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FACULTY OF PHYSICS AND MATHEMATICS

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Summary of the Doctoral Thesis

VISION IN HIGH LIGHT SCATTERING CONDITIONS

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Annotation

Assessment of visual quality of drivers arouses many discussions among visual care specialists. Some of the most significant parameters for assessment of vision for drivers are visual acuity and visual field. Now Also usefulness of contrast sensitivity tests is discussed. In this work we investigate another important visual parameter – light scattering in the eye (straylight).

First aim of the study was to evaluate impact of retinal straylight, created by entoptic and ectoptic factors on perception of colored (red, green and blue) visual stimuli. Second aim was to assess possibility to simulate high level light scattering conditions (fog, cataract) using light scattering filter – polymer-dispersed liquid crystal plate PDLC. We also wanted to check out is it improvement of vision, when yellow filter is used, related with optical factors (absorbing of short wavelengths light and decrease of light scattering) or neural ones (changes in perceived brightness of stimuli). The last, we estimated how small aperture in front of the eye changes retinal stray light.

During researches three methods were used – visual acuity measurements in normal conditions and in high light scattering conditions; an electrophysiological method visual evoked potentials (VEP) and a direct compensation method (van den Berg, 1986).

Visual acuity and VEP measurements showed the worst results for blue color stimuli in normal and high light scattering conditions. Results showed that in high light scattering conditions perception of colored stimuli is mostly influenced by neural factors not optical.

Using PDLC plate it is possible to get the same light scattering level as created by dense fog or cataract. There is no spectral dependence for scattered light in dense fog or in case of cataract. PDLC plate showed spectral dependence for scattered light. Such spectral dependence means that PDLC plates can adequately simulate the scattering produced by cataract or fog when achromatic stimuli are used.

Psychophysical retinal straylight measurement showed that yellow filter doesn't decrease amount of straylight in the eye. Improvement of contrast sensitivity in low light condition with yellow filters found by other authors is more related to neural mechanisms than to optical ones.

Results with aperture showed that it is possible to use a small aperture for evaluation of amount of the light which penetrates through the sclera and the iris.

Contents

Aims

Aims of the study:
To assess visual threshold changes for chromatic stimuli depending on light scattering level created by physiological factors of the eye or environmental factors (fog). To simulate similar conditions using light scattering filters. To find possibilities to decrease the amount of retinal straylight.

Tasks

1. To make equipment and develop methods for assessment of disability glare.
2. To evaluate spectral dependence of the retinal straylight in different light scattering conditions (in normal laboratory conditions, in an artificial fog and with light scattering filters).
3. To measure impact of the polymer dispersed liquid crystal PDLC filter on the vision
4. To assess possibility to simulate fog or cataract conditions with PDLC plate.
5. To evaluate how yellow filters or a small aperture in front of the eye change retinal straylight.

1 Introduction

Full assessment of visual quality of drivers, patients after laser refractive surgery and low vision patients is an important question for visual care specialists. Vision can be characterized by many parameters. Some of the most significant parameters are:

- visual acuity;
- visual field;
- contrast sensitivity.

Visual acuity is the primary measure of visual function in clinical settings (Williams *et al.,* 2008). However, this visual parameter not always is the most important in the performance of everyday tasks. For example, orientation-mobility skills of a patient are more correlated with the extent of visual field remaining and contrast sensitivity function than with visual acuity (Marron *et al.*, 1982).

Measurements of the visual field are usually done only for elderly patients. An increased risk to get an eye disease called glaucoma is related to the ageing process. Untreated glaucoma leads to a permanent damage of the optic nerve and results in visual field loss, which can progress to blindness. Visual acuity and visual field were two major parameters on which the previous European Commission standards on vision for driving were focused. (Council Directive 91/439/EEC (1991)). Other visual functions, such as contrast sensitivity, are mentioned in the new standards as an important parameters for drivers' vision assessment as well. (Rijn, 2005).

The contrast sensitivity CS is the reciprocal of the threshold contrast of the stimulus. If a subject is able to perceive the stimulus with a lower contrast than the other subject, his CS is better (Kaufman *et al*., 2003). Patients with an early cataract have significant correlation between impaired CS and complaints related to vision. In this case it is difficult to detect low contrast stimuli and therefore there appears problems to perform some everyday tasks successfully. For these patients visual acuity and visual field usually are not significantly changed. (Elliott *et al*., 1996).

The contrast perception is an important visual function; however, testing of contrast sensitivity cannot be regarded as a routine test in the visual care. Some reasons of this situation are the variety of available tests with different standards and the fact that not always it is useful to test CS in standard photopic conditions. CS could be more affected when there is a light source somewhere in the patient's visual field. The impairment of CS in the presence of a light source at some distance from the fixation point is related to light scattering in the eye (straylight). A typical relevant situation is night driving when there are oncoming car headlamps somewhere in the driver's visual field. This causes intraocular light scattering which is important factor that can affect road safety. There are discussions about the importance of straylight measurements in clinical practice and in assessment of drivers' visual functions (Rijn, 2005; Aslam *et al.*, 2007).

1.1 Retinal straylight and disability glare

In an optically perfect eye, light comes into the eye trough the pupil and is focused on the retina. In the real eye, part of the light reaching the retina does not participate in the formation of a normal image. This part of the light decreases image contrast and thus impairs the perception of the image. Sometimes this disturbing light is called scattered light, but not only light scattering creates light which is not focused on the retina. There are many factors which creates disturbing light in the eye-light scattering in the eye, light reflectance from optical parts of the eye and light which penetrates trough the sclera and the iris (Stiles, 1929). The most common terms which are used in literature to describe this disturbing light are:

- retinal straylight;
- disability glare.

Disability glare is the loss of retinal image contrast as a result of intraocular light scatter, or straylight (Aslam *et al.*, 2007; Fransen *et al.*, 2007). Besides the disability glare there is discomfort glare, too. Discomfort glare does not affect visual functions (Vos, 2003). This type of glare has not been evaluated in this research.

Retinal straylight can be created by entoptic and ectoptic factors. The most important entoptic factors are:

- The light scattering and reflectance from the cornea, lens and retina (Vos, 2003). All these 3 factors give the same amount of straylight in young subjects. With age, straylight produced by lens increases (development of early cataract) (Aslam *et al.*, 2007).

- The light which penetrates trough the sclera and iris. This factor is stronger for blue eyes (with small amount of pigmentation) (van den Berg *et al.*, 1991).

Ectoptic straylight sources could be a dirty windscreen of a car, fog, spectacles etc. (Vos, 2003; de Wit *et al.*, 2003).

Typical situation in which straylight affects perception of an object is shown in **Fig. 1.1**. In the picture on the left, the formation of fixation object (Landolt optotype "C") and peripheral light source images are shown in an optically perfect eye (without light scattering). In the picture on the right, the same situation is in the presence of intraocular light scatter. In this case a part of the light from peripheral glare source reaches the central part of the retina, thus reducing contrast of Landolt "C" retinal image.

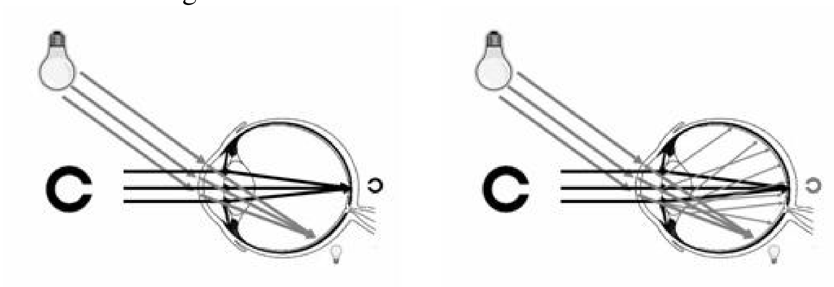


Figure 1.1. Formation of retinal images in an optically perfect eye (left) and in the eye with intraocular light scattering. In the image on the right, the light from a peripheral object reduces the contrast of fixation object image.

