SPECTRAL DISTRIBUTION AND DYNAMICS OF STIMULATORS FOR SELECTIVE CONE EXCITATION

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Abstract: For early detection of eye dysfunctions which are caused by glaucoma, optic neuropathy and other forms of ophthalmic and neurologic pathology a selective cone excitation on biological level is necessary. By the use of a RGB-stimulator which enables a free choice of stimulation-colour and –pattern it is possible to isolate the specific cone type responses. The right choice of a practical stimulator is very important for a high efficiency of the cone excitation. In our investigations we used two selection criteria - the spectral properties inclusive the effects on the biological level and the dynamic behaviour at the screen change for a stimulation sequence. For an easy handling with the stimulator and for a simple realisation of stimulation sequences, the tested RGB-systems are commercially available. After the investigation of the spectral and dynamic properties we could find a suitable cone stimulator.

Introduction

Colour vision defects and their correlation with ocular disease have been reported since the 17th century [1]. At the beginning of the 19th century Köllner implicated the progressive loss of colour sensation to eye diseases. For the first time he developed a distribution of two major colour sensation dysfunctions and tried to assign typically disease pattern to them. The so called Köllner-Rule predicates that retinal diseases develop blue-yellow discrimination loss, whereas optic nerve disease causes red-green discrimination loss [1], [2]. Today we know some exceptions to this rule. For example some retinal disorders such as central cone degeneration which may result in red-green defects [1], [3]. Especially on the field of colour defects the interest became capacious in the last two centuries. One focus was the use of colour perimeter to early detection of dysfunctions which are caused by glaucoma, optic neuropathy and other forms of ophthalmic and neurologic pathology. For a high diagnostic account, the investigation of the individual specific cones is necessary. A widespread method is the use of a coloured background in a perimeter, which should reduce the sensitivity of e.g. two cone types. A stimulation field causes the excitation of the remaining cone type. The Blue on Yellow perimetry utilises this mechanism and is so able to reach a partial isolated S-cone excitation = SWS (short wavelength sensitive cone mechanism) [4], [5]. For excitation of several cone types selectively it is suggestive to use an RGB-stimulator which enables a free choice of stimulation-colour and -pattern. The more complex and difficult stimulation technique - silent substitution technique (SST) - in combination with a suitable stimulator allows a sharper isolation of the specific cone type responses [5], [6].The choice of a practical stimulator is very important for a high efficiency of the cone excitation. The selection criteria are spectral properties as well as dynamic behaviour at the screen change by a SST stimulation sequence. For an easy handling with the stimulator and for a simple realisation of the SST the investigated RGB systems are commercially available.

The initial point for the spectral appraisal is the spectral distribution function from each primary valence of the RGB-system [7]. The proceeding at the spectral investigation is based on the principles of the picture generating by TFT-LCDs (thin film transistor - liquid crystal display) and Plasma systems. Only if the two points are completely investigated, the choice of a suitable stimulator can follow.

Materials & Methods

Technical Basics: Following stimulators were tested: two TFT displays “MYRICA V30” (Fujitsu Siemens®), “VP230mb” (ViewSonic®) a D-ILA projector “FX21” (JVC®), a DLP™ projector “XD400” (Mitsubishi®) and one plasma display “TH-42PHD5EX” (Panasonic®). These devices were divided into two groups regarding to their technology. The displays and the D-ILA projector are using an electro-optic-active material for modulation of the light and do not generate light. The modulating material is a liquid crystal (LC) with anisotropic characteristics (optical and electric anisotropy). The LC molecules show a weak dipole moment added by two dielectric numbers – one of them parallel to the molecule axis = $\varepsilon_{\parallel}$ and another perpendicular to it = $\varepsilon_{\perp}$ [8], [9]. By impressing an external electric field the own moment is superposed by an induced electric dipole moment. The result is a turning moment which affects all molecules. In case of positive electric anisotropy the moment turns the molecules parallel to the electric field. Thus the direction is switchable and therewith the optical attributes of the LC are influenceable. Based on these characteristics the LC is able to polarise transmitted light more or less. This is the basic function of the LCD. Is the LC located between two

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equal aligned polarisers, the first one polarises the light linear. After that a turning of the light polarisation axis about a fix angel occurs. The second polariser cannot be transmitted because of its alignment and the light will be absorbed. This cell seems black without applied voltage (OFF-state). By siting a voltage, the molecules align with the streamlines of the field as described above. Due to this abrupt changeover, the polarisation state of the light cannot follow. The result is a loss of turning in the LC layer. Transmitting light can now pass the second polariser, the LCD seems bright (ON-state). Thus it is possible to control the intensity of a wideband light which is generated behind the LC by transmitting through the pixels [9].

