of stereovision may be essentially affected if unequal images are formed in the eyes. Formation of different images on retinas may be caused by anisometropia (aniseikonia), cataract, amblyopia, etc. It is possible to model and to study these situations by static mist, light filters, light scatterers, and by hypercorrection to suppress reaction of the retina. In a case of cataract the major loss of the image quality is a decrease of its contrast. The present study has concentrated on the development of a method for assessment of the change of stereovision acuity, if the contrast of one eye stimulus is varied – in a case of isochromatic (grayscale in our study) stimuli and in a case the stereosensation is obtained by stimuli of two different colors for the right and left eye, correspondingly.

2. METHOD AND STIMULI

For such studies it is necessary to perform the following tasks.

1. To realize the separation of vision channels – using spectacles with colored (red and blue for our case) filters or liquid crystal shutters synchronized with stimuli displaying on a computer screen.
2. To determine a spectrum of radiation of the PC monitor screen phosphors and transmission spectra of light filters used in the experiment.
3. To evaluate the screen luminance as a function of the RGB videosignal and to perform γ-correction.
4. To provide a software for projection of two colors (black-white and blue-red) random dot stereostimuli on the monitor screen to assess psychophysically the stereovision threshold at variation of the stimuli contrast by:
    a) successive approximations,
    b) method of constant stimulus.

The diagram of stereovision studies to determine effects of different factors on the stereovision contrast threshold is shown in Fig. 1. Part of these experiments have been accomplished while appraising the methods, the rest (showed by dashed lines) are in progress.

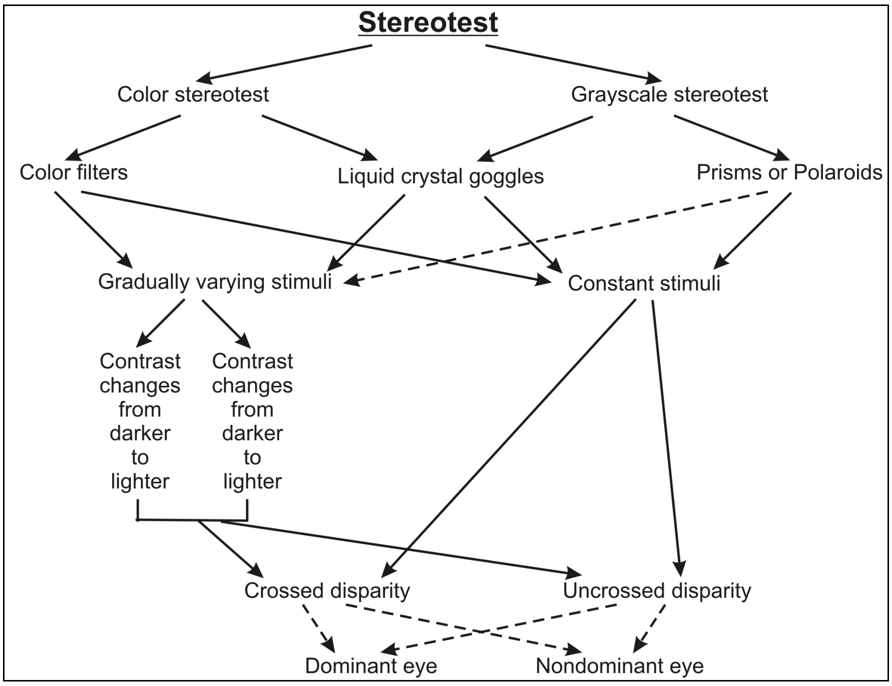


Figure 1: Scheme of studies (realized experiments marked with solid lines, experiments in progress with dashed lines).

We used *Visual Basic* software to simulate the random dot stereopair stimuli. Basically they represent either a circle or a square comprising black and white or blue and red random dots. In the central part of the stimuli a smaller circle (a segment of which is cut out) or a square is contoured. The contoured area also is hidden by random dots, however in one eye stimulus the marked out region is displaced to the right or to the left by a small distance – the stereoscopic parallax (Fig. 2). If an individual has developed stereovision he can see a three-dimensional object at the stimulus center after two non-identical figures are fused in his brain.

The contoured figure – the area of random dots at the center creating the stereosensation is shifted by one or more pixels aside. In this case both stimuli images are not identical, and the small difference between them is perceived in the brain. To the observer the figure shifted aside seems out of the monitor screen plane – to be pulled forward or pushed backward. The central figure of the image being shifted by one to five pixels to the left or to the right provides the stereopair with five crossed or uncrossed disparities. The corresponding stimuli stereoangle ω is calculated from equation (1):

$$w = \frac{PD \times \Delta l}{l^2}, \text{ and } \quad \Delta l = \frac{l \times y_p}{PD \pm y_p}, \tag{1}$$

where ω is the stereoangle (rad), y_p - the stereoparallax or displacement of out of plane images (m), l – the distance of the fixed point to eyes (m), PD – the pupil distance (m).

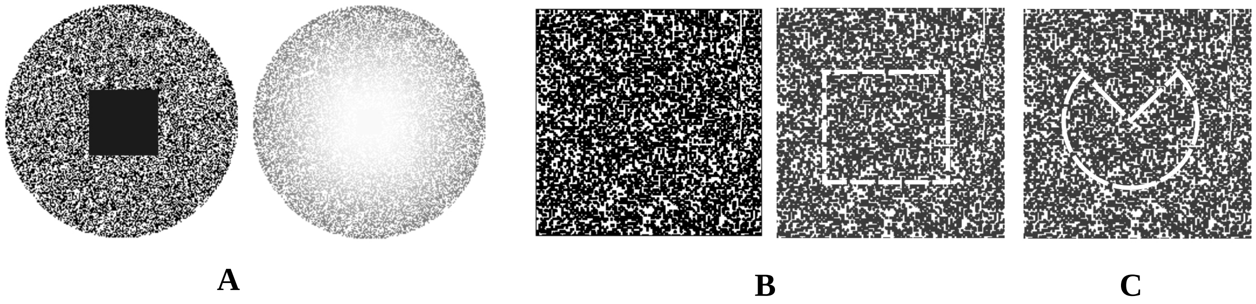


Figure 2: Pairs of random dot stereostimuli generated on PC screen: A – shows the grayscale stimuli with different contrast, B, C – stimuli for color stereotest (actually the areas of contoured figures consisting of similar random dots). When marked figures in center are shifted, in 3-D they seem to be pulled forward or pushed backward.

The contrast of the stimulus of one eye is maintained constant during the whole experiment – the random dots are either black or white, or black or red. In the RGB (red, green, blue) color system the black dots were formed with RGB values R = G = B = 0, white – as R = G = B = 255, and the red – as R = 255, G = B = 0. The red stimulus is chosen as the one with the constant and highest contrast for the reason that in a case of a cataract eye the intensity of scattered long-wave (red) radiation is the weakest compared to short-wave (blue) radiation. With account for the γ–correction of the display luminance ***I(RGB) = f(RGB)***, the contrast is defined as:

$$K(\%) = \frac{(I_{MAX} - I_{MIN})}{I_{MAX}} \times 100\% \tag{2}$$

The contrast of the stimulus for the other eye is continuously increased during the test either uniformly over the whole stimulus area or by Gaussian distribution (the lowest contrast in the central part). The test starts with a zero contrast – the small square or circle and surrounding random dots are white in case of the black and white stereotest, and all the image is uniformly blue $B = B_{max}$, and R = G = 0, in a case of the color stereotest. Compared with the black-and-white Freiburg stereotest[3] ours differs with an additional decrease of contrast in the center of the field of vision, so that the out of plane object contours are not seen before the stimuli images are merged.

3. TEST PROTOCOL

We used two psychometric methods to measure stereovision – of successive approximations and of constant stimuli. To find the values the stereoacuity threshold by successive approximations the contrast of the central figure in the random dot test is varied continuously from low to high (and also vice versa). The change of contrast is quit and the subject answer fixed when a spatial image is noticed. The respondent is forced to choose one of the answers: the object is pulled forward, pushed backward, detection the side of which the segment is cut out, or the stereoimage is absent. At the beginning of the test the subject stereosensation is absent since at low contrast levels the stereopairs on the screen do not create a stereoscopic image.

The other test program, using a constant stimuli method, randomly generates the stimuli of different contrast levels and different disparities to obtain the psychometric curves. They arouse the subject stereosensation immediately. The subject is forced to detect whether the spatial image is pulled forward, pushed backward, or is not seen. The right and wrong answers are stored for the further analysis of results.

Catch trials – occasions with “zero” parallax unable to cause stereopsis are included in both experiments. The flat images allow ascertaining whether or not guesses are made.

Before the tests the essence of the experiments is explained to subjects and operation of programs is demonstrated. At least five minutes are allowed for a training experiment. Subjects are seated at a distance of 60-180cm (±1cm) from the monitor and provided with liquid crystal shutters or color filter goggles. As soon as the stereosensation is experienced the subject takes part in test cycles. He specifies the corresponding forced choice. At a given distance 40 measurements are made in each cycle. The measurements taking about 60 minutes include twelve different disparities: six crossed and six uncrossed.

Two stages of the experiment may be distinguished: experiment comprises 40 cycles of different parallax values (crossed or uncrossed disparity) and 40 steps in the second stage changing contrast of the color. The test program allows setting the contrast increment corresponding to 1 to 6 relative RGB units (changing the corresponding **R**, **G** and/or **B** value by 1 to 6).

4. EXPERIMENT

Using the *OceanOptics S2000 Fiber Optics* spectrometer[4] transmission spectra of the light filters were measured as well the spectral distribution of the screen phosphors radiation to ensure that each of the subject eye would see a single color stimulus in the color stereotests (Fig. 3A and 3B).

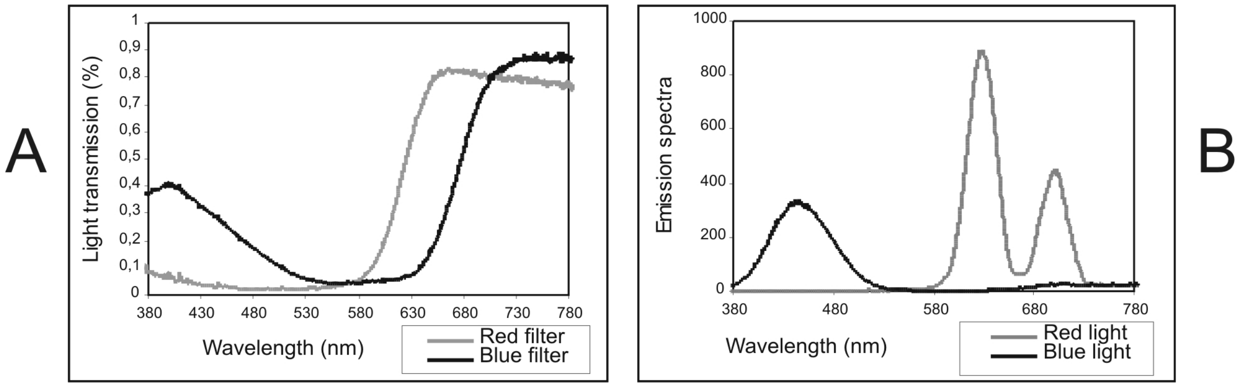


Figure 3: Used filters transmission spectra (A) and PC screen’s phosphors emission spectra (B).

In vision experiments using computer monitors it is necessary to evaluate the physical parameters of the stimuli. The screen brightness as function of the RGB video signal values (Fig. 4) was obtained by means of a digital luxmeter LUX

LD12Q-631. The photometric radiation characteristics of red, green, blue and composite white channels are shown in Fig. 4.

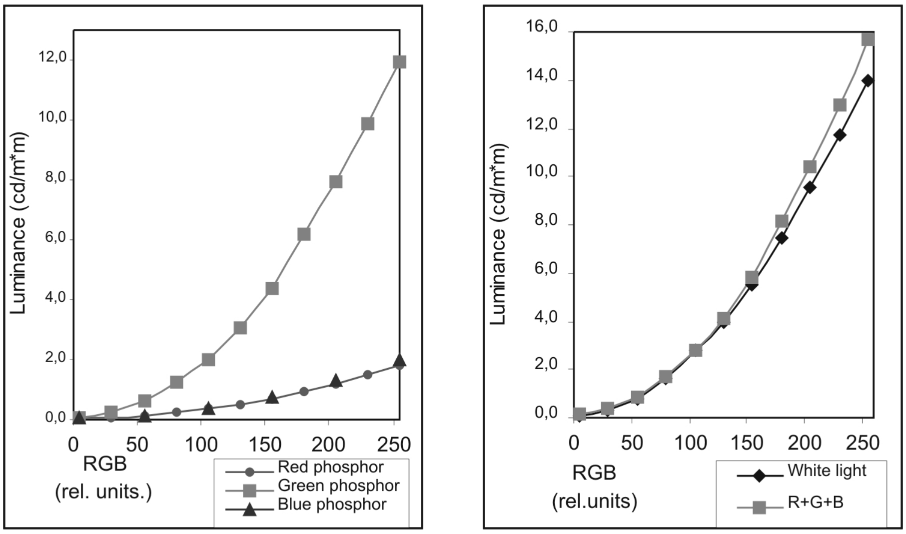


Figure 4: PC screen calibration’s curves. Vertical axis – screen luminance (cd/m^2) measured by a luxmeter attached to the screen. Horizontal axis – monitor video signal in RGB units. R+G+B – summation of three phosphors luminance.

In a case the colored spectacles are used, each eye distinguishes its own stimulus since color filters block the information assigned to the other eye. In a case of liquid crystal shutters an unnoticeable in time occlusion of each eye is switched at a frequency of 120 Hz. Thus, the stimulus is demonstrated to each eye 60 times per second[5, 6.] Since relaxation of the human visual system is slower as compared to the stimuli delay demonstrated to each eye, the stimuli are superimposed by the brain and perceived “simultaneously.“ As well light filters as the liquid crystal goggles decrease the stimuli luminance and, correspondingly, the retinal illuminance (measured composite transmission value of used LC (liquid crystal) shutters was[7] 21%).

Monitors used in experiments have 17 inch screens (0.27 mm/pix). Thus at the distance of 60 cm the stereostimuli are demonstrated to the subject at the minimum stereoangle of 92 arc sec. Using monitors with a resolution 0.28 mm/pix, the minimum stereoangle – 96 arc sec.