It is possible to show reduction of central image contrast in the presence of the peripheral glare source using contrast equations. One of the formulas which can be used for image contrast C calculation is Weber formula:

$$C = \frac{(L_o - L_b)}{L_b} \quad (1.1.),$$

L_o – luminance of the object; L_b – luminance of the background.

The straylight from peripheral glare source reaches the central part of the retina, thus making brighter the image of the perceived object and background. The same amount of light must be added to image luminance L_o and background luminance L_b to calculate the image contrast in this situation:

$$C' = \frac{(L_o + L_s) - (L_b + L_s)}{(L_b + L_s)} = \frac{(L_o - L_b)}{(L_b + L_s)} \qquad (1.2.),$$

where C' – the contrast of the image in the presence of straylight, L_s – the increase of luminance created by straylight (Narisada *et al.*, 2004). Equations (1.1) and (1.2) show that in the presence of straylight image contrast is always lower than without straylight.

1.2 Methods for assessment of retinal straylight

Over the years, many glare testers have been developed. There are two main principles which are used in the glare testers:

- Either the visual acuity or the contrast sensitivity is measured in the presence of a glare source in many testers.
- Direct measuring of the intraocular straylight in the central part of the retina.

There are some other methods for measuring glare effects; however they are not often used in clinics. We have tested the possibility to use VEP method for assessment of disability glare in this research. This method is described in the practical part of this research.

1.2.1 Disability glare measurements using contrast sensitivity and visual acuity tests

Disability glare testers which are based on the first principle were used in clinics earlier than the second method. Visual acuity and contrast sensitivity tests with peripheral glare sources are used in these methods (Beckman *et al*., 1992; Rijn *et al.,* 2005). If visual acuity or contrast sensitivity is tested with glare sources and without them, then difference between these both measurements shows the effect of disability glare on the vision. The main disadvantage of these testers is fact that not only optical factors but also neural factors affect results. Optical effects and glare sources produces disability glare, therefore theoretically should always impair visual functions. However some other researchers have shown that sometimes peripheral glare sources can improve test results (Waard *et al*., 1992).

In this research we used direct compensation method based on the second principle. This method is described in the next chapter.

1.2.2 Direct compensation method

First scientist publications about disability glare appeared long time ago (Holladay, 1926; Stiles, 1929). However a test which provides a direct measure of intraocular straylight was developed not so long time ago (Berg, 1986; Franssen *et al*., 2006). One method for measuring retinal straylight is direct compensation method (Berg, 1986). In this method flickering (~8 Hz) stimulus is showed. The stimulus consists of a concentric annulus and of a test field in the middle of the ring (**Fig. 1.2**).

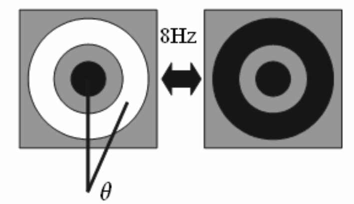


Figure 1.2. Stimulus in direct compensation method. Stimulus consists of flickering annulus. In the left on-phase is showed – annulus is white; in the right off-phase is showed. Test field is located in the middle of the ring.

During measurement subject must fixate on the test field. Due to the light scattering in the eye, the subject perceives flicker in the middle of the annulus, too. If a test field at the centre of the annulus is illuminated with light which is flickering at the same frequency as the annulus but in counter-phase, it is possible by adjusting the luminance of the test field to compensate the flicker of the straylight coming from annulus. The flickering in the centre then disappears. The subject's task during measurement is to fixate on the test stimulus and to find the level of test field luminance which compensates flickering in the centre of the annulus. In the direct method, the retinal straylight is measured according to the Commission International d'Eclairage (CIE) standards (Vos, 1984). From this concept the retinal straylight can be calculated from the formula:

$$s = \frac{\theta^2 L}{E} \qquad (1.3),$$

where L is the luminance of the test stimulus; E is the illuminance at the pupil plane caused by a straylight source; θ is the angular distance (degrees) of the glare source from the fixation point.

There is another method – compensation comparison method – for measuring retinal straylight. In this method similar principle is used as in direct compensation method. The main difference is that new method is suitable for random subjects and for routine clinical use. In our researches we used direct compensation method which is simpler as second method.

1.3 Spectral dependence of intraocular straylight

A spectral dependence of the straylight was the problem which has been studied for a long time. Many clinical studies have shown that straylight in the eye predominantly has Mie form, which is not strongly wavelength dependent (*Wooten et al.*, 1987; *Whitaker et al.*, 1993). A newer research has shown that in the young and well pigmented eye light scattering is strongly wavelength dependent and is close to the Rayleigh scattering ($\propto\lambda^{-4}$). Straylight is greater than in the Rayleigh model only for light with long wavelengths (red light) (**Fig. 1.3**). A red light enters the eye not only trough the pupil, but penetrates also through the ocular wall. This effect is greater for the less pigmented eyes. Results also showed that straylight dependence of the wavelength decreases with age (*Coppens et al.*, 2006).

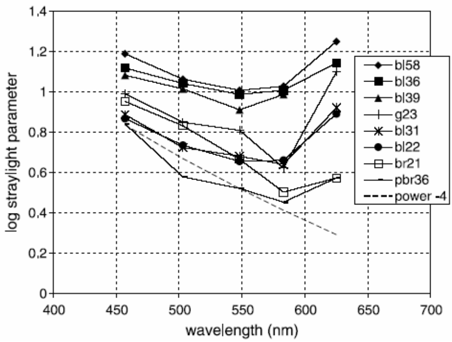


Figure. 1.3. Spectral dependence of straylight parameter *s*. Data are grouped by subjects' age and color of eyes (bl – blue; gr – grey; br – brown, pbr – dark–brown). (*Coppens et al.*, 2006).

Previously mentioned researches are related to the entoptic light scattering. One of our interests was to evaluate spectral dependence of the retinal straylight in a dense fog. In the case of light scattering in a fog, negligible spectral dependence would be expected. Rayleigh scattering dominates only if the size of the scattering particles is smaller or similar to the wavelength of the light. A fog consists of water droplets which mean size form is usually quite large and theoretically there should be the same scattering level for all wavelengths of the light (Friedlander, 2000; Mainster *et al.*, 2003).

Vos (2003) argues that the straylight veil produced by the ectoptic scatter (fog) adds to the entoptic veiling light. Therefore, if retinal straylight measurements are done in a fog, results are affected not only by optical properties of the fog, but also by light scattering in the eye. If the entoptic retinal straylight shows spectral dependence, we could expect some spectral dependence also for measurements done in a fog.

2 Methods and stimuli

2.1 Methods for retinal straylight assessment

We used 3 methods for assessment of the disability glare and the retinal straylight:

- visual acuity measurements in normal conditions and in high light scattering conditions;
- using an electrophysiological method Visual evoked potentials (VEP).
- using a direct compensation method (van den Berg, 1986).

2.1.1 Method for assessment of visual acuity in normal conditions and in high light scattering conditions

In the beginning of our researches for assessment of disability glare we used psychophysical visual acuity method. Measurements were done in normal light scattering conditions and in high level scattering conditions. There are two reasons why we chose such method for the assessment of intraocular light scattering. Firstly, such principle for measurements of disability glare is used in clinic (Rijn *et al.*, 2006) and the same method was used in previous researches done in our department (Ozolinsh *et al.*, 2004).

The "Freiburg Visual Acuity Test" (Bach, 2007) program was used for measurements of visual acuity. Stimulus was black Landolt C optotypes and they were shown using an adaptive staircase procedure.