The plasma stimulator is using phosphor for generating the light actively. First of all in every pixel element inert gas like Xenon is activated. In the form of plasma gas it sends out characteristic radiation in the ultraviolet band. This radiation invades the phosphor and activates atoms in its crystal lattice, which results in the emission of visible light. According to this principle every Pixel is able to send out light or seems black. The intensity of the light is inspectable only by pulse modulation or pulse frequency modulation, see Figure 3 [10]. Between both described technologies the DLP™ projector is located. The DLP™ chip is a digital micromirror device and cannot generate light directly. It works as a light switch and contains a rectangular array of huge amount of hinge-mounted microscopic mirrors. In one position the mirrors can reflect light from a light source through an optical system on a screen (ON-state). In the other position the light will be internally absorbed by a beam stop (OFF-state). Each mirror is able to switch on and off up to several thousand times per second, so it is possible to generate grey tones via frequency modulation [11].

The explained facts about the technologies already show that there must be differences in the spectral parameters and the dynamic behaviour. That has to be researched and observed. For the usage of the stimulators to a selective cone excitation it is important to compose the spectral impulses for a high effect on biological level. The maximum effect is definited by the spectral parameters. The evaluation of these parameters referenced to the biologically effect is presented in point *spectral properties*. Furthermore an exactly temporal and spatial modulation of the stimuli is important. A partial investigation you can find in point *dynamic properties*.

Spectral properties: The evaluation of the ability of the stimulator for selective cone excitation begins with its spectral distribution function $\Phi(\lambda)$. The measurement was done with the spectrometer CAS 140B (Instrument Systems®) that captures all spectral components simultaneously with a diode-array detector and a spectral resolution from 1.5nm. For the radiometric measurand the irradiance [W/m²nm] was chosen. The three primary valences of the stimulators were measured with maximum brightness in the range from 380nm up to 1050nm. For the further investigation only values up to 780nm were considered but for calculations of the potentially damage of the retina the extended range is needed. Because of the later application for central flash stimulation all measurements were made on the central point of the displays or on projection areas. Especially the LC-stimulators show a strong dependency of all parameters from the viewing angel. For multi focal stimulations the stimulator has to be tested on a suitable spatial grid

For validation of the spectral distribution concerning the biological effect two ways of calculation are possible. Basically the spectral properties of the stimulator, which are described in a technical level (RGB-system), must be transformed into the biological level of the L-, M- und S-cones (LMS-system). One way for solution is the usage of the cone fundamentals. They are based on the colour matching functions (CMFs). The cone fundamentals can be thought of as CMFs of three imaginary matching lights, each of which exclusively and separately stimulates the one of the three cone types [12]. Thus the cone fundamentals describe the match of intensities of the three cone primaries to the wavelength of monochromatic test light of equal energy. Per multiplication of the fundamentals with the spectra of the three primary valences of the stimulators, it is possible to calculate a 3x3 matrix. A specific cone type constant is needed additionally; so there are three constants k_l, k_m and k_s. In the result the matrix enables a direct transformation from the RGB-system into the LMS-system [13].

The second way calculates the biological effect of the stimulator by its description in the CIE XYZ-system. Therefore each colour valences of the stimulator were specified by three chromaticity coordinates. These coordinates belong to a virtual CIE primary valence system and they are always positive. In this XYZ-system an adjustment to special white points can be done easily. The usage of a special colour model makes it possible to quantify the amount of absorbed radiation for every cone type caused by a XYZ-defined stimulus. The outcome of this is a gauge for the biological effect in the LMS-system. A basic feature of the used model from Hunt is the choice of a set of spectral sensitivity functions for the cones of the retina. The set chosen by Hunt are linear combinations of the colour matching functions for a standard colorimetric observer [14]. The calculation from the XYZ-system to the LMS-System takes place via linear transformation by using a 3x3 matrix, see formula 1.

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0{,}38971 & 0{,}68898 & -0{,}07868 \\ -0{,}22981 & 1{,}18340 & 0{,}04641 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{1}$$

The L-,M- and S-values can be interpreted as amount of absorbed radiation on the considered cornea area. Following these values are named as an activation. By regarding the spectral distribution in association with the activation in the separate colour channels, a validation of the stimulator concerning to its biological effect is possible.