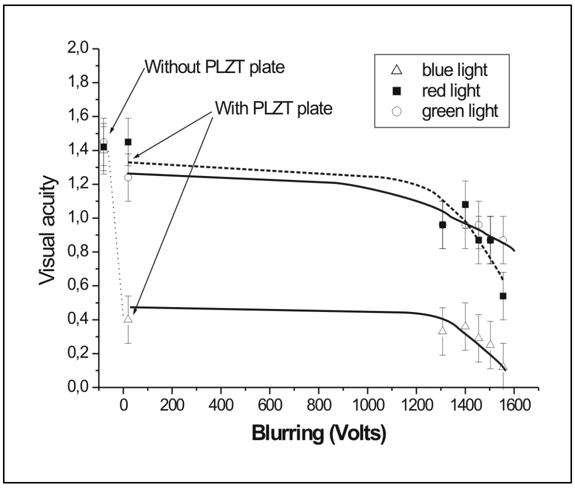


Figure 5: Before our experiments we detected visual acuity with colored Landolt C stimuli. Black figures were displayed on blue color screen (triangles), on red color screen (squares), and on green color screen (circles).

The blue image of the stereopair was chosen as a stimulus with changing contrast partially due to the greater scattering of the blue light present in a cataract case. We have used a test (similar to ***Freiburg Visual acuity test***[3], however by displaying Landolt C figures with only R, G or B monitor phosphors) to determine vision acuity for three primary colors. The dependence of visual acuity on the light scattering (caused by a special PLZT obstacle, allowing continuously increase the light scattering depending on the voltage applied to the obstacle[8]) is shown in Fig. 5.

5. RESULTS

The method has been appraised on 11 subjects, ages 20-24. All of them had binocular vision, good stereovision, corrected distant and near vision acuity *Visus* ≥ 1.0 (decimal).

Eight subjects had emmetropia. Three of subjects had second order myopia. The subjects used correction of vision during the experiments. The subjects' stereoacuity determined by the standard ***Titmus*** test was between 40 and 60 arc sec. The subjects had a pupil distance within the 57 to 68 mm limits. All had normal color vision.

The stereogram disparity is one of parameters affecting the contrast threshold of stereovision. The value of the stereoangle ω (1) calculated from the pupil distance ***PD*** and the distance of subject from the screen increases by 0.01 arc sec – at increase of the pupil distance ***PD*** by 1 mm (at displacement of images 1 pixel, when the operation distance is kept ***l*** being constant within the 45 to 120 cm limits). For the screen disparities –5 to +5 measured in pixels (under condition the horizontal and vertical scanning are calibrated correctly) the corresponding stereoangles for different operating distances are given in Table 1.

Table 1

Distance	Disparities									
	-5	-4	-3	-2	-1	1	2	3	4	5
45 cm	657"	523"	391"	259"	129"	128"	255"	380"	505"	628"
60 cm	493"	392"	293"	194"	97"	96"	191"	285"	378"	471"
1,2 m	246"	196"	146"	97"	48"	48"	95"	143"	189"	235"

Disparities in table are given in pixels on the PC screen (0.27 mm/pix). For negative screen disparities the central figure is perceived behind the basic plane (formation of uncrossed disparity). The given values are for subject's *PD*=62 mm.

By changing the pupil distance ***PD*** from 55 to 70 mm the corresponding change of the stereoangle is less than one ***arc sec*** within viewing distances between 60 and 180 cm. A higher error (3,7%) may be caused by the change of the dot size on the screen from 0.28 mm to 0.27 mm.

After determining of the set-up characteristics and preliminary tests, series of experiments were made to find the color stereovision threshold by variation of the contrast of one color (blue) stimulus, and to obtain the contrast threshold value at which the stimulus is still perceived as spatial the stereodisparity being fixed.

In the first test series the contrast of the stimulus was changed continuously – the threshold was determined by successive approximations the stimuli being separated by color filters or liquid crystal shutters. Results obtained for subject A at repeated tests are shown in Fig. 6.

The test program allowed determining the stereovision threshold changing the contrast of the blue stimulus. At higher disparities (5 pixels on the screen or 493 arc sec) the psychometric functions are steep (Fig. 7), and the threshold is determined more accurately. As the disparity decreases the psychometric curves are sloping gently and the obtained threshold values are less reliable.

In this region a linear relation between stereovision and the image contrast was assumed. It was analyzed in linear co-ordinates (the same relation correlates with a linear function in linear co-ordinates as well as with a power function in logarithmic co-ordinates).

After the first measurements it may be concluded that the software allows measuring the stereoangle and stereovision threshold if the image quality in one eye is varied. In the black and white test at the stereoangles 31-378 arc sec the stereosense threshold contrast values were $\Delta RGB/RGB_{max} = 0.1 - 0.2$ in RGB relative units. For the color stereotest the minimal blue contrast level was $\Delta RGB/RGB_{max} = 0.2 - 0.4$ in RGB relative units.

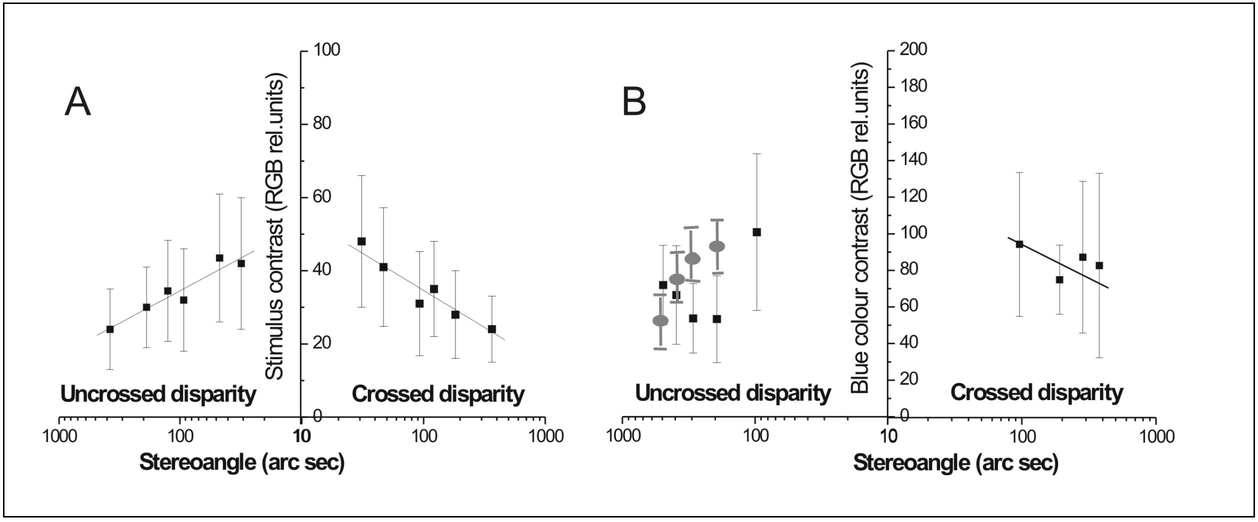


Figure 6: One eye stereostimuli contrast thresholds at different stereoangles were determined using stimuli successive approximation. A – grayscale stereotest results; B – red-blue stereotest results. Color contrast was measured in RGB relative units (color coding system units from 0 to 255). The gray circles (in B) show the blue color stimuli contrast thresholds that are appreciated with the constant stimuli method.

6. DISCUSSION

A lasting attention is required from subjects during experiments approaching the threshold gradually. Besides, due to binocular rivalry, – the dominating tint of the perceived binocularly color stimulus periodically varies. The “pumping” of colors is one of the factors causing a rather wide dispersion of results since the subject has difficulties to concentrate. With respect to dispersion, results obtained with constant circle stimulus are not much different from the square stimulus test with color filters.

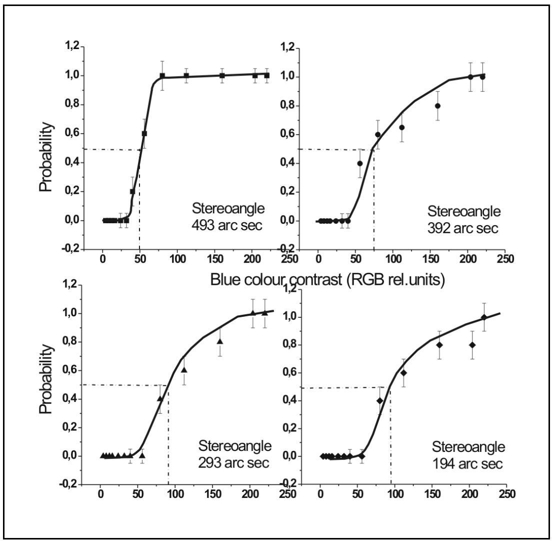


Figure 7: Psychometrical measurements with constant stimuli. Color contrast thresholds are shown with dashed lines.

Experiments with liquid crystal shutters to compare situations when both eyes are simultaneously subject to periodically interrupted stimulation in “opposite phases”[9,10]. Using liquid crystal shutters we wished to soften the effect of binocular rivalry on the process and results of the experiment, and we partly succeeded. The comfort of observing improved, and dispersion of results, compared with demonstration of similar stimuli separated by color filters, decreased (Fig. 6).

In most studies of effects of mono-ocular contrast on stereovision[11-14] relation between the magnitudes is described by a power function $y = a \times e^{b \times x}$ and data are analyzed in the logarithmic scale. Compared to recent studies[15, 16], we have considered a relatively narrow disparity interval.

Because of a rather wide dispersion the first results obtained with the color stereo test were not satisfying. In this case subject A had to choose between answers “seen” and “not seen” at observing the stereo image of a protruded square. Better results were obtained in a similar test with a hidden disk: the contrast of one color was varied continuously and the subject had to detect which side of the disk had a cut.

The stereovision software allowed finding the threshold value from measurements of psychophysical functions obtained by constant stimulus varying the contrast of one color stimulus. As the disparity decreases, the obtained threshold values are less reliable.

Results obtained with liquid crystal shutters are closer to what is expected: dispersion is reduced and the stereovision threshold appears at a lower contrast. Results obtained with a similar method in case of grayscale stimuli are less dispersed. However, with respect to stereoacuity, they are not much different from those obtained with blue-red stereostimuli separated by liquid crystal shutters.

Binocular rivalry at the color test causes an unpleasant feeling to the subject: the color of images varies between blue and red. The subject is unable to stand it longer than sixty minutes at a time. It is known from the retinal anatomy that the cones perceive colors only. The cones sensitive to long-wave radiation are stimulated by red light. The cones sensitive to the short-wave radiation respond to stimuli in the blue part of visible spectrum. Since there are much fewer cones sensitive to short-wave radiation in the retina area responsible for the central vision[17], it is supposed that fewer disparity fields creating the stereovision effect are involved in color tests. In case of grayscale tests, all disparity fields of the cones participate in stereovision. For that reason the stereovision threshold values found by means of grayscale stimuli of variable contrast are less dispersed (do not decrease) compared with results of color tests.

7. CONCLUSIONS

The method has been appraised and may be used to study the effects of contrast on the stereovision threshold. It is easier to work with constant stimuli in which case the obtained results are more accurate however these experiments take more time. The method will be used for modeling of more complicated situations of vision optics and to study the effects of external factors on the stereoacuity problems.

REFERENCES

1. B. Julesz, “Cooperative phenomena in binocular depth perception,” *Am. Sci.* **62**, pp. 32-43, 1974.
2. D. Regan, “Binocular vision” vol.9, In:*“Vision and visual dysfunction”*, Ed. J. R. Cronly-Dillon, Macmillan Press, London, 1991.
3. M. Bach, C. Schmitt, M. Kromeier, and G. Kommerell, “The Freiburg stereoacuity test: automatic measurement of stereo threshold,” *Graefe’s Arch. Clin. Exp. Ophthalmol.* **239**, pp. 562-566, 2001.
4. www.*OceanOptics*.com
5. Ji-eun Bahn, Yong-jin Choi, Jung-young Son, N. Kondratiev, V. Elkhov, Yu. N. Ovechkis, and Chan-sup Chung, “A device for diagnosis and treatment of impairments on binocular vision and stereopsis,” *Proc.SPIE “Stereoscopic Displays and Virtual Reality Systems VIII”*, Edit. A.J. Woods, M.T. Bolas, J.O. Merritt, and S.A. Benton, **4297**, pp.127-131, 2001.
6. S. W. Hatch and J. E. Richman, “Stereopsis testing without polarized glasses: a comparison study on five new stereoacuity tests,” *J. Am. Optom. Assoc.* **65**, pp. 637-641, 1994.

7. M. Ozolinsh, G. Papelba, and G. Andersson, “Liquid crystal goggles for vision science,” *Proc.SPIE “Optics for the Quality of Life”,* Edit. A. Consortini and G.C. Righini, **4829**, pp.1021-1022, 2002.
8. M. Ozolinsh, K. I. Daae, D. Bruenech, and I. Lacis, “Studies of time response of the vision binocularity by use of dynamic suppressing of retinal images,” *Proc.SPIE “1999 International Conference on Biomedical Optics”,* Edit. Q.M. Luo, B. Chance, L.H. Wang, and S.L. Jacques, **3863**, pp.521-525, 1999.
9. F. A. A. Kingdom and H. C. Li, E. J. MacAulay, “The role of chromatic contrast and luminance polarity in stereoscopic segmentation,” *Vision Res.* **41**, pp. 375-383, 2001.
10. D. R. Simmonsa and F. A. A. Kingdom, “Differences between stereopsis with isoluminant and isochromatic stimuli,” *J. Opt. Soc. Am. A.* **12**, pp. 2094-2104, 1995.
11. D. L. Halpern and R. R. Blake, “How contrast affects stereoacuity,” *Perception* **17**, pp. 438-495, 1988.
12. M. Rohaly and H. R. Wilson, “The effects of contrast on perceived depth and depth discrimination,” *Vision Res.* **39**, pp. 9-18, 1999.
13. T. Geib and C. Baumann, “Effect of luminance and contrast on stereoscopic acuity,” *Graefes Arch. Clin. Exp. Opthalmol.* **228**, pp. 310-315, 1990.
14. L. K. Cormack, S. B. Stevenson, and C. M. Schor, “Interocular correlation, luminance contrast and cyclopean processing,” *Vision Res.* **31**, pp. 2195-2207, 1991.
15. L. M. Wilcox and R. F. Hess, “When stereopsis does not improve with increasing contrast,” *Vision Res.* **38**, pp. 3671-3679, 1998.
16. L. K. Cormack, S. B. Stevenson, and D. L. Landers, “Interactions of spatial frequency and unequal monocular contrasts in stereopsis,” *Perception* **26**, pp. 1121-1136, 1997.
17. Roorda and D. R. Williams, “The arrangement of the three cone classes in the living human eye,” *Nature* **397**, pp. 520-522, 1999, www.opt.uh.edu/research/aroorda.