For measurements of spectral dependence of the intraocular light scattering we used also colored stimuli. In one of the researches

(Ozolinsh *et al*., 2006) we used red, green, blue and yellow Landolt optotypes (Weber contrast was 0.84; 0.30; 0.89 and 0.14 respectively). Distance from a monitor was 6m. Measurements were done in different visibility levels of an artificial fog.

In another measurements (Ikaunieks et al., 2008 (2)) black Landolt C optotypes on colored background (red, green and blue) were used as stimuli. Weber contrast for all stimuli was 0.85. Distance from a monitor was 4m. Measurements were done with and without the PDLC plate in front of the eye.

2.1.2 Electrophysiological method "Visual evoked potentials" (VEP)

Visual evoked potentials (VEP) is one of the electrophysiological methods which has been used in clinic and researches for evaluation of visual system. Special electrodes are attached to the patient's head and biosignals from the visual system can be recorded. Periodically changing stimulus which is used in this measurement is showed (**Fig. 2.1**). It is possible to assess visual system by analysis of recorded biosignal response to the stimuli (**Fig. 2.1**). There are two main parameters which are analyzed in the recorded curve – latency and amplitude. Latency is time (measured in ms) between appearance of the stimulus and the response. In the recording curve amplitude is measured from one peak minimum to the next peak maximum. Usually latency and amplitude of the first positive peak (P100) is analyzed. Latency become longer and amplitude smaller if there are some pathological changes or there are problems with detection of the stimulus.

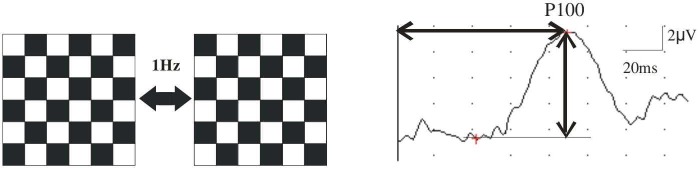


Figure 2.1. In the picture on the left is shown stimulus which is usually used in the VEP method. The stimulus is changing in time. In this research black and red, black and green, black and blue checkerboards were used. In the picture on the right response to checkerboard stimulus is shown. Horizontal line shows latency and vertical line shows amplitude of the peak P100.

Some authors used The VEP method to evaluate the effect of straylight on visual functions (Tetsuka *et al.*, 1992, Hidajat *et al.*, 2000). Electrophysical methods have some advantages in the comparison with psychophysical methods. Electrophysical methods are objective and conclusions about visual quality can be made by analysis of two parameters of the recorded curve: latency and amplitude. Each of these parameters is sensitive to the different aspects of the stimuli.

Also in this research the VEP method was used for assessment of the intraocular straylight and its spectral dependence. Ag/AgCl electrodes were used in the VEP method. The active electrode was placed on the scalp over the visual cortex at Oz, the reference electrode was placed at the Cz and the ground electrode at the earlobe, according to the “10–20” international system. Impedance was less than 10 kΩ for all recordings. The visual stimuli were pattern-reversal checkerboards (red-black, green-black and blue-black) consisting of 1 degree checks and reversing at 1Hz. Luminance of red, green and blue colors was 22 cd/m^2. The overall size of stimulus field was 20 degrees. The P100 (first positive wave) latency and amplitude were established for each VEP curve.

2.1.3 Stimulus in the direct compensation method

The direct compensation method was the main test for assessment of retinal straylight in our researches. Principle of this method is described in chapter “Direct compensation method”

Two different stimuli were used:

- stimulus which was showed on CRT screen;
- stimulus made from light-emitting diodes (LED).

There was specially made program used to show stimulus on CRT screen. Color of the annulus was red, green or blue. The CIE xy coordinates for colors used in all experiments were 0.59, 0.36 for red, 0.30, 0.59 for green and 0.16, 0.12 for blue (Minolta CS-100). Dominant wavelengths for colors were 471 nm, 546 nm and 604 nm, respectively. The same colors were used in VEP measurements. Stimuli were shown on the CTX PR960F 19" monitor. Distance from monitor was 0.6m.

Subjects chose compensation luminance of the test stimulus using a keyboard.

There are some disadvantages for the stimuli shown on computer screen. The CRT screen gives broadband red, green and blue stimuli. For straylight spectral dependence measurements monochromatic or narrow band stimuli are better than broadband stimuli. The second disadvantage is low luminance of blue color. Due to the low illuminance at the pupil plane caused by a blue annulus it is hard to find compensation luminance *L* for the test field. Another stimulus made from red, green and blue narrow band LED lamps were used (**Fig. 2.2.**)

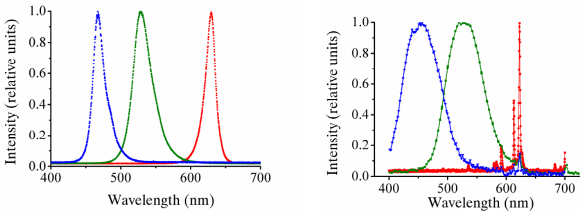


Figure 2.2. Spectral characteristics of the LEDs (to the left) and of the color channels of CRT monitor (to the right).

During the research process two LEDs stimuli were used – one for near distance (~0.6 m) and another for far distance (~5 m) measurements. The same principle was used in both stimuli. Difference was only in physical size of the stimuli (angular size were the same).

The stimulus consisted of light-emitting red, green and blue diode lamps, attached to a cork board (**Fig. 2.3**.) The lamps were arranged around the perimeter of a circle of a radius subtending five degrees at the subject eye. In the middle of this ring of LEDs, a circular plexiglass plate of thickness 14 mm was attached to the board. The disc was used as test stimuli in direct compensation method. Nine holes were drilled at regular intervals around the sides of this plexiglass plate for placement of three red, three green and three blue LEDs. When LEDs on the disc were illuminated, a mixture of total internal reflection and refraction resulted in the bright disc appearing to an observer. Size of the disc was 1.2 degrees.

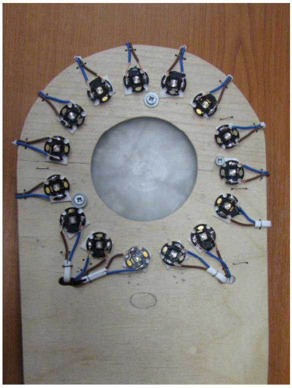


Figure 2.3. LEDs stimulus used for straylight measurements

The subject was sitting at a distance of 5 m from the stimulus for measurements of the scattering. The principle of production of the straylight due to the fog was the same as in the direct compensation method for the ocular straylight measurement (van den Berg, 1986). The LED lamps in the outer annulus flickered at 16 Hz and the subject's task was to adjust the counter-phase luminance flicker in the central disk to produce minimal perceived flicker. The luminance of the central plexiglass stimulus was changed using a power supply with a regulated output current. Measurements had been done for red, green and blue color separately. Luminance and illuminance values were calculated from calibration data. Calibration was made using chromameter Minolta CS-100 and light meter Meterman LM631.

2.2 High light scattering conditions used in measurements

High light scattering conditions were created using two different ectopic straylight sources:

- an artificial fog;
- by putting the polymer-dispersed liquid crystal PDLC cell in front of the eye.

Fog experiments were carried out in a fog chamber in Clermont-Ferrand. The fog in the chamber was uniform. The mean size of the droplets was ~4 μm (Colomb *et al.*, 2008). Visibility *V* of the fog was from 7 to 25 m. These high levels of fog density were chosen because it was easier to keep stable this level than for a fog with higher V values and lower density.