Dynamic properties: If the stimulator should be used for a SST application, it is necessary to generate special colour combinations [15]. By changing between the

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combinations, which causes different activations, it is important to have a fix and known timing. According to ISCEV standard e.g. a maximum stimulation rate for a flash stimulation must be ensured. 1.5Hz and the on-state is at most 20ms to avoid on-off effects. Within this time it is necessary to hold the luminance, which was calculated before, constant. The procedures in every screen change (= stimuli change), are combined as dynamic properties in the following. Referring to this the analysed stimulators only contain insufficient manufacturers' instructions.

The main parameter, which underlies the dynamic examination, is the response time for the screen change. For the evaluation of this parameter, there exist different definitions. By using the EN ISO 13406-2:2001, the determination occurs through the evaluation of the luminance progress during a complete screen change (black-white-black). The measurement limits refer to 10% and 90% of the maximum luminance. The analysis of a luminance proportional value is also possible. The starting point of all measurements consequently was the detection of a photometric value. Therefore it exists a multiplicity of different measuring instruments. While choosing an adequate technique it is useful to look at the timing parameters they shout measured. Furthermore the sensor must be aligned to the wave length range and the radiant intensity of the stimulator. For the precision of the measured values the spatial and temporal dynamic of the sensor is important. Exemplary the temporal dynamic can be estimated by calculating the time constant τ_{sum} of the measuring section. See formula 2.

$$\tau_{sum} = R_{in\_oszi} \times \left(C_{in\_oszi} + \left(C_{wire} \times l_{wire} \right) + C_{sensor} \right) \qquad (2)$$

With: R_{in_oszi} = input resistance from the digital oscilloscope; C_{in_oszi} = its input impedance; C_{sensor} = sensor impedance; l_{wire} = cable impedance [16]. For the evaluation of the spatial dynamic the sensor surface area referenced to the amount and width of the screen line is important. The lines were accessed by fixed line tact. The less lines are lying beyond the sensor area the less measurement errors follow. An acceptable compromise concerning to the needs above is a special PIN-diode (Siemens®). The analysis of the diode signal was made by using a digital oscilloscope (Tektronix®). The signal limits are the same as described is EN ISO 13406-2:2001. The test sequences for the stimulators which simulate the colour changes were generated with the help of the special software ImagePro. The response time for a screen change composed of rise- and fall-time for 55 different grey-tones was reached. Additional dependences of the dynamic, caused by e.g. temperature or the position of the stimulation on the display, were not considered.

Results

First of all the tested stimulators were evaluated by its spectral properties. Afterwards the suitable stimulators were investigates concerning to their dynamic properties.

Spectral properties: There are big differences between the tested stimulators in point of spectral distribution and the resulting activations of the several cone types in each colour channel. The greatest activation values show the S-cones for the blue colour channel, followed by the L-cones for the red channel and at least the M-cones for the green colour channel. That means that a selective M-cone excitation is the most ineffective. However, for the consideration of a visual evoked potential (VEP), caused by the stimulator, the absolute amount of cones of a cone type on the retina is important. By comparing the activations from the maxima to the minima between the stimulators, there is a range from 20% for the S-cones, 7% for the M-cones and 4% for L cones. These values are also reflected in the different spectra of the stimulators. The following figure shows this fact in case of the blue channel spectra from the D-ILA projector compared to the plasma display. The activations are 0.9 for the projector and only 0.83 for the display.