P III

Liquid crystal goggles for vision science applications

Maris Ozolinsh[a], Gunta Papelba[a], and Gunnar Andersson[b]
[a]Department of Optometry and vision science, University of Latvia (ozoma@latnet.lv)
[b]Chalmers TH, Göteborg, Sweden

ABSTRACT

Spectral and switching characteristics of two manufacturer liquid crystal goggles are tested, and a contrast ratio for the computer display phosphors wavelengths is determined. Goggles are used in vision science experiments for random dot stereo stimuli phase separation. The human stereovision acuity and threshold was studied for case, when one eye random dot stereo stimulus simulated on the display is continuously blurred or the stimulus contrast is decreased.

Keywords: liquid crystal goggles, vision science, stereovision.

1. INTRODUCTION

Eye image separation is needed in several vision science experiments, mainly studying human stereovision. Separation can be realized haploscopically, by color filters[1] or applying so called phase separation technique,[2, 3] when stimuli for both eyes are displayed periodically for a short while only for the left or right eye. In most cases stimuli are simulated by computer and showed on the PC screen. To realize the phase separation special shutters placed before eyes are used. Ferroelectric PLZT ceramics[4] goggles used formerly for this purpose[5] had sufficient transmission, an excellent contrast ratio and switching speed, however they needed high control voltages and were expensive. In the last years experiments have been carried out using liquid crystal (LC) goggles[2,6,7] - they have a lower switching speed, a lower contrast ratio. However due to the great popularity of various virtual reality, mass production of such glasses sharply has decreased their price.

LC are offered by companies distributing scientific instrumentation *Cambridge Research Systems Ltd.* (they offered also more sophisticated and more expensive ferroelectric LC goggles),[5] *Moscow Institute of Cinematography*[3] and by computer hardware companies as *"ELSA"*.[8] The proposed LC goggles have a number of figures given in specification, characterizing their performance in vision science, however a more detailed characterizing fails. Nowhere one can find LC of which class are used, that can help to predict the overall LC goggles performance. That is of a great interest when LC goggles are used for other vision care applications as studies and treatment of children ambliopia.[7,9]

The aim of the present paper is to report the spectral and switching characteristics for LC goggles of different origin used in a series of stereovision experiments.

2. RESULTS

Commercially availably nonferroelectric LC goggles of two origin (*Moscow Institute of Cinematography* (***IC***), and "***ELSA***") have been studied to determine the following characteristics: a) transmission switching characteristics applying "fast" (corresponding to the frame frequency 2x60 Hz) rectangular pulses and "slow" saw pulses; b) spectral transmission for ON and OFF states (using *"Ocean Optics"* spectrometer); c) contrast ratio for 3 fixed wavelengths

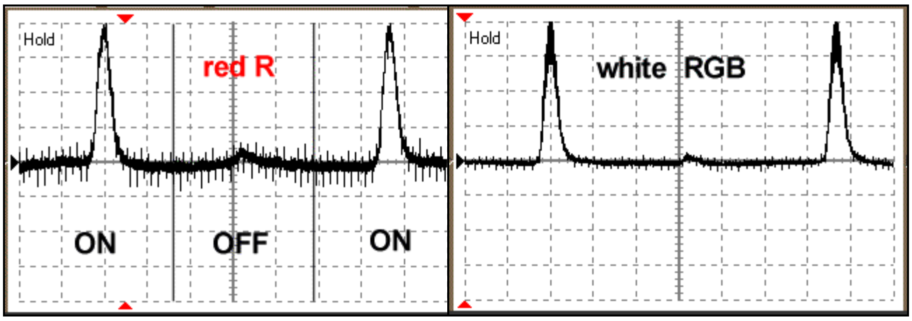


Fig.1. Transmission *vs.* time for different monitor phosphors: red (left), composite white (right). High frequency spikes have electric origin from a LCD control circuit.

19th Congress of the International Commission for Optics: Optics for the Quality of Life,
Giancarlo C. Righini, Anna Consortini, Editors, Proceedings of SPIE Vol.4829 (2003)

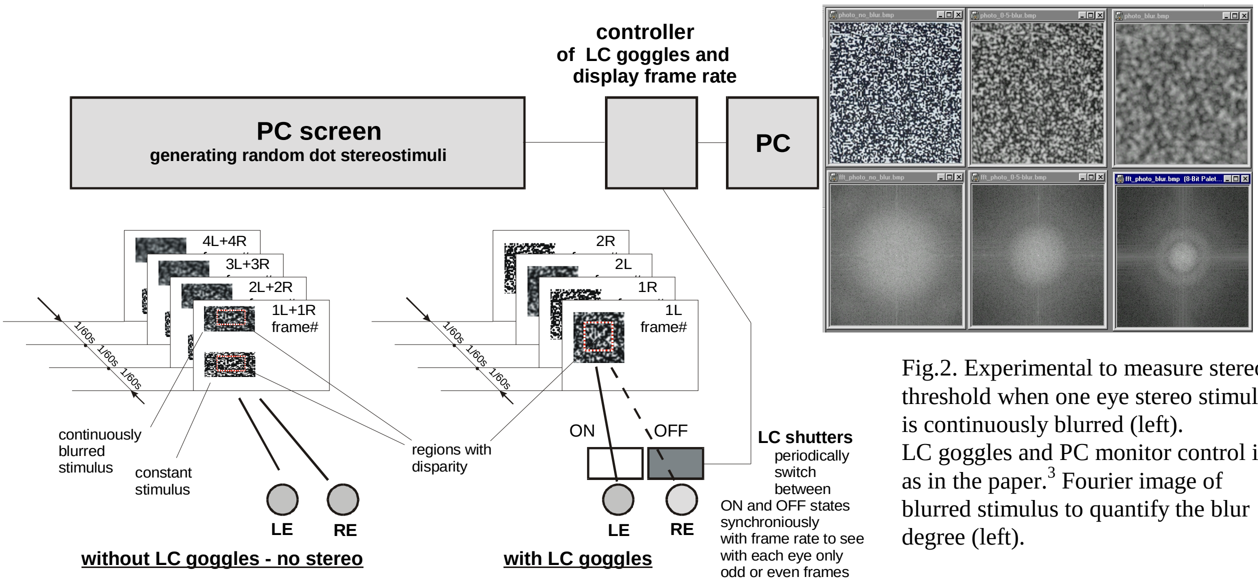


Fig.2. Experimental to measure stereo-threshold when one eye stereo stimulus is continuously blurred (left). LC goggles and PC monitor control is as in the paper.[3] Fourier image of blurred stimulus to quantify the blur degree (left).

(using as a source blue, green, and red LED, and PC screen R, G, and B phosphors). Fig.1 shows the time dependence of the relative transmittance of the LC goggles[3] within the spectral range of the monitor red phosphor - left, and of the composite white signal RGB (255,255,255) - right. The higher peaks correspond to the even frames when the LC goggles are switched ***ON***, the lower peaks to odd frames when goggles are switched ***OFF***. The overall contrast ratio for a composite white phosphor is 1:20, as compared with the lowest contrast ratio - 1:13 observed for the red phosphor. As the contrast ratio is lowering with the increase of the wavelength, one can proposed that the reason would be insufficient retardation of the LC cell by the applied voltage for switching ***OFF***. The measured composite transmission values were - 21% for ***IC*** goggles and 25% for ***ELSA*** goggles.

Using the mentioned goggles we have successfully developed some stereovision diagnostics techniques to simulate conditions when the optical quality of one eye is diminished due to refractive errors or by a lens cataract. These techniques allow to study stereo threshold dependence using gray random dot stereo stimuli when - a) either dominant or non-dominant eye stimulus is continuously blurred; or - b) the contrast is decreasing uniformly within the area of all stimuli, or corresponding to the Gaussian distribution. We have applied the LC goggles also to compare the stereo threshold in a similar situation when stereo sense is induced by two isoluminant monochromatic (red and blue) stimuli, and stimuli separation is realized: a) using the color filters, b) by phase separation with LC goggles. In a situation when the contrast of the stimulus for one eye is much less as for other eye, and due to the different stimulus color and therefore due to a bad correspondence of the eyes receptive fields, the binocular rivalry easy switches on. Simultaneously oscillating suppression of one eye image takes place. Phase separation using LC goggles allowed to diminish this effect and to obtain more unambiguous results. Fig.2 shows the experimental scheme to study the stereovision threshold and acuity when the stimulus of one eye is continuously blurred. Stimuli are generated on the PC screen. An adapter controls switching the LC goggles and doubling of the display frame rate.[3] Fourier analysis is used to measure the degree of stimulus blurring.

CONCLUSSIONS

Spectral and switching characteristics of two LC goggles are tested. As compared with the *Cambridge* ferroelectric LC goggles the studied goggles have a lower contrast ratio, however they still allow successfully to design diagnostic techniques to measure the stereo acuity if stimuli images on the both eyes retina have disbalanced quality.

REFERENCES

1. A.G. Bennett, R.B. Rabbetts, *Clinical visual optics* (Butterworths, London, 1984).
2. M. Bach , C. Schmitt, M. Kromeier, and G. Kommerell, Graefe's Arch. Clin. Exp. Ophthalmol., **239**, 562 (2001).

3. J.E. Bahn, Y.J. Choi, J.Y. Son, N.V. Kodratiev, V.A. Elkhov, Yu.N. Ovechkis, and C.S. Chung, Proc. SPIE, **4297**, 127 (2001).
4. M. Ozolinsh, A. Kapenieks, and A. Krumins, Ferroelectrics Lett., **21**, 111 (1984).
5. http://www.crsltd.com/catalog/stereo-goggles/
6. F.A.A. Kingdom and D.R. Simons, Vision Research, **36**, 1311 (1996).
7. V.A. Elkhov, Y. N. Ovechkis, L.A.Pautova, Y.Z.Rosenblum, O.S.Lev, and A.A.Pautov, Proc.SPIE, **4611** (in print).
8. http://www.elsa.com
9. S.Villani , Proc. IX Baltic Congr.of Ophthalmology&Optometry, Riga, R42 (1998).

P IV

PERCEPTION

VOLUME 31 SUPPLEMENT

25TH EUROPEAN CONFERENCE ON VISUAL PERCEPTION

GLASGOW, 25-29 AUGUST 2002

ABSTRACTS

25th European conference on visual perception (Glasgow, UK, 25.-29.August, 2002) ***"The effect of image blurring degree, luminance, and chromatic contrast in one eye on stereovision"*** G.Papelba, M.Ozolinsh, I.Cipane, and J.Petrova "Perception" Vol.31, supplement, p.156, 2002

The effect of image blurring degree, luminance, and chromatic contrast in one eye on stereovision

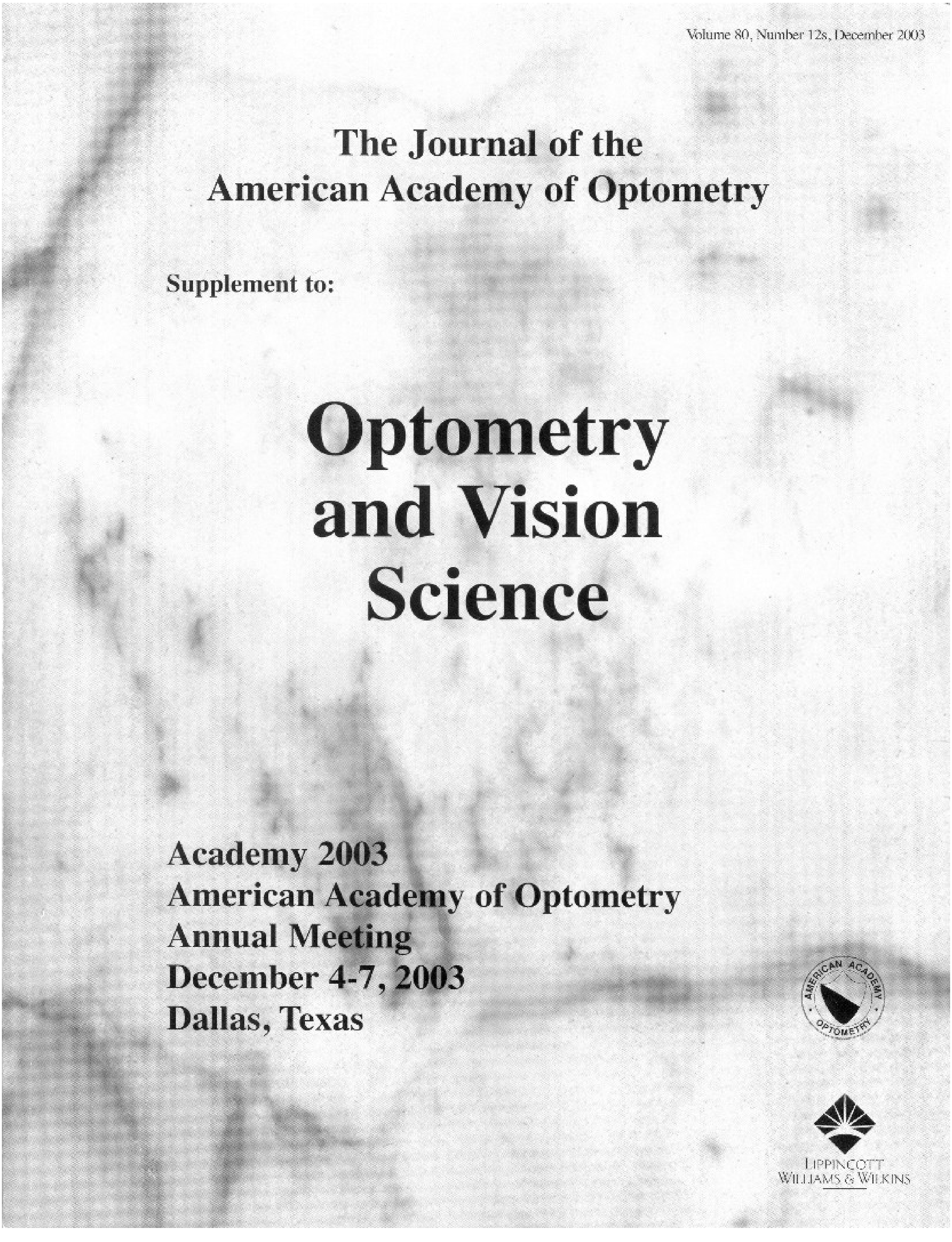
G.Papelba, M.Ozolinsh, I.Cipane, and J.Petrova
Department of Optometry and Vision Science
University of Latvia, Riga, LATVIA

The main goal of this investigation was studies of the stereovision threshold when the stimulus in one eye undergoes blurring, or when it loses intensity or colour contrast.