Density of the fog was controlled by a transmissometer consisting of a light source, a sensor and data acquisition system. This system measures the atmospheric transmission factor, T, defined as the ratio between the light flux emitted by a light source, Φ_o, and the light flux transmitted through a foggy atmosphere, Φ (Colomb *et al.*, 2008). Transmission factor can be described by Bouguer-Lambert's law :

$$T = \frac{\Phi}{\Phi_o} = e^{-\sigma_t d} \quad (2.1.),$$

where σ_t – extinction coefficient, d – distance between light source and sensor. Usually another parameter visibility V is used to describe density of a fog. Visibility (meteorological range) V can be defined as distance from a black object on a white background at which contrast ratio due to atmospheric conditions equals to threshold Weber contrast ratio C. For $C = 0.05$ visibility V can be calculated from the Koschmieder equation (Hinds, 1999):

$$V = -\frac{\ln 0.05}{\sigma_t} = \frac{3}{\sigma_t} \quad (2.2).$$

Some of measurements were carried out using the polymer-dispersed liquid crystal PDLC cell. It is possible to alter the light transparency of the PDLC plate when there is applied an AC voltage. The PDLC plate was placed in front of the right eye. One of the aims of the research was to assess possibility to simulate high level light scattering conditions (fog, cataract) using light scattering PDLC plate.

Simulating vision through a cataract will allow eye-care specialists to experience the visual implications for a patient who has a cataract. Cataract simulation is also useful to research purposes (*de Wit et al.*, 2006). A cataract and a fog are important factors which can affect driving safety (Owsley *et al.*, 2002; Cavallo *et al.*, 2001) hence such simulation may be used to investigate the effect of cataract and fog on driving safety.

The PLDC cell consisted of two glass plates forming a 10 microns gap 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 (589 nm) and for liquid crystal no=1.528. These plates generated different levels of scattering when AC voltage was applied. When electrical field was not applied to the PDLC cell, liquid crystal droplets were randomly oriented and the difference between refractive indices of the polymer and liquid crystal caused light scattering. When the electric field was applied, the liquid crystal droplets were aligned in one direction and PDLC transparency increased (Ozolinsh *et al.*, 2004).

One of the tasks of this research was to measure transparency of the PDLC cell for red, green and blue light. As light source diode-pumped all-solid-state laser emitting at three different visible wavelengths (473, 532 and 635 nm) was used. Through PDLC passed light was registered with photodetector. Results of this measurement are showed in **Fig. 2.4**. Spectral dependence of scattered light decreases when there is increased transparency of the filter (applying AC voltage).

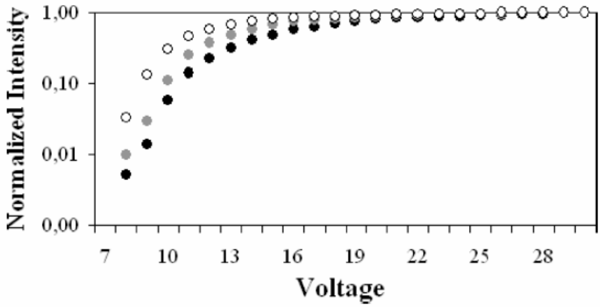


Figure 2.4. Changes in transparency of the PDLC cell by applied AC voltage to the filter. Measurement were done for red (635 nm, white circles), green (532 nm, grey circles) and blue (473 nm, black circles) light (Bueno *et al.*, 2008).

2.3 Retinal straylight measurements using a yellow filter or an occluder with small aperture

Researches which are developed by other authors show that it is possible to increase the contrast sensitivity using yellow filters especially in mesopic conditions (Pérez-Carrasco *et al.*, 2005). There are mentioned some optical reasons which improve the contrast sensitivity for a subject. A yellow filter eliminates short wavelength or blue light radiation, causing a decrease of chromatic aberration and light scattering (Miller, 1974).

However some authors argue that improvement of the contrast sensitivity is not due to optical properties of the lens, but neural factors. A yellow filter increases apparent contrast of the stimulus thus improving contrast sensitivity (Kelly, 1990; Rabin *et al.*, 1996). This effect is stronger in mesopic lightning conditions. Enhancement of brightness perception with a yellow filter could be related with chromatic pathways and also with changes in pupil sizes when yellow filters are used (Rabin *et al.*, 1996).

One of the tasks of our research was to assess possibility to decrease amount of the retinal straylight with yellow filters. First we assessed impact of yellow filter on contrast sensitivity. Contrast sensitivity was measured in normal (photopic) and low light level (mesopic) conditions with and without yellow filter in front of the eye (transmittance 67 %). Luminance of the stimulus background was 60 cd/m^2 and 0.35 cd/m^2 respectively. Pelli-Robson contrast sensitivity chart was used for research. 27 subjects (age 21–29 years) participated in measurements. To evaluate effect of filter color on contrast sensitivity, measurements were done also with neutral (grey) filter. Transmittance of the grey filter was 73 %.

Straylight measurements were done with the direct compensation method, using LED stimulus. Red, green and blue stimuli were used. Measurements were done with and without yellow filter. Filter material was a planum ophthalmic lens mad from polymer material *CR39*. Lens transmittance of the light was 67 %. Spectral transmittance of the filter is showed in **Fig. 2.5**. Four subjects participated in the experiment. The age of all subjects under test was 21–28 years. Measurements were done for one eye. Another eye was covered.

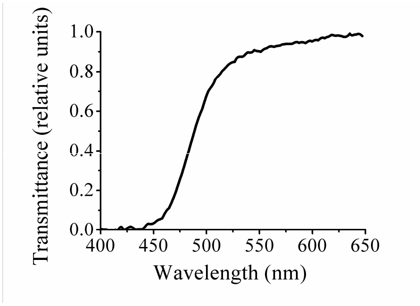


Figure 2.5. Light transmittance of the yellow filter.

Not always the reason for increased straylight level in the eye is some pathological changes in the eye. The retinal straylight which is mentioned previously usually is higher for subjects with blue eyes comparing with the same age brown eye subjects. Subjects with blue eyes have smaller amount of pigmentation and more light penetrates trough the sclera and the ris than for subjects with brown eyes.

The amount of reflectance of the fundus and the eye wall translucency has to be estimated for more accurate identification of sources which increase the retinal straylight in pathological eyes. Some other researchers have created an iris pigmentation classification system based on comparison of iris pigmentation with a set of 24 standard eye photographs (Franssen *et al.*, 2008). One of our tasks was to assess possibility to decrease the amount of retinal straylight putting an occluder with small aperture (diam. 5mm) in front of the eye. This occluder will decrease amount of light which come into the eye trough sclera and iris (**Fig. 2.6**).

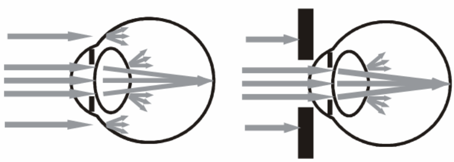


Figure 2.6. Straylight sources in the eye are shown in the picture on the left. Main sources are light scattering and reflectance in the optical part of the eye and light which penetrates trough the sclera and the iris. If an occluder with a small aperture is put in the front of the eye, less light comes into the eye through the sclera and the pupil (in the picture on the right).

Straylight measurements were carried out with a circular aperture (5mm in diameter) placed in a trial frame, and also without the aperture. The other eye was covered. Measurements with direct compensation method were done for red and green light. Eight subjects (age 21–28) participated in these experiments. Size of the aperture 5mm were chosen to reduce forming of diffraction. It is known that diffraction influences visual acuity if the eye pupil is smaller than 3 mm (Rabetts, 1998).

3 Results and discussion

3.1 Visual acuity measurements in the fog

Results of visual acuity for two-colored stimuli – Landolt-C in various colors on the white background-depending on the fog density are depicted in **Fig. 3.1**. Two participants with normal (corrected) visual acuity took part in these experiments.