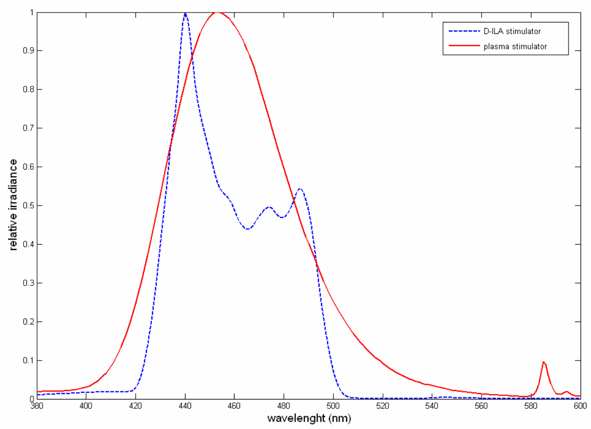

Figure 1: relative irradiance for two stimulators

For a usage as a selective S-cone stimulator this investigation is very important. All calculated values are based on the 2 degree standard observer. In Figure 2 the results for one stimulator are shown. A comparison of the channels makes clear the fact of overlapping filter edge. Almost every tested stimulator shows these edges. The result is a reduced activation level. Only the D-ILA projector has sharper edges. By considering all results, three stimulators are suitable for a further investigation. The D-ILA projector as well as the TFT-display "MYRICA V30" has high activation levels in all channels. With limitations in the blue colour channel the plasma display was also tested for its dynamic properties.

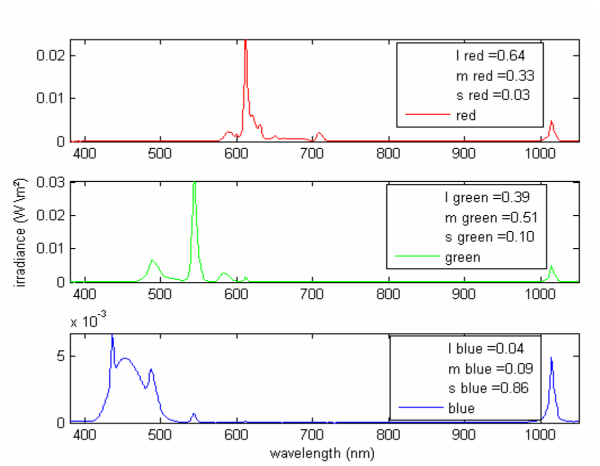

Figure 2: RGB-activation for the "MYRICA V30"

Dynamic properties: As noted below the D-ILA projector and the TFT display use a LC-crystal as the electro-optical element. But their production of colour and picture is very different from each other. The projector uses one LCoS chip (Liquid Crystal on Silicon) which reflects light from a light source. The production of colour is sequential via a colour wheel. The display has three filters per pixel which enables an additive colour mixing. The plasma display also has three different coloured pixel, but they generate the light actively (see Materials & Methods). In Figure 3 the pulse frequency modulation for a mixed colour is shown.

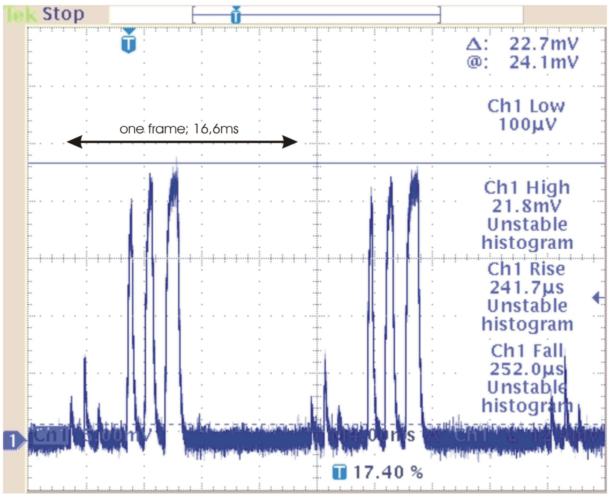

Figure 3: blue-tone - RGB = 0;0;150, time base 4ms

The pulses with lower ms limits can be perceived by the human eye and can change the VEP. For this reason we renounced the application of plasma displays. The D-ILA projector showed excellent response times at the screen change. For example a black–red-change had a 6ms rise-time and a 4ms fall-time (see Figure 4).

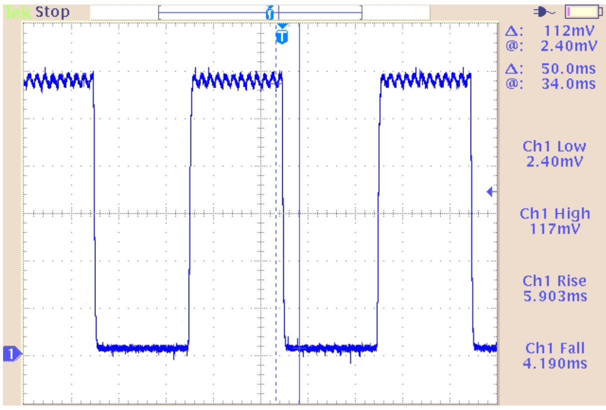

Figure 4: full black-red change; D-ILA - Beamer

Furthermore the dependency of response time for the tested sequences is very low. However the non direct view presentation of stimulations represents a problem. The resulting spectrum is dominated by the reflection properties of the presentation area. The requirements on the place of investigation are increased.