In our experiments we used red – blue (R/B) and black – white (B/W) random-dot pairs of stereostimuli generated on PC screen. Stimuli presented to the right eye and the left eye were separated: (a) haploscopically, with prisms, (b) with blue and red filters, and (c) by phase separation, with liquid-crystal shutters that were synchronised with the display frame rate. Two ways of stimulus imbalance were applied: optical blur, and B/W and R/B colour contrast change in the stimulus presented to one eye. The sequence of blurring images was generated according to the continuous Gaussian distribution (FFT analysis and cross-correlation were used as an objective measure of blur in parallel with the subjects' 'vision acuity', and testing against the Landolt C chart with the same degree of blurring). The subjects' task was to mark when they lost and regained stereopsis. In order to study the effect of contrast of the stimuli presented to one eye on stereoacuity. The B/W and R/B contrast of the stimuli presented to the dominant or nondominant eye stimuli was continuously changed – either uniformly or more in the centre than in peripheral area according to the Gaussian distribution.

The stereovision acuity decreased with the change of colour contrast and with blurring intensity. The minimal contrast level needed for depth perception was 6 % – 8% for R/B colours, and 2% – 6% for B/W if contrast in the stimulus presented to the other eye was held 100%. But the actual values depended on the size and type of disparity.

P V



Volume 80, Number 12s, December 2003

The Journal of the
American Academy of Optometry

Supplement to:

Optometry and Vision Science

Academy 2003
American Academy of Optometry
Annual Meeting
December 4-7, 2003
Dallas, Texas

Lippincott
Williams & Wilkins

Academy 2003 “The future in sight: Today’s Research, Tomorrow’s Practise” (Dallas, USA, December, 2003) ***“Clinical investigation of stereoacuity for patients having real or induced anisometropia and cataract”*** G.Krumina, M.Ozolinsh “Optometry and Vision Science” Vol.80, 12s, p.41, 2003

Clinical investigation of stereoacuity for patients having real or induced anisometropia and cataract

Gunta Krumina, Maris Ozolinsh
University of Latvia, Department of Optometry and Vision Science
Riga, LATVIA

Purpose: To determine how stereopsis is affected in conditions induced anisometropia and induced cataract and compared the data of patients with anisometropic amblyopia and with cataract.

Methods: The induced anisometropia was simulated with ophthalmic lenses and the induced cataract was simulated on computer screen. Stereovision was detected using the clinical TNO test, an established random dot test. We have tested 300 patients of age 13 to 79. In experiment stereopsis was measured in both crossed and uncrossed disparity. We have simulated blurring (as in cataract) with a special program and have tested the 12 subjects’ stereothreshold. We have measured the stereoacuity of 135 subjects with the condition of simulated anisometropia.

Results: We have observed that blurring effect in one eye in both situations (induced anisometropia and cataract) decreases stereoacuity. The condition of anisometropia decreases stereoacuity more then blurring in both eyes together. Approximately 40 percent from patients have difference between the stereoacuity of crossed and uncrossed disparity. Stereovision threshold are better for younger patients and for older patients without cataract.

Conclusion: Stereoacuity depends on visual acuity in one or in both eyes. Difference between visual acuity of the eyes decreases stereoacuity. Induced anisometropic amblyopia and cataract show approximately the same effect as in real eye conditions.

P VI

Accepted for publication in Ferroelectrics (2004)

Eye cataract simulation using polymer dispersed liquid crystal scattering obstacles

Maris Ozolinsh and Gunta Papelba
University of Latvia, Kengaraga 8, LV-1063 Riga, Latvia
ozoma@latnet.lv

Polymer dispersed liquid crystals with electrically induced variations of light scattering extent similar to that of transparent PLZT ceramics are used for simulation of different development stages of eye cataract. Wavelength dependencies of scattering are determined in the visible spectral range, and human visual response looking through the scattering obstacle to the onset of various spatial frequency stimuli is determined psychophysically and electrophysiologically in order to find correlation between the scattering extent, visual acuity and visual evoked potential VEP chromatic characteristics.

INTRODUCTION

Human's response to visual stimuli passes along a complicated and branched visual pathway (1). The first stage of it is an optical one – light goes through the transparent segments of the eye reaching well-arranged neural cells of the retina. Further the neural activity waves emerging from the retinal ganglion cells travel toward the brain visual cortex, where the binocularly originated information flows together and is processed. Here in visual cortex zones the sensation of the spatial and colour structured image is created, the feedback for the eye accommodation and vergence functions is provided, the higher-level sensation (recognition, depth sensation, binocular suppression and rivalry, *etc.*) are achieved. Some eye pathologies affect the visual response at the first stage – like as eye cataract. However a decreased quality of the eye retinal image influences all processes in the following pathway. In the case of eye cataract regions of the eye lens is filled with globules, protein coagulates fatty droplets and detritus with the refractive indices differing from surrounding lens tissues (2). That causes less or more remarkable light scattering in the eye and formation of opaque eye lens regions. Evaluation of the retinal image quality in various stages of cataract development; determination of the image quality loss impact to the further neural visual response; introducing objective measures correlating with the cataract development – these are the direct tasks in focus of investigators for early diagnostics and treatment of cataract. Same significant is to get a taste of the cataract stages knowing the actual retinal image, or some specific measures characterizing the stage of cataract. Such measures can be obtained as well in a subjective way psychophysically determining the overall response to the different spatial frequency and colour visual stimuli or objectively measuring the stimulus induced neural activity – so called visual evoked potentials VEP. Getting answers to these questions needs investigation of a great number of patients at different cataract development stages, thus very helpful is implementing of the cataract simulation for subjects with normal visual function.

Previously to simulate cataract we used obstacles from transparent PLZT ceramics with electrically controllable light scattering (3). The present paper reports on studies where artificial cataract is created using polymer dispersed liquid crystal (PDLC) cells. We had the following tasks of our studies.

1. To ensure conditions where changeable and sufficient light scattering would be obtained in a simple way using the voltage low enough for convenient PC control. To determine spectral and voltage characteristics of the efficiency of the light scattering of PDLC obstacles.
2. To determine characteristics of the optical transfer of the system: "PDLC obstacle - artificial eye – CCD" for objects of different spatial frequencies and colours.
3. To study the impact of the experimentally induced cataract on the overall visual acuity determined psychophysically and on VEP signals in order to introduce a measure characterizing the degree of light scattering of artificial cataract.

RESULTS AND DISCUSSION

PLDC cells used in experiments as eye obstacles consist of two glass plates with transparent ITO electrodes forming a 10 microns gap ***d*** of a composite polymer (PN393 *MerckKgaA*) with dispersed liquid crystal (BL035 *MerckKgaA*) droplets of micrometers size. Values of the refractive index were – for polymer n=1.473 (589nm) and for liquid crystal n_o=1.528 and n_e same as for polymer. Applying the AC voltage ***U*** aligns directors of liquid crystal droplets along the direction of the electric field ***E*** in the layer - light passing the cell does not meet refractive index variations, and no scattering takes place. At absence of an external influence droplets are randomly oriented causing local optical non-homogeneities and light scattering. Optical anisotropy created by droplets is high, and noticeable light scattering occurs passing through a PDLC layer (4,5). The scattered light ***Is*** is strongly wavelength dependent in visible spectral range. Fig.1 shows the spectral dependencies of attenuation of the directly transmitted light. As such obstacles oft are used

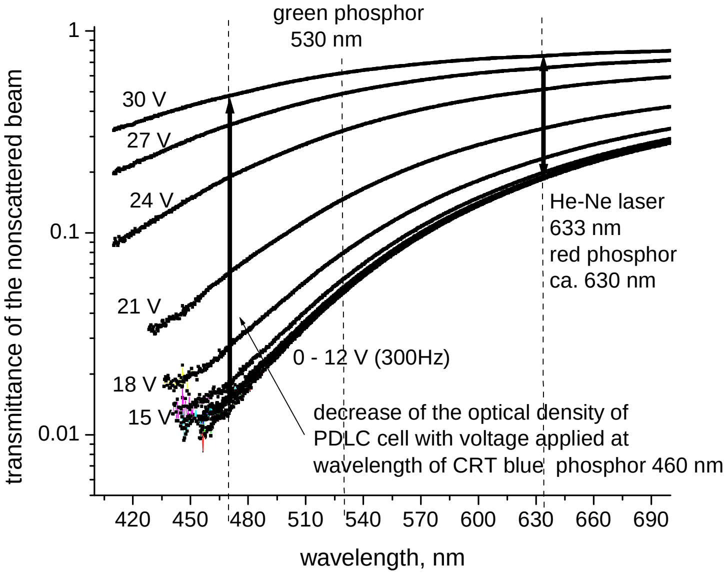


Figure 1. Spectral depedencies of transmittance of PDLC for directly transmitted light at different voltages applied to the cell. CRT phosphor emission maxima wavelength at 460 (blue), 530 (green) and 630 nm (red) are marked with dashed lines.

detecting visual stimuli demonstrated on colour CRT, the emission wavelengths of the red **R**, green **G** and blue **B** phosphors are depicted in the same graph. As compared with similar previous experiments when transparent PLZT ceramics were used for the electrically induced scattering, the effective scattering coefficient of PDLC

$m_s = \frac{1}{d}\ln\left(\frac{I_T}{I_0}\right)$ is much higher (up to 3x10^3 cm^{-1} for blue light), however the active PDLC layer thickness is much less than the scattering PLZT ceramics plate thickness 1.5mm. Scattering follows the Mie theory, the scattered light is still polarized for the case of polarized incident radiation (6). The degree of polarization *(* $p = \frac{I_{s_{par}} - I_{s_{per}}}{I_{s_{par}} + I_{s_{per}}}$, where of $I_{s_{par}}$ and $I_{s_{per}}$ are fractions of the scattered light with polarization parallel and perpendicular to polarization of the incident beam I_o) of the scattered light decreases with the extent of scattering. Figure 2 shows the scattering indicatrix of the red He-Ne laser beam (λ=633nm) passing through one PDLC cell in the absence of the electric field.

In previous studies Bueno *et al.* have proposed the loss of the light polarization as a criterion to evaluate the early eye cataract development (7). Such criterion is an objective and easy achievable one in the model conditions, however using this way in vivo diagnostics for human eye needs applying a complicated ellipsometric double-pass

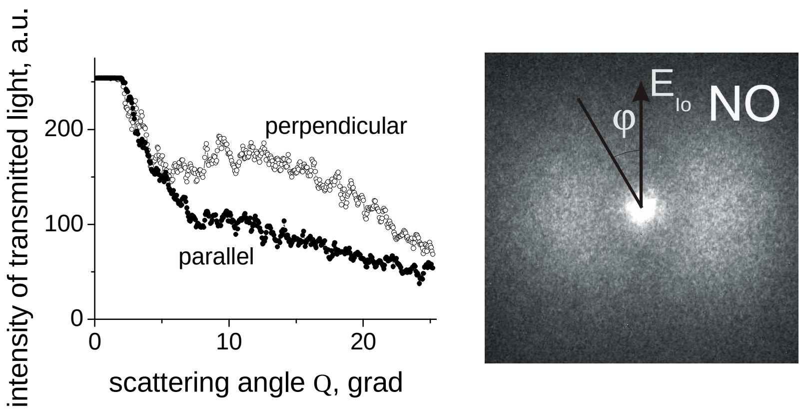


Figure 2. Intensity indicatrix of the transmitted light along directions j = 0 and j = 90^{o} according to the linear polarized incident light electrical field vector E_{Io} .

measuring technique (8). IN PDLC the scattering extent can be induced continuously and repeatable within voltage ***U***=0-30V, easy achievable by an appropriate PC control. Higher scattering can be ensured combining in series more than one PDLC cell. In order to find correlation of the scattering in the eye (or in model experiments using scattering obstacle in front of a normal eye) with parameters of the visual response one can take two ways - either psychophysical determination of the overall visual response; or measuring objectively neural activity caused by the onset of different visual stimuli. We have used both of these methods. Firstly, we have determined visual acuity for different colour stimuli having either various luminance or chromatic contrast. Secondly, we have measured visual evoked potentials VEP, demonstrating on the CRT screen different colour and size check pattern reversals.

Visual acuity at different degrees of the induced light scattering was determined from psychometric function using constant stimuli method. In this method subject was forced to choose one of four available orientation of the standard Landolt **C** demonstrated on PC screen in series with random size and orientation. Scattering has remarkable wavelength dependence, thus we used the following stimuli: high contrast black on white background, black-blue, white-yellow, and white-grey with luminance contrast similar to those of white-yellow stimuli. An eye of humans has a complicated structure of retinal photoreceptors and receptive fields. In the eye central part (*fovea*), responsible of the visual acuity, the density of red (long wavelength **L**) and green (middle - **M**) cones is much higher and intermediate distance much shorter as for blue (short - **S**) cones (9). Light scattering decreases the contrast of the retinal image comparing to the contrast of stimuli, besides, in greater extent

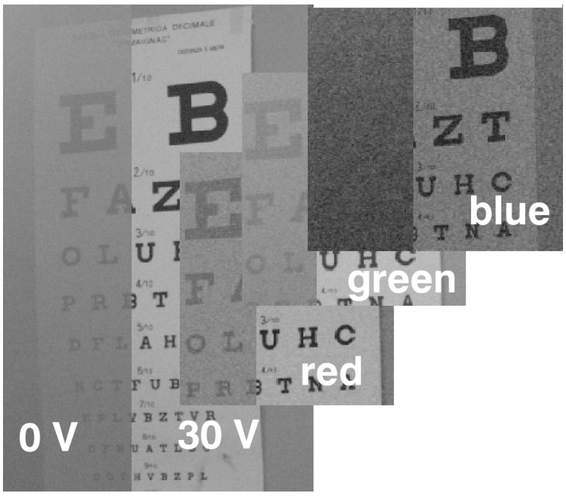


Figure 3. Snapshot of the visual acuity chart through PDLC scattering cell (left side – cell at scattering state **U** = 0V, right side – transparent state **U** = 30V). The image separated **R**,**G** and **B** channels are shown as excerpts at right.

for blue as for red. In Fig.3 a composition of snapshots of the visual acuity chart taken by CCD camera with focal length 18mm through the PDLC cell is depicted: the left side of the chart - with PDLC in the nonscattered state (**U**=30V); on the right - in the opaque state (**U**=0V). At the right, images splitting **R**, **G**, and **B** channels reveal the strong difference in the focal image contrasts for different colour stimuli.