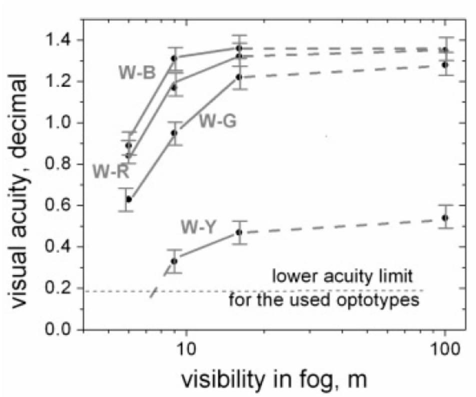


Figure 3.1. Visual acuity in the fog for different color acuity charts. W–R, W–G, W–B, and W–Y notes results for charts with red, green, blue and yellow Landolt-C stimuli on the white background, correspondingly. Data on the right present visual acuity without the fog (Ozolinsh *et al.*, 2006).

Visual acuity in the fog was the highest for blue Landolt-C optotypes and the lowest for yellow optotypes on the white background. One of the reasons of these results is different luminance contrast of all stimuli. The highest contrast was for white-blue (W–B) stimuli, the smallest for white-yellow (W–Y). The luminance of colored Landolt-C optotypes presented on a computer screen was chosen corresponding to the red (R channel), green (G), and blue (B) color contributions in achromatic white stimuli. The brightest was the G channel, and the darkest – the B channel. For white-blue stimulus the white background consists of light emitted by all three channels. The optotype area emits light only from the B channel. This results in the greatest luminance contrast for the white-blue stimuli, thus advancing the visual acuity for the white-blue stimuli. In case of white-yellow the main channel is B, because the yellow color consists of R and G channels and the white background consist of all three channels.

These results confirm assumption that short light wavelengths (blue light) in the fog is scattered more than longer wavelengths similar as in atmosphere (Godish, 2004). However there are influences on visual acuity results not only from optical factors, but also from neural factors. These results do not give full answer about spectral dependence of the retinal straylight in the fog.

3.2 Visual acuity measurements with the PDLC occluder

In the next visual acuity measurements (Ikaunieks et al., 2008 (2)) we used black Landolt optotypes on different color backgrounds – red, green or blue. Weber contrast for all stimuli was the same – 0.85. These stimuli were chosen to reduce influence of neural factors on the results. High light scattering conditions were created using the PDLC cell (light transmittance 0.4). The PDLC cell was put in front of the right eye. Left eye was covered. 4 subjects (S1, S2, S3 and S4) participated in these measurements. Age of the subject was from 21 to 28 years. Results of all subjects are shown in **Fig. 3.2**.

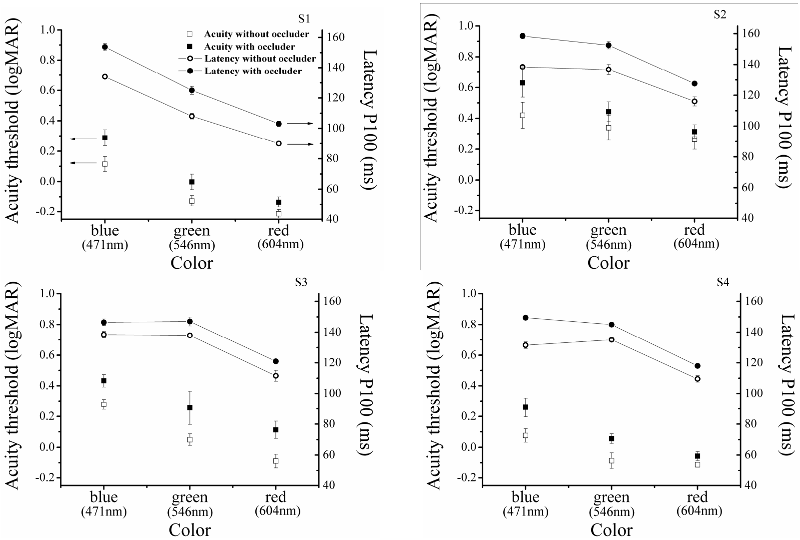


Figure 3.2. Visual acuity and latencies P100 for all subjects (S1, S2, S3, S4) depending on stimulus background color in acuity measurements and checkerboard color in VEP measurements. Measurements had been done with and without light scattering occluder (the PDLC plate). Dominant wavelengths are given for each background color. Lower logMAR values mean better visual acuity (Ikaunieks et al., 2008 (2)).

Visual acuity measurements without light scattering occluder reveal the best visual acuity for red and the worst for blue color stimuli. For all subjects (except subject S4) visual acuity data for red, green and blue color stimuli were different. For subject S4 the difference in visual acuity for red and green background is not statistically significant. The light scattering occluder reduces visual acuity values for all color stimuli. Only for one subject (S4) the difference between visual acuity values for red color stimuli with and without eye occluder is not statistically significant. For 3 subjects (S1, S2 and S4) the greatest reduction of visual acuity caused by the light scattering PDLC occluder was for the blue color and the smallest for the red color stimulus. One subject (S3) has shown reduction of visual acuity similar for all three colors.

Results show that visual acuity for colored stimuli is more affected by neural factors than optical. One of such neural factors is retinal receptive fields. The retinal receptive fields RF have different sizes, those in the periphery are larger and are more efficient in discriminating of blue-yellow, whereas those in the fovea centre are smaller and more efficient in discriminating of green-red stimuli (Schwartz, 2004). Additional measurements with different methods would be useful to get more accurate data about the intraocular light scattering in a fog and other high level light scattering conditions.

3.3 Results of the VEP measurements

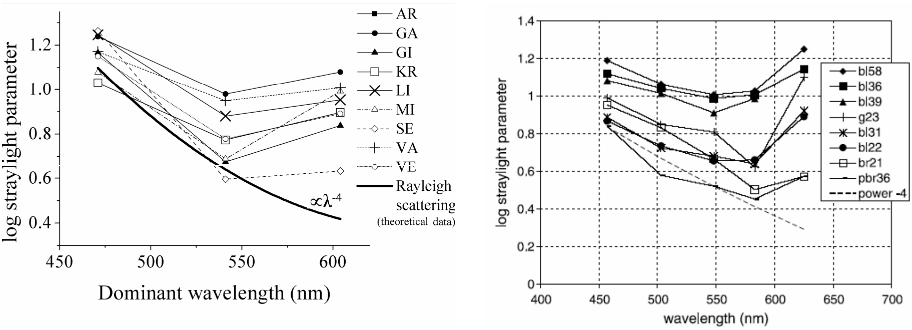
The VEP results for the red-black, green-black and blue-black checkerboard stimuli are shown in **Fig. 3.2**. Latencies P100 were analyzed in the VEP measurements for the three color stimuli. Differences in VEP amplitudes measured with and without the eye occluder were not statistically significant due to the low signal to noise ratio, therefore amplitudes were not analyzed. In experiments without the light scattering occluder all subjects had the smallest value of P100 latencies for the red color (red-black checkerboard stimuli). Subjects S2, S3 and S4 had revealed no statistically significant difference of the P100 latencies for the blue and green color stimuli. Only the subject S1 had a statistically significant greater value for the blue P100 latency in comparison with the green stimuli. The light scattering occluder caused increase of P100 values for all color stimuli. The smallest values of P100 latencies, similar as in conditions without the scattering plate, were for the red stimuli. The higher of P100 values in measurements with the light scattering occluder were determined for the blue stimuli (subjects S1, S2, S4). On the contrary, the P100 latencies of the subject S3 for the blue stimuli were not different in comparison with latencies for the green stimuli in measurements with the light scattering occluder. The greatest relative changes in P100 latency values comparing results of measurements with and without the scattering occluder were observed for the blue color stimuli, the smallest – for the red color stimuli (subjects S1, S2 and S4). For the subject S3 we have revealed more or less proportional increase of P100 latencies for all color stimuli. By analysis of results of the P100 latencies and visual acuity measurements we have found good correlation between these characteristics for subjects S1 and S2 (R^2>0,79). For two other subjects correlation had lower R^2 values.