The best compromise represents the "MYRICA V30". The measured timing parameters for the investigated grey tone sequences are shown in Figure 5. Every grey tone sequence is readable by a combination of line- (x-axis) and column- (y-axis) vector. On the z-axis the considering time parameter is displayed. Regions of lower times (local minimum) and grey tone combinations, which are adverse for a stimulation (local maximum), appear.

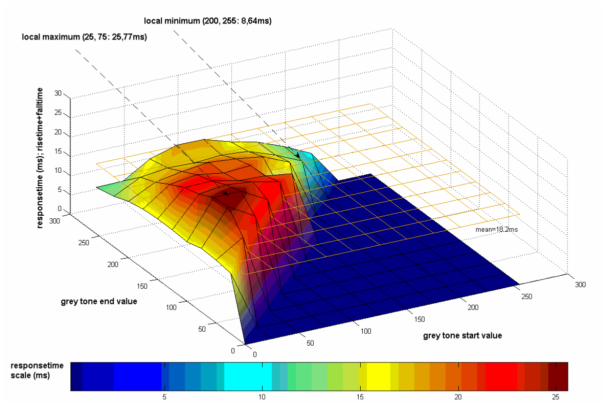

Figure 5: response times "MYRICA V30"

The figure makes clear that a combination differing from black-white causes higher response times. The maximum amounts to 26ms, but the minimum is only 33% of this value (8,6ms). Thus the stimulator has a dynamic which is different from the displayed colour value. The manufacturers' instructions do not explain these facts but it must be known for generating a suitable timing. In the figure below it is represented clearly.

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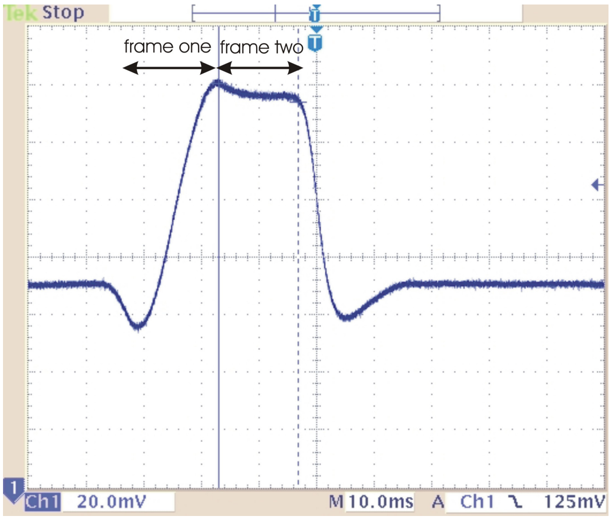

Figure 6: dynamic of a SST stimulation

For a calculated SST colour combination a special response time follows. The figure shows two frames for the on-state. One frame is needed for reaching the maximum and calculated luminance. It is recognizable that two frames = 33,3ms are needed for the on-state, but no critical excess length is incidental.

Discussion

For the excitation of several cone types with a stimulator extensive preliminary investigations are necessary. The choice of a suitable stimulator already begins with a comparison of the different technologies. Associated to that a continuative analysis of the spectral properties takes place. It was shown that it is possible to transform from the technical RGB-system into the biological LMS-system by using a special colour model. Only at this level the evaluation of the stimulator and its effect on the cones can be done. There are existing two similar ways of calculation. We took a decision on the calculation via the XYZ-system. Parallel to the spectral evaluation there must be an analysis of the dynamic behaviour. The correct choice of a stimulation timing is important for a later SST sequence generation. The stimulators are tested concerning to their response times for different screen changes. One stimulator with a suitable compromise could be found. To generate VEPs, plasma displays shout not be used. By testing mixed colours this fact becomes clear. Also the dynamic characteristic from LC-displays could be investigated. They showed an explicit dependence of response time for differed screen changes which influenced the number of frames for the on-state of stimulations.

Conclusions

Finishing it can be noticed that the accomplished evaluation of the stimulators for the use of selective cone excitation is essential. Only on this way it is possible to find a suitable stimulator. At the moment the selected stimulator is used in a clinical study to applying the SST.

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