Figure 4 shows results of subjects visual acuity obtained in a subjective way. The most drastic decrease of the visual acuity is observed for black-blue (display RGB values – *0,0,0* for black and – *0,0,255* for blue) and for white-yellow (*255,255,255* – for white and *255,255,0* – for yellow) Landolt **C** stimuli. In both of these cases the only colour channel

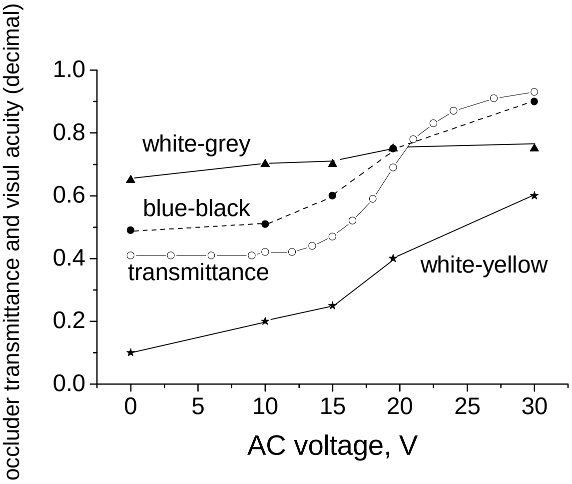


Figure 4. Occluder transmittance and visual acuity *vs.* voltage applied to PDLC cell. Stimuli: high contrast blue on black background, low contrast (10%) white on gray and white on yellow background.

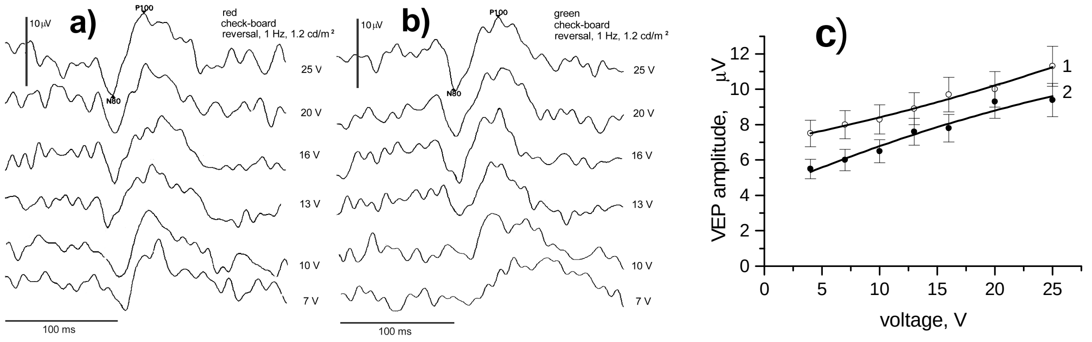


Figure 5. Visual evoked potentials, when red-black (a) and green-black (b) check board reversals are demonstrated (monocular) through PLDC cell with different AC voltage applied. Two maxima - negative N80 and positive P100 occur with delay *ca*. 80 and 100ms, respectively, after stimuli reversal. VEP amplitude (the potential difference between two maxima points) decreases at higher scattering extent (c) for red (curve 1) and green (curve 2) stimuli.

participating in stimuli recognition is the most scattered **B** channel. Comparing results for the white-yellow and white-grey stimuli with the same luminance contrast, a lower specific contribution of the **B** channel in white-grey case determined much less decrease of the visual acuity comparing to the white-yellow stimuli.

For the objective evaluation of the visual response to polychromatic stimuli when the induced light scattering is ensured by the PDLC cell we used modified *Tomey* EP-1000 visual evoked potential system. Potentials were recorded for coloured check-board reversals with frequency 1Hz and different check size, technique reported elsewhere (10). The flow of neural activity initiated by the reversal of such visual chess-board like stimuli responds as manifest oscillations of potential measured attaching an electrode at the scalp occipital area Oz, uppermost of them – minimum N80 (observable with a 80ms delay after reversal – latency) and maximum P100 (100ms latency). The latencies grow and the amplitude – the potential difference between N80 and P100 diminishes if visual stimuli initiate lower neural response. Figure 5 shows VEP waveforms for red-black and green-black check-board reversals (both of average luminance 1.2cd/m^2, and check size 0.3^o) for different voltages applied to the scattering PDLC obstacle.

One can see the diminishing of the amplitude by increasing the scattering, caused by lowering of the retinal image contrast. Using blue-black check-board diminishing of the VEP amplitude is more obvious, however the waveforms are harder to analyse, eventually due to the smaller and nonregular retinal density of the blue photoreceptors per image unit check size. The data of electrophysiological VEP diagnostics – decrease of the VEP values at calibrated stimuli luminance, and changes in amplitude ratio values r = VEPgreen/VEPred can be used as some objective parameters to characterize eye cataract in different development studies.

SUMMARY

Polymer dispersed liquid crystal cells have been successfully adapted to vision research experiments to simulate different development stages of artificial eye cataract. Using simulation experiments, various light scattering for different wavelength and different red **L**, green M and blue **S** cone sensitivity and retinal density allow to find criteria for evaluation of the cataract development.

The authors would like to thank A.Kozachenko and G.Ikaunieks for their essential help in development and setting up of experiments.

REFERENCES

1. Hart WM. Adler’s Physiology of the Eye, Mosby Year Book. Missouri: Mosby-Year Book; 1992.
2. Tuchin V. Tissue optics: light scattering methods and instruments for medical diagnosis. Bellingham: SPIE Press; 2000.
3. Ozolinsh M, Lacis I, Paeglis R, Sternberg A, Svanberg S, Andersson-Engels S, and Swartling J. Electrooptic PLZT Ceramics Devices for Vision Science Applications Ferroelectrics 2002; 273: 131-136.
4. Cox SJ, Reshetnyak VYu, and Sluckin TJ. Theory of dielectric and optical properties of PDLC films. Mol Crystals and Liquid Crystals 1998; 320: 301-320.
5. Cox SJ, Reshetnyak VYu, and Sluckin TJ. Effective Medium Theory of Light Scattering in PDLC films. J Phys D: Appl Phys 1998; 31: 1611-1625.
6. Born M, Wolf E. Principles of Optics. Cambridge: Cambridge University Press; 1999.
7. Bueno JM, Berrio E, Ozolinsh M, and Artal P. Degree of polarization as an objective tool to evaluate scattered light in the human eye. In: Friesem AA, Turunen J, eds. Selected papers 8, University of Joensuu. Joensuu: University of Joensuu; 2003: 128-129.
8. Bueno JM, Artal P. Double-pass imaging polarimetry in the human eye. Opt Lett 1999; 24:64-66.
9. Roorda A, Williams DR. The arrangement of the three cone classes in the living human eye. Nature 1999; 397: 520-522.
10. Porciatti V, Sartucci F. Normative data for onset to red-green and blue-yellow chromatic contrast. Clin Neurophys 1999; 110: 772-781.

P VII

Proceedings of the IV interregional seminar of Moscow Helmholtz Research Institute for Eye Diseases *"Ocular biomechanics 2004"*, Ed. by E.N.Iomdina, I.N.Koshitz, pp.82-89, 2004

STEREOVISION BY VISUAL STIMULUS OF DIFFERENT QUALITY

G.Krumina[1], M.Ozolinsh[1], V.A.Lyakhovetskii[2]

[1] University of Latvia, Department of Optometry and Vision Science, Latvia, gkrumina@cfi.lu.lv

[2] Saint-Petersburg Electrotechnical University, Saint-Petersburg, Russia

Abstract

Abstract. *Purpose: a) investigation of the stereovision formation for subjects with induced amblyopia (aniso-accommodation) or real amblyopia, and/or with uncorrected anisometropia; b) to compare estimated stereothresholds with actual data of subjects with visual acuity difference in both eyes.*

Method: In our experiments amblyopia and uncorrected anisometropia were induced by different blurring intensities with the defocusing method (positive and negative optical lenses were placed in front of the left and right eyes) and with similar stimuli generation on the computer screen. The program presents on the screen stereostimuli with small and large disparity sizes thus allowing to investigate fine and course stereovision, with continuously changes of the "bad seeing eye" retinal image quality.

Results: In induced cases of uncorrected anisometropia the stereothreshold increases more in hyperopic anisometropia as in myopic anisometropia. The stereothreshold values of induced amblyopia and/or of uncorrected anisometropia are close to the values of the stereothreshold of real conditions of amblyopia. Two subjects with a high degree of amblyopia (not seeing clinical TNO test) took participation in a collateral experiment. The new method gave chance them to see course stereovision images.

Conclusion: The stereothreshold changes depend on the quality of images in both eyes. By greater differences in perceived images the stereothreshold is higher, and stereovision couldn't develop ever or it can be destroyed.

Ke ywords: *stereoacuity, stereoangle, liquid crystal goggles, anisometropia, blurring, random-dot stereotest.*

Introduction

Binocular vision consists of three levels – bifoveal fixation, fusion and the highest level – stereovision. The main function of stereovision is to assist in subjects' orientation, to help in an accurate determination of distances between objects in space. It is an essential aid for drivers in safe manoeuvring, for surgeons, for sportsmen – basketball players, golf players and others. At the same time subjects lacking stereovision have found different other ways of monocular accommodation facilitating to adapt in surroundings.

Stereovision cannot develop without bifoveal fixation and fusion. The presence of binocular vision at levels of bifoveal fixation and fusion however does not assure the presence stereovision. The positive test of stereovision at the same time verifies the full binocular vision and further independent tests of bifoveal fixation and fusion are needless. Assessing binocular vision in a clinic uses different stereo tests.

Doctor devotes usually no more than 1-2 minutes to assess stereovision. If the subject does not recognize various stereo stimuli during this period of time the test is interrupted. In clinics such procedure is considered to be sufficient to prove the presence or absence of stereovision. Actually the negative test according to such procedure leaves over the answer. Most likely subjects do have stereovision that can be revealed under special conditions helping them to identify stereostimuli.

Goodwin and Romano[1], and Lovasik and Szymkiw[2] have estimated stereothreshold changes in cycloplegia for different eye pupil sizes and object illumination, when conditions of aniseikonia, and blurring condition were induced for one or both eyes with optical lenses. Authors have concluded that stereothreshold changes are greater if one only eye is blurred. In these experiments the visual acuity was chosen as a criterion to interpret stereovision formation at different right and left eye conditions.

The purpose of our investigation was to create and to develop a stereotest with a wide range of disparity from small stereoangle values below the stereoacuity level up to high (1000 and more arc sec) disparity values, together with facilities to simulate worse seeing conditions for the better seeing (dominant or non-amblyopic) eye. Such method gives a choice to practise stereovision and to improve stereoacuity as well to investigate stereovision for subjects with amblyopia and cataract as well for subjects without any vision deficiency however in induced amblyopia and cataract conditions.

People with a high degree of amblyopia have vision acuity less than 0.2 in the eye with low vision. This eye has produced a blurred image since childhood. Thus in the absence of stereovision it is not known, either stereovision is not developed by the blurred image on the amblyopic eye retina[1,3] or that is a result of other eventually neural factors. Perhaps in order to facilitate recognition of the stereostimuli it is valuable to create more balanced neural response of amblyopic and non-amblyopic eyes making both the stimuli similarly blurred – for non-amblyopic eye in a forced manner.

The present research is devoted to characterize stereovision in cases when one eye retinal image or neural response are less or more inefficient as compared with other eye response. The main task of our research was studies of the formation of stereovision without cycloplegia (blocking the accommodation process) in order to investigate the difference between myopic and hyperopic anisometropia and degree of amblyopia on the stereothreshold: a) for patients with eye anisometropia, and b) for patients with induced anisometropia using monocular blurring of retinal image with positive and negative lenses, or blurring of one eye stimuli on PC monitor. An additional task was studies of the test methods possibilities to teach and train subjects with amblyopia and cataract skills to recognize and to see random-dot stereotests.

Method

In the first stage of our experiments induced anisometropic conditions were simulated in real conditions (without accommodation) using monocular overcorrection with positive and negative lenses. The highest degree of aniseikonia produced by lenses was up to 7%. 125 clinic patients with different types of ametropia age of 14 to 79 served as subjects. As stimuli we used the standard TNO stereotest at 40 cm distance provided for detection of stereoacuity within 15 to 800 arc sec ranges.

A number of these subjects were involved in the next stage of studies, when stereostimuli were presented on the flat computer screen. They were, at first, ten subjects with a good visual acuity (*visus* 1.0); secondly, two subjects with a high degree of amblyopia in one eye (*visus* 0.1 without and *visus* 0.2 with correction). Amblyopia had developed for both subjects due to the great difference between both eyes refraction (2.5-3.0 diopters). Both subjects had a hypermetropic refraction of amblyopic eyes. The subjects have had the amblyopic treatment in childhood without any positive results, and the vision acuity of the amblyopic eye has not improved. Binocular vision using *Schober* and *Worth* tests was determined as a weakly pronounced. An attempt to determine stereovision for theses two patients with a clinical TNO test was not successful.

For ten subjects having good stereovision we applied blurring for one eye as a result of induced anisometropia a) by optical lenses, b) by eye visual stimuli on computer screen.

In our stereo test the random-dot stereopair was demonstrated on the computer screen. The left and right eye stereo stimuli were separated using liquid crystal goggles synchronized with the even and odd PC screen frame sequence. It gives a possibility to demonstrate a clear stimulus for the amblyopic eye that project a blurred image to our brain. For the eye with good vision the stimulus is blurred already on the PC screen. Thus stimuli, when they reach the brain, are equally blurred and eventually they might create at least crude stereovision for an amblyopic subject. The method is designed with a computer program using special video cards ensuring the formation of stereo pictures with special liquid crystal stereo goggles. In case of amblyopia program can fix the time needed to form a stereo picture.

To learn to see stereostimuli and formation of stereovision in case of amblyopia takes much time. It is necessary to find the optimum blur in one or both eyes, as well to perform the stereotest at the optimum disparity value. The first step is when using additional density filters for the non-amblyopic eye in combination with blurring stereovision at last is acquired. The next step is to check either subject recognize stereostimuli in the clinical TNO test also based on the random-dot method. As extra density colour filters we used goggles with transparency for the eye with good vision up to three times less as compared with colour filter for amblyopic eye.

Results

Oft that is hard or even impossible to determine stereovision for people with far progressed cataract or amblyopia with standard tests used in clinics. The stimuli stereoangle of these clinical tests lies within 15 – 500 arc second range.