Results in VEP method for subjects have more differences than in acuity measurements. The one of the reason could be that VEP results are affected by different properties of stimuli and subject's anatomical and physiologic parameters of visual pathways (Arden *et al*., 1977). Hidajat and Goode found that the glare affect only VEP amplitudes, not latencies (Hidajat *et al*., 2000). This data do not correspond to our results which have shown significant changes in latencies when light scattering was increased. Hidajat and Goode put light sources near the stimuli to create the straylight. As it was previously mentioned (see chapter "Method for assessment of visual acuity in normal conditions and in high light scattering conditions"), such method not always is good to create the glare, because not only optical factor, but neural lateral interactions are involved in such measurements (van den Berg, 1994).

VEP method did not show advantages in comparison with visual acuity method. Results are affected not only by optical but also by neural factors in both methods. Beside precision in the VEP method is affected by the signal to noise ratio. However, results for the colored stimuli in both methods have shown good correlation and it is possible to use the VEP method for the assessment of visual acuity for the colored stimuli.

3.4 Spectral dependence of retinal straylight measured with direct compensation method

Retinal straylight values for the red, green and blue color are shown in **Fig. 3.3**. Measurements were done with LED stimulus. Data are compared with other authors' results. 9 subjects (age 21–28) participated in this experiment.



Ikaunieks *et al*, 2009 (2)

Coppens *et al.*, 2006

Figure 3.3. In the picture on the left retinal straylight values of 9 subjects for the blue (dominant wavelength 471 nm), green (546 nm) and red (604 nm) stimuli are shown. The black line corresponds to the Rayleigh type scatter ($\propto\lambda^{-4}$). In the picture on the right data from other authors are shown. Results are grouped by age of subjects and eye colors (bl – blue; gr – grey; br – brown, pbr – dark brown).

The largest retinal straylight was for light with short wavelength (blue color), the smallest straylight was for light with middle wavelength (red light). For measurements of the retinal straylight we used broad band stimuli (**Fig. 2.2.**). Coppens *et al.* in their measurements used monochromatic stimuli. However, our results show similar tendencies with other researchers' data for the same age group (Coppens *et al.*, 2006). We did not group subjects by color of the eye, because it was not task of our research.

Since we get similar spectral dependence of the retinal straylight with other authors' data, in next intraocular light scattering researches we used only the direct compensation method. And the principle used in the direct compensation method is the most promising in comparison with other light scattering tests (van Rijn *et al.*, 2005).

3.5 Spectral dependence of retinal straylight in the fog

Straylight parameter values *s* and their standard deviations, obtained by subjects GI and MO (aged 29 and 59 respectively) in different visibility levels of fog for different color light sources, are shown in **Fig. 3.4**.

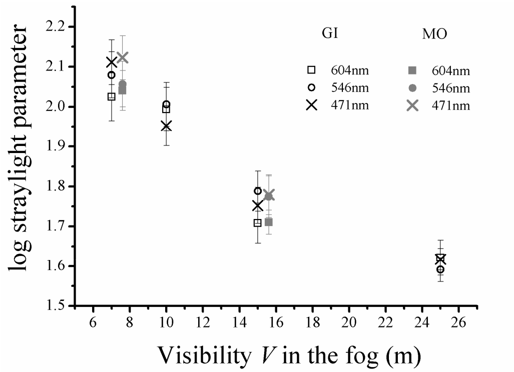


Figure 3.4. Values of the logarithm of the straylight parameter *s* for two subjects at different levels of fog visibility *V* and for different colors (blue (471 nm), green (546 nm) and red (604 nm)) of scattered light *s*. For subject MO, measurements were made only at fog visibility *V* of 7 and 15 m. Data for subject MO are shifted 0.6 units to the right (Ikaunieks *et al.*, 2009 (1)).

Reduction in the visibility *V*, of the fog results in an increase in the straylight values for all three colors. Values of log(*s*) under any visibility condition are very similar for all colors, implying that the scattering by the fog droplets shows little or no spectral dependence. Such results will be expected due to the relatively large size of the scatterers – water droplets of mean size 4 µm (Colomb *et al.*, 2008).

For subject GI measurements were done at fog visibility 7, 10, 15 and 25m. For subject MO, measurements were made only at fog visibility *V* of 7 and 15 m. No statistically significant differences were found between the intraocular straylight values of *s* determined by the two subjects for different colors.

Straylight measurements taken with a commercial device show that subjects GI and MO have different levels of entoptic (intraocular) scatter due to their different ages.
As mentioned previously retinal straylight could be produced by entoptic factors s_{ent} and ectoptic factors s_{ekt} (Vos, 2003). Total retinal straylight is the sum of both factors:

$$S = S_{ent} + S_{ekt} \quad (3.1).$$

Therefore we might expect that different straylight values would be found for the two subjects in fog (at least for low fog densities). However our measurements showed similar values in fog for both subjects. This inconsistency could be due to the limited precision of our measurements but can more probably be attributed to the fact that the straylight values in fog were much higher than those under normal conditions (**Table 1**). We can suppose that, for the dense fogs, entoptic straylight has only a weak impact on the total straylight value.

The relationship between the visibility V and the straylight parameter s is close to exponential ($R^2 > 0.85$). Such a relationship would be expected from Equations (2.1) and (2.2). Expressing the extinction coefficient σ_t from Equation (2.2) and placing this expression in Equation (2.1), we can obtain a relationship between the visibility V and the transmission factor T:

$$T = e^{-\left(\frac{3}{V}\right)d} \quad (3.2).$$

The distance between the light source and sensor d in our fog measurements was constant at 5 m (and equal to the distance at which measurements were made). Equation (7) shows that the relation between visibility V and the transmission factor T, both of which are related to the light scattering properties of the fog, is exponential. If we hypothesize that, for dense fogs, entoptic straylight has only a weak impact on total straylight, in our experiment we actually measured the light scattering properties of the dense fog. With increasing or decreasing visibility V, the light scattering properties of the fog changed exponentially. Our results confirm that entoptic straylight has a weak impact on total straylight in dense fog conditions.

3.6 Use of PDLC cell for simulating of high level light scattering conditions

Results with and without the light scattering filter under normal laboratory conditions using the CRT stimuli are shown in **Fig. 3.5**. For both subjects (GI and VK) intraocular straylight values with and without the PDLC plate are the greatest for the blue color. Under natural conditions (without the light scattering filter) significantly greater s values were found with red stimuli as compared with green. These results agree with those of previous studies, which showed higher straylight values for red compared with green light (Coppens *et al.*, 2006). When light scattering was induced by the PDLC plate with transparency 0.4 both subjects showed a greater straylight value s for the green than for red stimulus.

Fig. 3.6. shows in more detail the dependence for subject GI of the straylight parameter s on the light transparency and scattering levels of PDLC plate for the three colors. Measurements at transmittance 1.0 were made with the naked eye, without any scattering filter. For all transmittance levels, the greatest straylight values s were observed for blue stimuli. Comparing the results for green and red stimuli, although for the low-scattering, high-transmittance condition the red scattering s_r was higher, the straylight values s_g for green stimuli increased relatively faster as the transmittance decreased and the scattering increased, so that at high scattering levels $s_g > s_r$.