The technique used in our experiments allows to assess both the coarse and fine stereovision both for crossed and uncrossed disparity. Random-dot stereograms exclude any indications where the stereo picture is going to form when looking only with one eye. It is clarified that 30% people may not have stereovision at one disparity, however they have it at the opposite disparity[4]. However, all clinical stereo tests are used at crossed disparity and stereovision at uncrossed disparity is not checked at all.

Considering the obtained results for more than one hundred subjects on the influence of artificial amblyopia on the quality of stereovision one can see a pronounced diminishing of the stereoacuity on difference in the both eye visual acuity (close to linear in the reference frame log(stereothreshold) *vs.* difference in visual acuity). For the visual acuity difference $\Delta VS=0.8$ (decimal) the stereothreshold value is 360±50 arc sec. For patients with real amblyopia and cataract the stereothreshold value at $\Delta VS=0.8$ equals to 330±90 arc sec (see Fig.1 A and B).

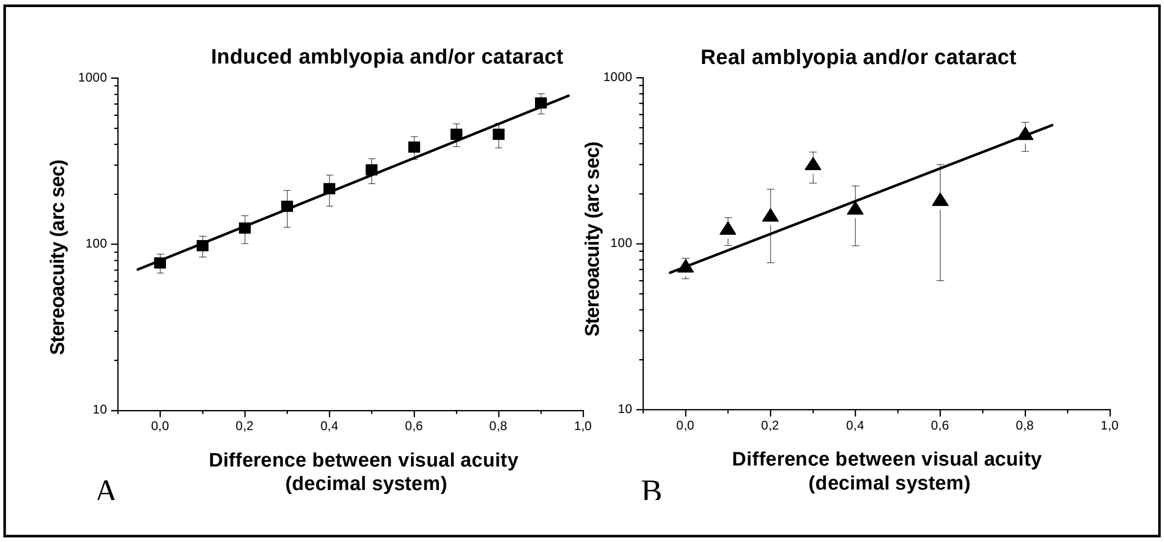


Figure 1 Dependence of stereothreshold – minimum resolved stereodisparity in arc sec on difference between the left and right eye visual acuities: a) for subjects without eye pathologies when amblyopia was induced by blurring one eye retinal image using positive and negative lenses, b) for subjects with real amblyopia and cataract.

It means that in cases when the difference of the left and right eye visual acuity is very big we could predict that an approximate threshold of stereovision is comparatively high and tests and trainings of stereovision is reasonable to begin at big stereoangles. For such patient having the primary binocular level determined by *Schober* and *Worth* tests we would still predict the presence of the coarse stereovision. At induced anisometropia we have observed tendency that the decrease of stereoacuity depends on the eye refraction (hypermetropia, myopia). If there is emmetropia in one eye and hypermetropia in another then for the difference of eye refraction 2.5 diopters the threshold of stereo vision is very low – about

530±35 arc sec. Contrary, if the individual has emmetropia in one eye and myopia in another, then the stereo threshold at same 2.5 diopters refraction difference equals to 214±21 arc sec (see Figure 2 A).

Data from the overcorrection of one eye are presented in a semilog graph. Averaged data lie along a straight-line for positive as well for negative overcorrection with a slope coefficient *k* that can be considered as a sensitivity coefficient of stereovision. It should be mentioned that all measurements are done for subjects in the longer time interval. Within it subject's vision can be influenced by many factors the most essential of which is feeling well and the state of one's health. That leads to data deviations different to each of individuals.

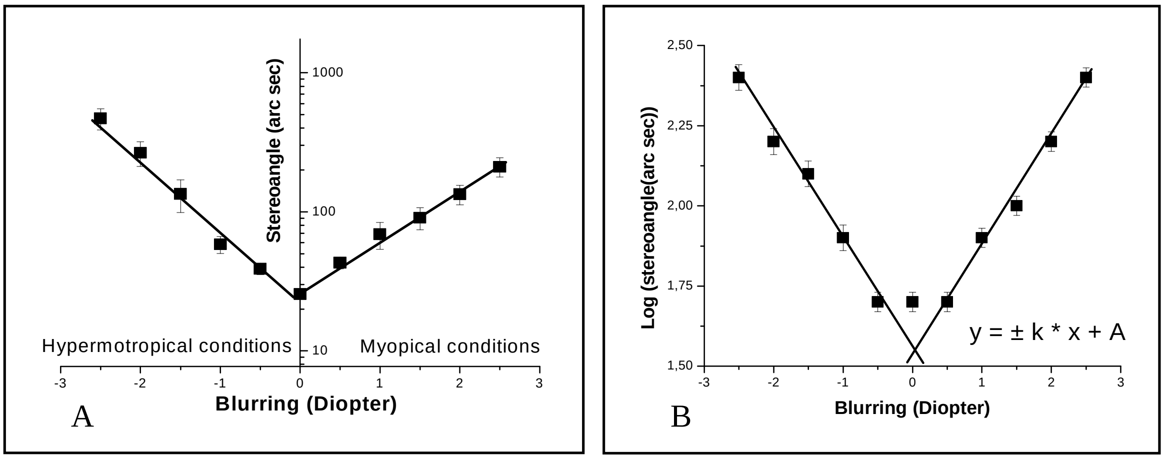


Figure 2 Stereothreshold dependences on induced anisometropia by positive lenses (myopic conditions) and by negative lenses (hypermetropic conditions) placed in front of one eye. Left graph (A) – experimental values (averaged for 125 subjects); right graph (B) – schema of the calculation of stereovision sensitivity coefficient (average value 0,34 ± 0,18 log(stereo angle)/D) – ratio of log(stereothreshold) and monocular overcorrection; k=Δlog(stereothreshold[arc sec]/ΔD[diopter].

They can vary within days and even hours of the current test. However we are sure about one conclusion – the relationship between the stereovision minimum angle and the optical overcorrection is a linear one in the interval from -2.50 to +2.50 D.

Extrapolation of two straight lines gives an intersection point. The point found in such way determines the expected minimal stereoscopic angle. Some authors think that the highest stereoacuity is 5-10 arc sec and that it is possible to improve the minimal stereoscopic angle with a help of special exercises. How much it is possible to improve for each subject we don't know. However we have observed that manipulating with the optical overcorrection in ca. 50% of cases a better stereoacuity was obtained using a small overcorrection as compared to stereoacuity without overcorrection, (i.e. at the initial position). The ordinate of the intersection point shows at which overcorrection diopters we can expect maximum improvement if stereovision is determined by a TNO test (see Fig.2 B). Under induced conditions of cataract it is found that stereo acuity decreases both in the case of crossed and uncrossed disparity if the vision acuity decreases in one eye (see Figure 3).

We have estimated the monocular visual acuity by positive and negative overcorrection for presbyops - subjects without the accommodation facility. That is not possible for young subjects, because by added negative lenses they can use accommodation thus compensating overcorrection and seeing the image clear.

Figure 4 A shows the estimated visual acuity for presbyops with different added optical lenses in the overcorrection range from –2.5 D to +2.5 D. One can see in the diagrams that with adding negative overcorrection lenses the visual acuity decreased more than in the case of positive overcorrection. In its turn Figure 4 B shows the relationship between the visual acuity and the stereothreshold values, both detected applying additional optical lenses to simulate hyperopic and myopic anisometropia.

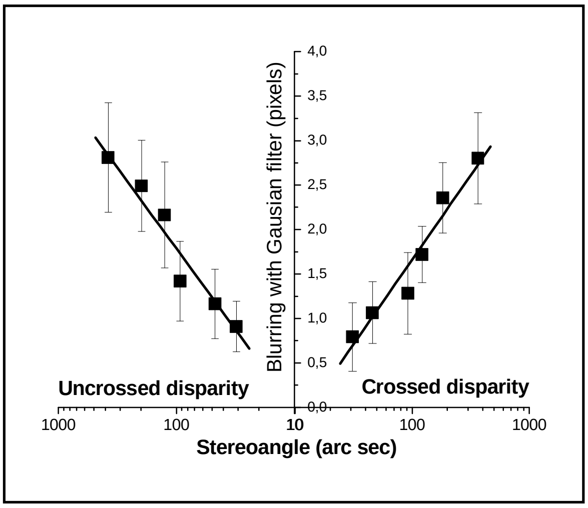


Figure 3 Relationship between stereothreshold and stereodisparity values when one of the stereopair image demonstrated on PC screen is blurred using Gauss filter for two kinds of stereodisparities – crossed (right side of graph) and uncrossed (left side of the graph) disparities.

In standard clinical tests stereoimages are separated using colour filters or polarizators, and both eyes perceive images simultaneously**.** In such case the eye that sees a clear image becomes the leading eye. The blurred picture from the eye not seeing well can be suppressed[3] due to competition of the brain activities. Due to that the images from the both eyes are not fussed together, and the individual does not see the stereo tests.

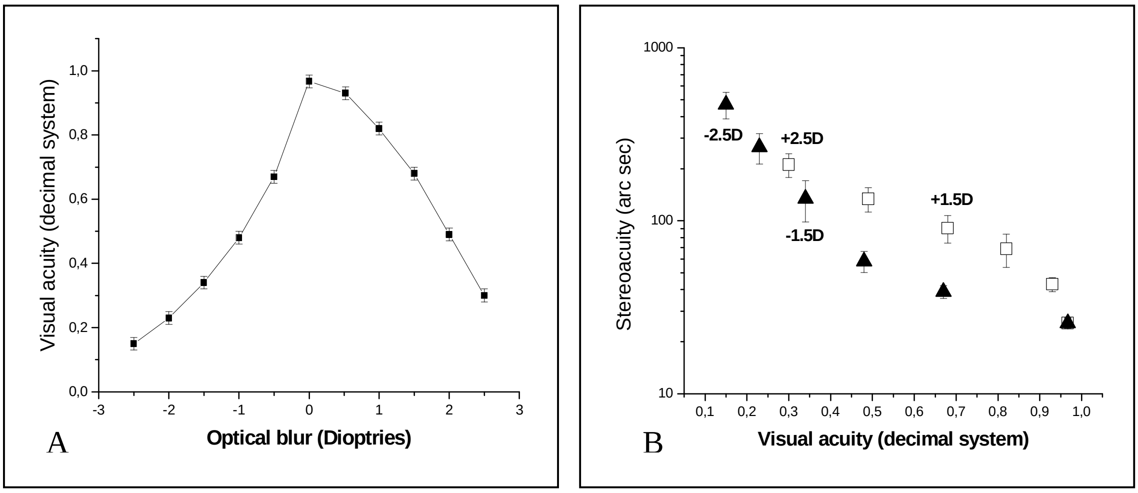


Figure 4 Dependences of visual acuity on optical blur using monocular overcorrection (A) and stereothreshold on visual acuity of the blurred seeing eye (B). In the monocular overcorrection with negative lenses the slope acuity/blur is steeper as compared with overcorrection with positive lenses. In the right graph (B) stereothreshold was estimated with negative lenses (closed triangle) and positive lenses (open square).

In order to diminish the great eye dominance of amblyopic subjects we have used stereostimuli phase separation. It was accomplished alternately switching stimuli for the left and the right eye with the liquid crystal goggles – controllable light shutters switching in time with the display frame rate. The even PC frame sequence displays stimuli for stimulating the right eye and the uneven sequence – for stimulating the left eye. The alteration of sequences is sequential and quick in order not to destroy the perception mechanism of binocular vision.

Such stereoimage separating forms compulsory conditions so that both images – the clear and the blurred one reach the brain and possibly are not suppressed at once.

The procedure of teaching subjects with amblyopia to recognize stereotest images had several stages. At first subjects looked at these tests for a long time (40-60 seconds) trying to catch sight of the hidden depth object, the initial stereodisparity of the random-dot stimuli was within the range of 1000-2000 arc sec.

The following actions was taken in further steps: a) the stimulus for the well seeing eye was blurred, and subjects should to look for a long time at the stereotest; b) the stimuli for both eyes were blurred. When the stereo sense was eventually provoked, it was checked once again with the clinical TNO test. In this case the stimulus of the well seeing eye was deliberately suppressed so helping to avoid suppressing the amblyopic eye image. Bringing the test plates closer to the eyes enlarged the stereo angle, and finally the stereovision was aroused also with the TNO test. Afterwards the plates were held at the correct distance and the stereo acuity was assessed repeatedly. The obtained data are given in Table 1.

1.Table

	Stereovision with TNO test before experiment	Stereovision with new method	Stereovision with TNO test after the experiment
Subject 1	Not found	Forms in 5- 10 minutes	Sees 480”-240”
Subject 2	Not found	Forms in 5- 10 minutes	Sees 480”

Besides the steps of the procedure outlined above, the well seeing eye was deliberately covered with a lens blurring the picture. Another way taken in experiments was placing in the front of the better seeing eye a filter reducing the stimulus luminance much below the bad seeing eye stimulus. Such action diminished neural activity flowing out of the non-amblyopic eye, and similarly the dominance of this eye could be depressed for the reasons described above.

Discussion

During tests of the binocular vision for individuals who have a reduced visual acuity, the lack of stereovision very often is – diagnosed because it is not found using the clinical tests. Rutstein and Corliss[5] have concluded that the critical level of amblyopia for hyperopic anisometropia was 2.72 D and for myopic anisometropia was 6.21 D.