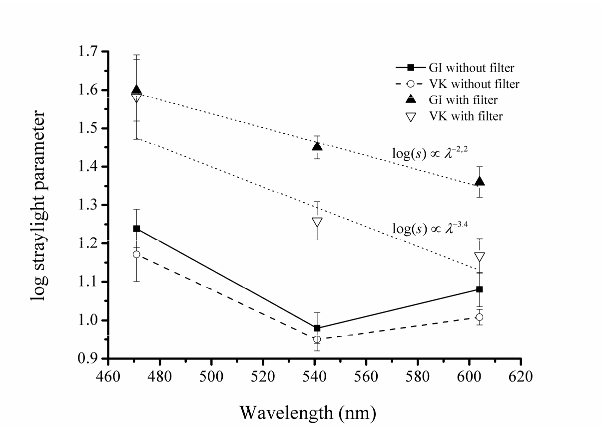


Figure 3.5. Logarithm of straylight parameter, *s*, at different wavelengths for two subjects (GI and VK) without and with a polymer dispersed liquid crystal (PDLC) filter. A fit to the spectral dependence of the straylight measured with PDLC filter is shown for both subjects (Ikaunieks *et al.*, 2009 (1)).

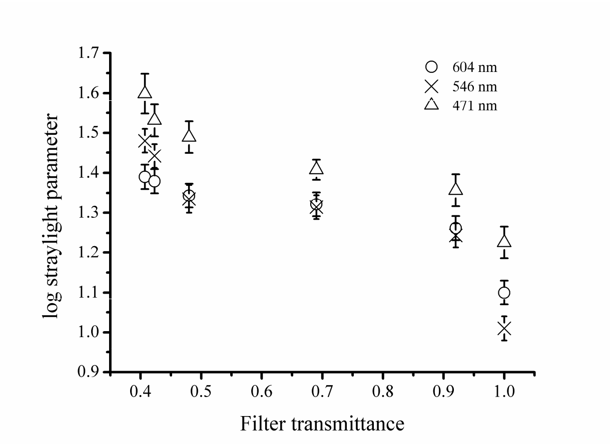


Figure 3.6. Logarithm of straylight parameter *s* for broadband red, green and blue stimuli using PDLC filters with different transparencies (measured at 530 nm) for subject GI. Measurements at transmittance 1.0 were made without any filter in front of the eye (Ikaunieks *et al.*, 2009 (1)).

Measured straylight in experiments with electrically controllable scattering in the PDLC plate reached values up to 1.6 log(s) units and showed a noticeable wavelength-dependence (**Fig. 3.5**). Physical measurements of light scattering by PDLC filters also show wavelength-dependence (**Fig. 2.4**) (Ozolinsh *et al.*, 2004, Bueno *et al.*, 2008). The scatterers in a PDLC filter are, however, of submicron size and hence larger than the scattering particles in the young cornea or clear lens (radius of protein α-crystallins is ~10 nm (van den Berg, 1997)). Thus the straylight initiated by light scattering in the PDLC plate has a weaker spectral dependence than that of Rayleigh scattering ($\propto \lambda^{-4}$). Approximation of the spectral dependence of the scattering to a power function of the form $s \propto \lambda^m$ gives a power value $m = -2.2$ for subject GI and $m = -3.4$ for subject VK (**Fig. 3.5**). Such spectral dependence means that PDLC plates cannot adequately simulate the scattering produced by cataract or fog when polychromatic stimuli are used.

However, by itself the scattering parameter s fails to give enough information to allow decisions on visual quality in different conditions to be made. When choosing an appropriate light scattering filter for cataract simulation, the impact of the filter on contrast vision and visual acuity is also important (de Wit *et al.*, 2006). Our previous measurements show (Ikaunieks *et al.*, 2008 (1); Ikaunieks *et al.*, 2008 (2)) that decimal visual acuity when looking through the PDLC plate with high-contrast Landolt stimuli is ~1.4 (–0.15 in logMAR units). Such a level of visual acuity is acceptable for early cataract stimulation (de Wit *et al.*, 2006). We also found a similar visual acuity (~1.3 in decimal units) for fog with a visibility V = 15 m (Ozolinsh *et al.*, 2006). This shows that, with a PDLC filter, we can roughly simulate some levels of fog or cataract when achromatic stimuli are used.

Table 1. Straylight values and spectral dependencies for different visual conditions (Ikaunieks *et al*., 2009 (1))

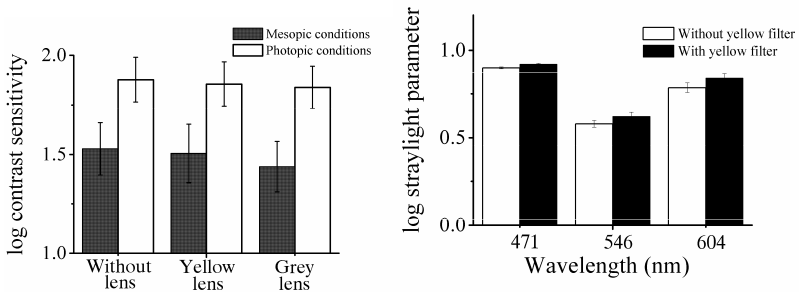
	Log (*s*) values for visible	General characteristic of spectral dependence
29 year old subject GI (normal condition)	1.08–1.24	Maximal value for blue color, minimal for green color [For short to medium, wavelengths close to Rayleigh scattering (power -4)]
Artificial fog (for visibility 7–25 m)	1.60–2.10	No spectral dependence
PDLC scattering filter (transparency 0.4)	1.36–1.60	Straylight value reduces with increasing wavelength; power -2.2 (for subject GI) and -3.4 (for subject VK)
Non-pathologic age-induced increase of straylight parameter*	< 1.20	Close to clear eye
Cortical cataract†	1.36	No or small spectral dependence, which decreases with the amount of light scatter (results from lens *in vitro* studies)‡
Nuclear cataract†	1.53	
Post-subcapsular cat. †	1.68	

*Data from Coppens *et al.* (2006).
† Data from de Waard *et al.* (1992).
‡ Data from Costello *et al.* (2007); Thaung *et al.* (2002) and van den Berg (1997).

3.7 Changes in retinal straylight looking through yellow filters

Averaged contrast sensitivity values of 27 subjects in mesopic and photopic conditions are showns in **Fig. 3.6.a**. Measurements done with yellow filter didn't show statistically significant values comparing with measurements done without filter. In mesopic conditions contrast sensitivity was significantly lower with grey filter than with yellow filter. In mesopic conditions we also asked subjects to assess in which case – without filter; with yellow filter or with grey filter – they feel more comfortably. 56 % subjects answered that they feel more comfortable with yellow filters than with grey filter or without any filter in front of the eye. Our measurements partly approve other author results (*Kelly*, 1990), which showed small improvement of object perception looking through yellow filter.

Results of the straylight parameter *s* measurements done with and without a yellow filter for one subject are shown in **Fig. 3.6.b.**



a) b)

Figure 3.6.
a) Averaged contrast sensitivity values of 27 subjects in mesopic and photopic conditions. Measurements first were done without filter, than with yellow filter (transmittance 67 %) and the last with grey filter (transmittance 73 %). Standard deviations are showed for each measurement. (Slica *et. al.,* 2010).
b) Straylight values with and without a yellow filter for the blue (471 nm), green (546 nm) and red (604 nm) stimuli. Results are shown for one subject. Standard deviations are showed for each measurement (Ikaunieks *et al*., 2009 (2)).

The straylight was stronger in the measurement with a yellow filter than in the normal conditions for all three colors. The same tendency was also found for others subjects. Our additional measurements showed that tinted spectacle lens increases retinal straylight more than clear lens (Stepanovs *et al.,* 2010). Other authors have shown that colored contact lenses (amber and grey-green) also show larger straylight values than clear contact lenses (Cerviño *et al.*, 2008). We can conclude that tinted filters (also yellow) increase the retinal straylight. Larger retinal straylight was also for the blue light, which is absorbed for the greater part by yellow filter. These results do not confirm the assumption that yellow filter removes blue light and thus reduces light scattering in the eye. In other investigations authors argued that the improvement of contrast sensitivity in low light condition should be more related to neural mechanisms (brightness – enhancement effect) than to optical ones (*Kelly*, 1990; *Rabin* et al., 1996). Our results confirm such assumption.

3.8 Evaluation of amount of light which penetrates through sclera and iris using occluder with small aperture

Results of measurements of the straylight parameter *s* which had been done with and without aperture (diam. 5 mm) for green and red color are shown in **Fig. 3.7**. For each measurement the standard deviations is shown. A circular aperture in front of the eye reduces intraocular light scattering from both light sources (red and green). As it was expected, the greatest changes are for the red color, since less light penetrates through the ocular wall when the aperture is used.

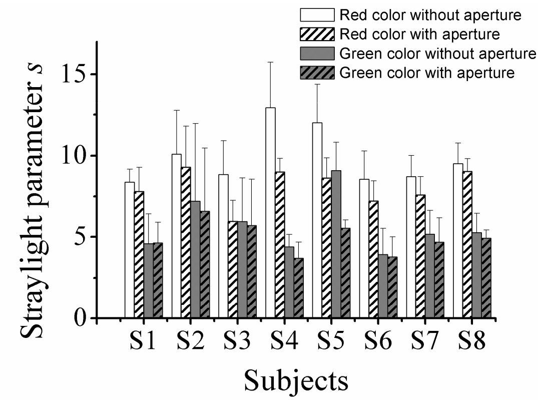


Figure 3.7. Straylight values for red and green color stimuli with and without 5mm aperture (Ikaunieks *et al.*, 2009 (2)).

Statistical analysis (t-Test: Paired Two Sample for Means) shows that the retinal straylight for the red light significantly decreases ($p<0.004$) if a small aperture is put in front of the eye. Results for the green color measured with and without an aperture did not change significantly. Results show that it is possible to use a small aperture for evaluation of amount of the light which penetrates through the sclera and the iris. Additional measurements are needed to assess possibility to use such method for evaluation of pigmentation level of the eye in clinics.

4 Conclusions

1. Three methods – psychophysical visual acuity measurements with and without glare source, VEP method and direct compensation method – were evaluated for disability glare and straylight measurements. Straylight the mostly reduces perception of blue color stimuli. Perception of color stimuli in normal and high level light scattering conditions is more affected by neural than optical factors.

2. For subjects younger than 30 years retinal straylight has spectral dependence close to Rayleigh scattering ($\propto \lambda^{-4}$) with increment of straylight values for long wavelengths light.

3. Psychophysical retinal straylight measurements didn't show spectral dependency in the dense fog (*Visibility* V= 7–25 m). Entoptic straylight (Log(s) ≈1.10) in such conditions is significantly smaller than ectoptic straylight created by artificial fog (Log(s) ≈1.80).

4. With PDLC plate it is possible to simulate the same light scattering level as created by dense fog or cataract. The straylight initiated by light scattering in the PDLC plate has spectral dependence therefore it is possible to use PDLC plate for stimulation of dense fog or cataract only when achromatic stimuli are used.

5. Measurements show that for subjects younger than 30 years yellow filter don't reduce light scattering in the eye.

6. When light which penetrates through the sclera is reduced by putting small aperture (diam.=5 mm) in front of the eye, retinal straylight for red light decreases more than for green light. Results show that it is possible to use small aperture for evaluation amount of pigmentation in the eye and amount of light which penetrates through sclera.

5 Publications

1. Ozolinsh, M., Colomb, M., Ikaunieks, G. and Karitans, V. (2006). Color stimuli perception in presence of light scattering. *Visual. Neuroscience.* 23, 597–601.
2. Bueno, J. M., Ozolinsh, M. and Ikaunieks G. (2008). Scattering and depolarization in a polymer dispersed liquid crystal cell. *Ferroelectrics* 370, 18–28.
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5. Ikaunieks, G. and Ozolinsh, M. (2008). Effect of light scattering simulation in the eye on different color stimuli perception. *IFMB Proceedings*, 20, 367–370.
6. Ikaunieks, G. and Ozolinsh, M. (2008). Factors affecting intraocular light scattering from different color straylight sources. *Proc. SPIE*, Vol. 7142, p. 71421A.1–71421A.6;

   DOI:10.1117/12.815622.

Thesis in international conferences

1. „**Developments in Optics and Communications**”, Riga, April 23–25, 2010. Influence of tinted spectacle lenses on intraocular stray light. Stepanovs A., Ikaunieks G., Ozola K. and Ozolinsh M., *Abstract book*, Riga, 2010, in press
2. „**Developments in Optics and Communications**”, Riga, April 23–25, 2010. Effect of yellow filters on vision. Slica S. and Ikaunieks G., *Abstract book*, Riga, 2010, in press
3. „**Developments in Optics and Communications**”, Riga, April 24–26, 2009., Effect of optical and physiological factors on light scattering in the eye. Ikaunieks G., Ozolinsh M., Stepanovs A., Lejiete V. and Reva N., *Abstract book*, Riga, 2009, p. 40
4. „**14-th Nordic – Baltic Conference on Biomedical Engineering and Medical Physics**”, Riga, June 9–13, 2008. Effect of light scattering simulation in the eye on different color stimuli perception. Ikaunieks G. and Ozolinsh M., *Abstract book*, Riga, 2008, p. 100
5. ”**The 6-th International Conference on Advanced Optical Materials and Devices**”, Riga, August 24–27. 2008. Factors affecting intraocular light scattering from different color straylight sources. Ikaunieks G. and Ozolinsh M., *Abstract book*, Riga, 2008, p. 89
6. „**4-th European Meeting in Visual & Physiological Optics**”, August 31 – September 2, 2008. Heraklion, Greece. Intraocular light scattering from different color straylight sources. Ikaunieks G. and Ozolinsh M., *Abstract book*, Greece, 2008, p. 40
7. „**30-th European Conference on Visual Perception**”, Arezzo, Italy, August 27–31.2007. Light-scattering effect on colour-pattern VEP response. Ikaunieks G., Ozolinsh M. and Fomins S., *Perception. ECVP Abstract Supplement*, Vol. 36, Great Britain, 2007., p. 39
8. „**Developments in Optics and Communications**”, Riga, April 27–29, 2007. Retinal straylight measurements with different wavelength light. Ikaunieks G, Lejiete V. and Ozolinsh M., *Abstract book*, Riga, 2007, p. 16.

9. „**29-th European Conference on Visual Perception**", St-Petersburg, Russia, August 20–25. 2006. Light scattering effect on central and peripheral visual acuity. Ikaunieks G. and Ozolinsh M., *Perception. ECVP Abstract Supplement*, Vol. 35, Great Britain, 2006., p. 129
10. „**29-th European Conference on Visual Perception**", St-Petersburg, Russia, August 20–25. 2006. Scattering-induced luminance and colour contrast decrease in visual perception. Ozolinsh M, Colomb M, Parkkinen J, Ikaunieks G, Fomins S, Karitans V and Krumina G., *Perception. ECVP Abstract Supplement*, Vol. 35, Great Britain, 2006., p. 136
11. „**28-th European Conference on Visual Perception**" Different colour contrast stimuli perception in fog. Ozolinsh M., Colomb M., Ikaunieks G. and Karitans V., *Perception. ECVP Abstract Supplement*, Vol. 34, Great Britain, 2005., p. 192

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