That means that the retina of the more ametropic eye in hyperopic anisometropia rarely receives a clear image, and however in the case of mild myopic anisometropia the more myopic eye can sometimes be used for near work. By standard clinical tests assessment of stereovision lasts no longer than 1-2 minutes. In the case of amblyopia this time mostly is not enough to make sure conclusions about the presence of stereovision. Ophthalmologists and optometrists prescribe a number of exercises for treatments of amblyopia in childhood. Also liquid crystal goggles are applied in vision practice for children with disturbances of binocular vision to stabilize and develop it[6]. If no practicing was done in childhood or it was ineffective, the vision acuity does not improve and remains unchanged for the rest of life.

One aim of our research was to investigate the influence of induced anisometropia on the quality of stereovision and to assess the prognosis to obtain – the coarse stereovision at high degrees of anisometropic amblyopia. Further we liked to create conditions to facilitate provoking of stereovision for individuals with amblyopia, and for those failed in diagnosis of stereovision with the clinical stereo tests.

Possibly also amblyopic subjects have stereovision, however they yet cannot give an affirmative answer looking on stereostimuli of the standard clinical tests due to the lack of experience and the restricted test time.

A special test[7] developed by us displaying random-dot stereostimuli on a computer screen, first of all allowed to produce a blurred stimulus also for the well seeing eye. Thus two blurred pictures of the same size reach the brain, and perhaps they are perceived in our brain as more similar thus diminishing one eye dominance. Using the liquid crystal shutters it is possible to stimulate the amblyopic eye at least for some moment, i.e. eye alone sees the stimulus and this information reach the primary vision cortex

Such conditions could make the brain to receive both eye images and to fuse them without suppression to form stereo sensation. A patient with amblyopia needs a longer time to “control” the sensor fusion mechanism in the process of stereovision, however thereafter he is capable to see the hidden depth image. Going on with looking at the stereo stimuli even with great disparities subjects needed long adaptation time (at least 20-30 seconds) until they saw the stereo image. A difference in the ease to recognize stereostimuli exists also for normal subjects. Thus time needed to see crossed disparity images is shorter as compared with uncrossed disparity stimuli[8]. Authors have mentioned also that comparing stereoacuity for such cases, the acuity by crossed disparity was better.

After the amblyopic patients for the first time affirmed their depth sense while applying the random-dot stereotest as described above, the stereovision was assessed also by clinical tests. To ease at the beginning the clinical stereotest – we held the TNO test much closer to eyes than it is prescribed (increasing the disparity angles). Besides the longer adaptation period than during the clinical vision test was needed. Usually stereotests are used to determine amblyopia, anisometropia or aniseikonia that can destroy the binocular functions of vision, stereopsis included.

However methods to state and unambiguously to distinguish the destroying factors of optical and neural perception have not been found and worked out yet. The researchers try to fix criteria for aniseikonia[2] destroying stereovision and decreasing stereoacuity. It is necessary to establish relationships between degrees of monocular and binocular amblyopia and the change in the quality of stereovision[2,3,5,9]. Some authors have found that good visual acuity only does not prove the existence of stereopsis or the quality of stereovision[1].

We have observed in our practice cases when vision acuity in one eye was decreased for three or four decimal vision acuity lines together with good vision acuity for another eye, however subjects still had good stereoscopic vision. In opposite, in 0.8% cases out of 793 optical patients we found good vision acuity and binocular vision but no stereoscopic vision was tested with standard clinical tests.

Other authors[2,9,10] concluded the influence of relative monocular blurring (loss of monocular visual acuity) on stereovision. The authors represent different outlooks, presented experimental data differs – eventually as a result of different research methods and initial conditions.

It is revealed in quantitative measurements that the stereothreshold increase inducing aniseikonia and blurring measured by the Titmus test is almost twice greater as compared with the increase obtained at same conditions by the Randot test[2]. Thus authors want to suggest advantages of the Titmus test in clinics to diagnose more precisely the pathologies of binocular vision high degree aniseikonia, refractive amblyopia and anisometropia based on difference in retinal image sizes. The Titmus test is also easier perceived and understood by children, and it is more sensitive to the disturbances of binocularity.

Based on our research we could conclude that the stereothreshold is higher (i.e., stereoacuity is worse) in uncorrected hypermetropic anisometropia compared to uncorrected myopic anisometropia cases. It is known from literature that subjects with hypermetropic anisometropia more often have amblyopia then subjects with myopic anisometropia[5]. We observed that stereothreshold stereoacuity increased in induced cataract and/or amblyopia if the quality of visual stimuli has been declined for the dominant eye.

In our studies we have established that the stereoacuity could be improved for amblyopic subjects with adding for the good eye extra filters with three times less light transparency. Using colour filters with the equal transparency supplied with the standard TNO stereotest for real amblyopic subjects stereothreshold is higher.

Conclusion

That can be shown that the standard clinical stereotests carried out in the restricted time can fail to diagnose the presence of stereovision in cases of amblyopia, aniso-accommodation and cataract – for subjects with lower level binocular vision and) decreased visual acuity in one of eyes. We have investigated patients with real amblyopia, aniso-accommodation and cataract and simulated pathologies (using optical blur by positive and negative lens overcorrection and stimuli blurring on PC screen) to study influence of the induced uncorrected anisometropia, amblyopia and cataract on the subjects' stereoacuity. It is determined, that for the case of uncorrected hypermetropic anisometropia stereothreshold is higher compared to uncorrected myopic anisometropia. Comparing obtained data for subjects with artificially induced uncorrected anisometropia, amblyopia and cataract with values for subjects with real pathologies the degree of the stereoacuity worsening is similar if the visual acuity is chosen as the influence criterion.

The techniques developed in our research can be used in vision assessment to diagnose stereovision and to create a stereo test adapted to the clinical conditions so that the quality of stereovision can be assessed as quickly as possible. The stereotest has a wide range of the stimuli stereodisparity capable to facilitate provocation of stereo sense for patients with high degree of amblyopia and to train patients without and with pathologies in order to improve their stereoacuity.

References

1. R.T.Goodwin, P.E.Romano. Stereoacuity degradation by experimental and real monocular and binocular amblyopia. – *Invest.Ophthalmol.Vis.Sci.,* **26**, pp.917 – 923 (1985).
2. J.V.Lovasik, M.Szymkiw. Effects of aniseikonia, anisometropia, accommodation, retinal illuminance and pupil size on Stereopsis. – *Invest.Ophthalmol.Vis.Sci.,* **26,** pp.741 – 750 (1985).
3. T.Simpson. The suppression effect of simulated anisometropia. *Ophtha.Physiol.Opt.,* **11**, pp.350-358 (1991).
4. R.van Ee, W.Richards. A planar and a volumetric test for stereoanomaly. – *Perception,* **31**, pp.51-64 (2002).
5. R.P.Rutstein, D.Corliss. Relationship between anisometropia, amblyopia, and binocularity. – *Optom.Vis.Sci.,* **76**, pp.229-233 (1999).
6. Ji-eun Bahn, Yong-jin Choi, Jung-young Son, N. Kondratiev, V. Elkhov, Yu. N. Ovechkis, and Chan-sup Chung, "A device for diagnosis and treatment of impairments on binocular vision and stereopsis," *Proc.SPIE "Stereoscopic Displays and Virtual Reality Systems VIII",* Edit. A.J. Woods, M.T. Bolas, J.O. Merritt, and S.A. Benton, **4297**, pp.127-131 (2001).
7. G.Papelba, I.Cipane, and M.Ozolinsh. Stereovision studies by disbalanced images. *Proc.SPIE "Advanced optical devices",* Edit. J.Spigulis, J.Teteris, M.Ozolinsh, and A.Lusis, **5123,** pp.334-340, (2003).
8. A.K.C.Lam, P.Tse, E.Choy, and M.Chung. Crossed and uncrossed stereoacuity at distance and the effect from heterophoria. – *Ophthal.Physiol.Opt.,* **22**, pp.189-193 (2002).
9. A.K.C.Lam, A.S.Y,Chau, W.Y.Lam, G.Y.O.Leung, and B.S.H.Man. Effect of naturally occurring visual acuity differences between two eyes in stereoacuity. – *Ophthal.Physiol.Opt.,* **16**, pp.189-195 (1996).
10. P.P.Schmidt. Sensitivity of random dot stereoacuity and snellen acuity to optical blur. – *Optom.Vis.Sci.,* **71**, pp.466 – 471 (1994).

T I-VIII

Sixth International Meeting of American Academy of Optometry (Madrid, Spain, 7.-9.April 2000) “***Stereoresistance – a new characterisation of stereothreshold under external influence***” G.Papelba, I.Lacis, M.Ozolinsh, K.I.Daae

Stereoresistance – a new characterisation of stereothreshold under external influence

Gunta Papelba, Ivars Lacis, Maris Ozolinsh,
Department of Optometry and Vision Science, University of Latvia, Riga, Latvia
Kjell Inge Daae
Institutt for Optometri, Hogskolen I Buskerud, Kongsberg, Norway

Purpose. The main goal of this investigation was to study the stereovision threshold under static and dynamic conditions of blurring of the stimulus for one eye.

Method. Three different test techniques were developed. First, studies of stereovision quality at near using monocular overcorrection with a standard TNO test. Second, determination of the influence of monocular overcorrection on the maximal stereoangle at far using original projection line test technique with polaroids or colour filters for stimuli separation. Third, studies in static and dynamic conditions of correlation between the decrease of the monocular acuity and the stereothreshold using a light-scattering obstacles placed between one eye and a random dot stereopair. The obstacle made of electrooptic PLZT ceramics provided a continuous quasistatic and dynamic change of blurring of a retinal image, thus decreasing the contrast of the stimulus.

Result. For tests both at near and at far a decrease of the stereovision quality with overcorrection is close to linear. A ratio between the stereothreshold (in lines for TNO test) and overcorrection would be taken as a measure of stereo-resistance (sensitivity). The stereoresistance differs for positive and negative overcorrection and for near vision has an average value, for 125 patients, from –1,5 to +1,6 (lines/D), having the tendency for negative value being bigger. Using the third method, light scattering induced by applying the voltage to the PLZT ceramics obstacle, decreased the monocular acuity at far down to 0.5, causing the loss of the stereosence for value of disparity of 2∞ within 0.5 s after switching on scattering.

Conclusion. Three different test methods are used to evaluate the external influence to the stereovision quality. A new term – stereoresistance – is proposed to characterise diminishing of the stereosense with overcorrection. More detailed studies comparing stereovision changes caused by overcorrection and by blurring due to light scattering would give additional information of the impact of anisometropia on the stereothreshold.

99th Annual Meeting of DOG 2001 (Berlin, Germany, September 29 - October 2, 2001) ***"Blurring effect to stereoscopic vision"*** Gunta Papelba, Maris Ozolinsh,

Blurring effect to stereoscopic vision

Gunta Papelba, Maris Ozolinsh

Department of Optometry and Vision Science, University of Latvia, Latvia

PURPOSE: The main goal of this investigation was studies of the stereovision threshold under static and dynamic conditions. These stimuli were blurring (with electrooptic PLZT ceramic) of the stimulus for one eye.

METHODS: Studies in static and dynamic conditions of correlation between the decrease of the monocular acuity and the stereothreshold using a light scattering obstacle placed between one eye and a random dot stereopair. The obstacle made of electrooptic PLZT ceramics provided a continuo quasistatic and dynamic change of blurring of a retinal image, thus decreasing the contrast of the stimulus. Subject must determine the figure with the highest stereoangle seen when the light scattering is dynamically switched on.

RESULTS: By increasing intensity of blurring, the stereoacuity and the visual acuity remain constantly. Contrast vision is sensitive to minimal change of blurring. Achieving critical point, where U/Uvs=0,5 = 0.68 the stereoacuity and the visual acuity start to change gradually (the stereoacuity increases, but the visual acuity decreases), but contrast vision in the critical point is declined approximately to half.

CONCLUSION: Contrast vision is more sensitive to the intensity of blurring than visual acuity. Quality of stereovision strongly depends on intensity of blurring and frequency of blurring appearance. It seems that, change of contrast vision is the most affecting to stereoscopic vision.

The 3rd International Conference “Advanced Optical Materials and Devices – AOMD – 3” (Riga, Latvia, 19.-22.August 2002) ***“Spatial and temporal transmittance of liquid crystal goggles used in vision tests”*** M.Ozolinsh, G.Papelba, G.Andersson

Spatial and temporal transmittance of liquid crystal goggles used in vision tests

M.Ozolinsh[1]. G. Papelba[2]
Institute of Solid State Physics and Department of Optometry and Vision Science,
University of Latvia, Riga
G. Andersson
Chalmers TH, Göteborg, SWEDEN

Characteristics of two liquid crystal (LC) stereogoggle kits - first one, designed in the Inst. of Cinematography *(1C},* Moscow [1], and second one, as a 3-D device distributed for mass consuming by a company ***"ELSA"*** [2] have been studied. In both goggles twisted nematic LC shutters were used, thus their switching speed and contrast ratio were lower comparing with special goggles using ferroelectric ceramics or ferroelectric LC cells [3]. To switch the twisted nematic LC cells from the ON (maximum transmittance) to OFF state, bursts of square wave, sinusoidal, either of more complicate positive-negative waveform are applied. Thus the ON-OFF transient of such goggles depends of the control waveform amplitude and little on pulse frequency (0.5-1.5 kHz), the transient is forced, and it happens relatively fast *(ca.* ms). The OFF-ON transient after removal the control voltage is activated by the elastic fields in LC, and it depend on LC viscosity, thus on temperature. Figure below shows an example of the optical response of a strobe pulse LED light source (2 ms) passing the goggle LC cell. Testing both types of the goggles in quasistatic conditions (by a constant amplitude alternating squarewave voltage) the obtained ON-OFF contrast ratio was greater as 100:1 for all three used for testing LED wavelength (red - 635nm, green - 565nm, blue - 470nm), if the incident light was normal to the cell surfaces. For normal incidence in dynamic conditions the ON-OFF ratio was worse, besides it was time dependent (from the vision science experimental point of view - dependent on stimuli placement on the computer screen). However the main decrease of the ON-OFF contrast ratio is caused by oblique viewing the stimuli on the screen - that can diminish the contrast ratio for composite white RGB stimuli till 30:1. The measured white light transmission values for the open LC shutters without applied voltage were - 28% for ***ELSA*** goggles (22% for red, 31% - green, 28% - blue), and 20% for ***1C*** goggles and, and for dynamic use in open state (at the end of the ON state) - 24% for ***ELSA*** goggles and 18% for ***1C*** goggles.

Experimental use of the goggles for the stereovision tests approved their ability for vision science applications.

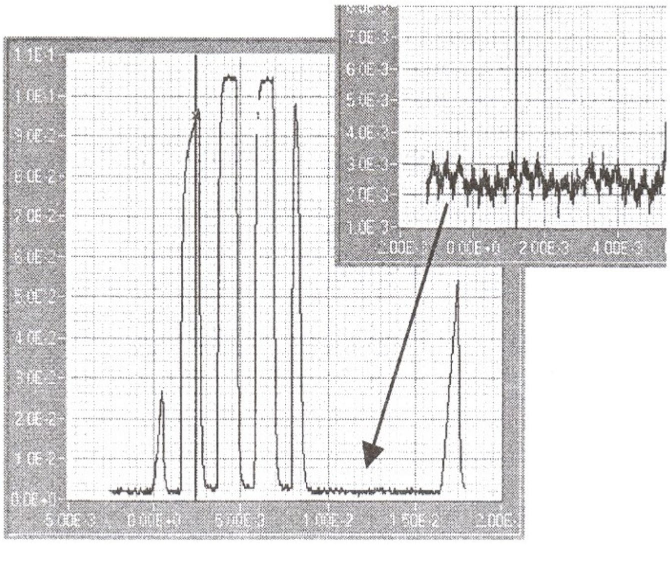


Figure Transmittance *vs.* time for **1C** goggles. ON state corresponds to one frame (120frame/sec). A green LED is used as a strobe light source. Insert shows with greater resolution the OFF state transmittance.

[1] J.Bahn, Y.Choi, J.Son, N.Kodratiev, V.Elkhov, Y.N.Ovechkis, C.Chung, A Device for Diagnosis and Treatment of Impairments on Binocular Vision and Stereopsis, Proc.SPIE, 4297, 127-131(2001).
[2] *http://www.elsa.com*
[3] *http://www.crsltd.com/catalog/fe-l/,* "FE-1 Goggles"

---

ozoma@latnet.lv

The 3rd International Conference "Advanced Optical Materials and Devices – AOMD – 3" (Riga, Latvia, 19.-22.August 2002) ***"Method of determination of stereopsis colour contrast threshold"*** G.Papelba, M.Ozolinsh, J.Petrova

Method of determination of stereopsis colour contrast threshold

G. Papelba, M. Ozolinsh, and J. Petrova
Department of Optometry and Vision Science, University of Latvia, Riga,
LATVIA

The goal of this investigation was to develop a technique of the stereovision threshold's determination if the colour contrast of the right and left eye stereopair images differ. Using the basic principles of random-element stereovision's test, a red-blue (**R/B**) stereogram is created and shown on the PC screen, where the blue image contrast ratio is continuously increased. We used in experiments different stereostimuli: 1) a square in the middle with randomly generated different and either crossed or uncrossed disparity (a square before or behind the main plane); 2) a circle with a cut-out segment, and, 3) a square in the middle, with additional reference stereostimuli placed in the periphery with a maximum **R/B** colour contrast. A subject should determine segment's orientation and distinguish the crossed or uncrossed disparity. For the stimuli separation we used colour filters. Stereostimuli **R** and **B** images differed not only spatially within the disparity region, however they had an essential difference in the colour contrast within all stimulus area. That caused a serious binocular rivalry - continuous perception pulsations in time between red and blue images, more manifest when the low contrast stimulus was shown for the dominant eye. The rivalry effects became less manifest when instead of colour filter separation a phase separation with liquid crystal shutters was used. For three tested subjects the stereothreshold decreased by increasing the low contrast image contrast ratio. To distinguish stereostimuli with disparity of 10 arcsec the minimal contrast level of blue **B** image was 6-8% (red **R** image contrast kept 100%).

[1] A.A.F.Kingdom, D.R.Simmons, The Relationship between Colour Vision and Stereoscopic Depth Perception, 1, 10-19 (2000)

[2] D.R.Simmons, A.A.F.Kingdom, The Role of Chromatic Contrast and Luminance Polarity in Stereoscopic Segmentation, *Vision Research,* **41,** 375-383 (2001)

[3] J.Bahn, Y.Choi, J.Son, N.Kodratiev, V.Elkhov, Y.N.Ovechkis, C.C.Hung, A Device for Diagnosis and Treatment of Impairments on Binocular Vision and Stereopsis, *Proc.SPIE, 4291,* 127-131 (2001)

---

papelba@tiger.cfi.lu.lv

Evaluation of image's quality to stereovision acuity

G.Papelba, M.Ozolinsh, I.Cipane
Department of Optometry and Vision Science, University of Latvia, Riga,
LATVIA

We report on development of experimental technique and studies of stereovision acuity by disbalanced image quality for the left eye (LE) and right eye (RE), when stimuli as black-white random dot stereopairs are displaced on a computer screen. We separated RE and LE stimuli a) with haploscopic technique - prisms; and b) with phase separation - with liquid crystal shutters synchronised with the display frame rate. Two ways of stimuli disbalanced were applied — optical blur, and contrast change of one eye stimulus.

To detect the blur extend needed to suppress stereopsis, a stimulus for one eye as a serie of image files was composed. Each next image of the sequentially has underwent the directional and Gaussian smooth (the FFT analysis and cross-correlation were used as parameters). The destination of experiment is to fix when a subject can distinguish the crossed and uncrossed disparity when the quality of the stimulus worst image is improving, and *vice versa.* To study the stimuli contrast effect on stereoacuity, the contrast of the one eye stimuli was continuously changed - either uniformly or more in the centre as in peripheral area according to the Gaussian distribution.

We have the first results of three subjects with this method. If the contrast of the best stimuli image kept ^100%, subjects detect stereopsis with disparity of 10 arcsec above the first image contrast level of 2-6%. This method gives other possibilities to investigate stereovison under various blurring effects.

[1] D.R.Simmons, The Minimum Contrast Requirements of Stereopsis, *Perception,* 27, 1333-1343,(1998)

[2] J.Bahn,.Y.Choi, J.Son, N.Kodratiev, V.Elkhov, Y.N.Ovechkis, C.Chung, A Device for Diagnosis and Treatment of Impairments on Binocular Vision and Stereopsis, *Proc.SPIE,* **4297,**127-131,(2001)

[3] S.B.Stevenson, L.K.Cormack, A Contrast Paradox in Stereopsis, Motion Detection and Vernier Acuity, *Vision Research,* **40,** 2881-2884, (2000)

---

papelba@tiger.cfi.lu.lv

The XXXV Nordic Congress of Ophthalmology (Tamper, Finland, 23.-27.August, 2002), ***“Stereovision acuity studies by disbalanced eye image quality”*** G.Papelba, I.Cipane, and J.Petrova

STEREOVISION ACUITY STUDIES BY DISBALANCED EYE IMAGE QUALITY

Papelba G., Cipane I., Petrova J.

Department of Optometry and Vision Science, University of Latvia, Riga, Latvia

We report on development of experimental technique and studies of stereovision acuity by disbalanced image quality for the left eye (LE) and right eye (RE), when stimuli as black-white random dot stereopairs are displaced on a computer screen. We separated RE and LE stimuli a) with haploscopic technique – prisms; and b) with phase separation – with liquid crystal shutters synchronised with the display frame rate. Two ways of stimuli disbalanced were applied – optical blur, and contrast change of one eye stimulus.

To detect the blur extend needed to suppress stereopsis, a stimulus for one eye as a movie .gif file was composed. Each next frame of the sequentially has underwent the directional smooth (the FFT analysis was used as parameters). Stimuli were separated haploscopically. The destination of experiment is to fix when subject loss the stereopsis or regained it back. To study the stimuli contrast effect on stereoacuity, the contrast of the one eye stimuli was continuously changed – either uniformly or more in the centre as in peripheral area according to the Gaussian distribution.

THE INFLUENCE OF BLUE-RED COLOUR’S CONTRAST TO STEREOACUITY

Papelba G., Petrova J., Cipane I.

Department of Optometry and Vision Science, University of Latvia, Riga, Latvia

Purpose. The main goal of this investigation was studies of the stereovision threshold under colour (blue and red) contrast changing.

Method. Using the basic principles of random-element stereovision’s test is created red-blue stereogram where contrast level is changed in the determined time. We have three programs for red-blue stereograms: 1) square in the middle, what can change its position before and behind screen, 2) ring with segment, and subject must determine segment’s orientation and the position of ring (before and behind screen), 3) square in the middle, but in periphery are greater stereoacuity elements. Program fixates the subjective answer, when stereoimage is seen and subject must determine crossed and uncrossed disparity’s situations. Simultaneously is recorded the contrast’s level of correspondent colour. Additionally we measure patient’s visual acuity and the illumination’s intensity of room.

Results. Three subjects have the individual minimal threshold of stereovision, approximately 2-5 arcsec, which depends on the external influence and the time of training. The quality of stereovision acuity decreases by changing of contrast. But it depends on disparity’s size and disparity’s type too.

3^d International Conference “Television: Transmission and Processing of Images” (Sankt-Peterburg, Russia, 5.-6.June 2003) ***“Spectral composition description of images for objects in the perception of depth”***, Lyakhovetskii V.A., Papelba G

ЗАВИСИМОСТЬ ХАРАКТЕРИСТИК ВОСПРИЯТИЯ ГЛУБИНЫ ОБЪЕКТОВ ОТ СПЕКТРАЛЬНОГО СОСТАВА ИЗОБРАЖЕНИЙ.

В.А. Ляховецкий*, Г. Папелба**
**Санкт-Петербургский Государственный Электротехнический Университет*
***Department of Optometry and Vision Science, University of Latvia*

В настоящее время благодаря увеличению быстродействия и объемов хранимой информации стало возможным появление систем виртуальной реальности, при работе с которыми ощущается эффект присутствия. Одной из важных составляющих этого эффекта является ощущение глубины сцены – объекты виртуальной реальности должны быть или казаться трехмерными. Для создания устойчивого ощущения глубины необходимо, чтобы глаза наблюдателя воспринимали несколько различные изображения объектов сцены. Устройства визуализации, на которых синтезируются изображения, являются плоскими. Поэтому для создания стереоэффекта используют либо специальные шлемы, в которых левый и правый глаз наблюдателя направлены на различные мониторы, либо стерео-очки. Заслонки стерео-очков, синхронизированные с частотой обновления монитора, обеспечивают разделение изображений, при котором левый глаз наблюдателя видит, например, четные, а правый – нечетные кадры.

При разработке методов синтеза трехмерных сцен неизбежно возникают вопросы, связанные с изучением пороговых значений характеристик бинокулярного зрения. Для их изучения проводятся психофизические эксперименты и разрабатываются модели бинокулярного зрения человека.

Одним из важнейших признаков стереоизображения, достаточным для получения стереоэффекта, является диспаратность – горизонтальный сдвиг между проекциями объекта сцены на сетчатки глаз. Нами изучалась зависимость остроты бинокулярного зрения, связанной с минимальной диспаратностью, при которой возможно разделение планов глубины стереоизображения, от его спектрального состава. В исследованиях использовался особый тип изображений – случайно-точечные стереограммы (СТС), представляющие собой шумоподобный паттерн, не содержащий иных признаков глубины кроме диспаратности.

СТС в градациях серого размером 7x7 см, в центре которых был закодирован квадрат размером 5x5 см, предъявлялись наблюдателю (всего 11 испытуемых, возраст 21-23 года) на экране монитора (частота кадров –120Гц) через стерео-очки (частота кадров для одного глаза – 60 Гц). Размер элемента СТС составлял 1 пикс. В ходе экспериментов (40 опытов в 1 серии испытаний) случайным образом изменяли степень размывания одной из частей СТС (использовался гауссовский фильтр из графической оболочки *Corel Photo Paint* с радиусом размывания от 0.1 до 5 пикс.) и диспаратность стимула (от -4 до 4 пикс.). Время предъявления одной СТС составляло 1 сек. Наблюдатель, находившийся на расстоянии 80 см от монитора, должен был принять решение о положении стимула относительно плоскости фона (за плоскостью фона / перед плоскостью фона). Программно определялась минимальная диспаратность, при которой наблюдатель был способен различить закодированный квадрат в центре СТС.

Психофизические опыты показали, что острота бинокулярного зрения уменьшается по мере увеличения степени размывания изображения. Результаты опытов с разработанной моделью бинокулярного зрения человека качественно совпали с данными психофизических исследований.

Разработанная модель имитирует работу сетчаток, наружных коленчатых тел (НКТ) и первичной зрительной коры (ПЗК) человека. На вход модели – слои “фоторецепторов” – подается стереограмма. “Фоторецепторы” (палочки и три вида колбочек) конвергируют на “биполярные”, которые, в свою очередь, конвергируют на “ганглиозные клетки”. Далее сигналы, без искажений пройдя через НКТ, доходят до бинокулярных «нейронов» ПЗК. Выходом модели является потенциал вергентности (ПВ) – функция, значениями которой является суммарный ответ пула расположенных вблизи друг от друга бинокулярных “нейронов”, тормозно настроенных на некоторую диспаратность.

В модели реализованы современные представления о существовании высокочастотного и низкочастотного бинокулярных каналов - ПВ вычисляется отдельно для пулов, образованных «нейронами» с различными размерами рецептивных полей. Диспаратности поверхностей, закодированных в СТС, соответствуют минимумы ПВ.

Использование модели позволило предложить физиологические механизмы для объяснения выявленной зависимости. Предполагается, что высокочастотный бинокулярный канал предназначен для детального рассматривания стереоизображения. Чем глубже минимум ПВ, рассчитанного в высокочастотном канале, тем устойчивей фузия. Низкочастотный канал предназначен для управления высокочастотным каналом. Он определяет диапазон диспаратностей, в рамках которого наблюдатель способен выделять планы глубины из СТС. При небольших диспаратностях минимумы ПВ, соответствующие диспаратностям стимула и фона, сливаются, становятся неразделимыми, что и соответствует невозможности для наблюдателя воспринимать объекты с под пороговыми значениями диспаратности.

При размывании части СТС минимальная диспаратность стимула, при которой минимумы ПВ, соответствующие диспаратностям фона и стимула, разделяются, увеличивается. То есть, размывание изображения блокирует работу бинокулярных нейронов низкочастотного канала с рецептивными полями, меньшими чем степень размывания, что и приводит к зависимости остроты стереозрения от спектрального состава изображения.

PhD student of University of Latvia:

M.Sc. **Gunta Krūmiņa**

.... 28th February 2004

Scientific supervisors:

Dr.habil.phys. **Māris Ozoliņš**

.... 28th February 2004

Dr.habil.phys. **Ivars Lācis**

.... 28th February 2004