Measuring the brightness of the retinal reflex to study the accommodative response of stimuli with various spectral distribution

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Introduction.
It is known that brightness of the retinal reflex depends on the refractive state of an eye. This phenomenon is often faced by optometrists and ophthalmologists. Thus accommodation of an eye also contributes to the retinal brightness. This means that the retinal brightness could be used to measure the accommodative lead and lag characteristic to the accommodative response [1].
There is a wide variety of techniques for measuring the dynamic accommodation, i.e., the characteristics of accommodation while the gaze is fixated onto moving targets. Among these methods the following methods can be mentioned: infrared photorefraction [2], measurement of anterior chamber depth, MEM dynamic retinoscopy, 3-D OCT, autorefraction etc. However, brightness of the retinal reflex has never been used previously for measuring the accommodative response.
The goal of this study was to design a method and device for measuring the accommodative response to stimuli with various spectral distribution and determine how chromatic aberration affects the behaviour of accommodation in the case of different vergence of stimulus.

Methods.
The effect of changing the accommodative power on brightness of the retinal reflex was first demonstrated in the artificial lens. The artificial eye consisted of a converging lens simulating the cornea and a manually tunable lens ML-20-35-NIR-HR (Optotune) [3]. In the back focal plane a dark matterial with reflectance R = 10 % at the wavelength 850 [nm] was placed.

The manually tunable lens ML-20-35-NIR-HR (Optotune)

Next, the experiment was done also in a living eye. The subject was required to fix the gaze at the region of the stimulus close to the spots created by the near infrared beam. The stimulus was shown to the subject at seven distances: 1 [m], 0.67 [m], 0.5 [m], 0.4 [m], 0.33 [m], 0.29 [m], and 0.25 [m]. At each distance the stimulus was shown sequentially in seven colours: red, green, blue, white, yellow, cyan, magenta. At each combination of the distance and colour one measurement took about 30 seconds. During this period 60 light integrating cycles were performed. During each cycle the light reflected from the retina was integrated for 0.13 seconds. The light gathering was controlled by a circuit the two core elements of which were microcontrollers PIC16F676 and PIC16F84A. The data collected was sent to PC through COM port at baud rate 9600 bps.

In the third stage, the response of the photodiode was modelled as described further.

$$S_R = \pi \cdot \left(d_{1r} - \frac{n_2 \cdot ((n_2 - d_{c1} \cdot F_{cornea}) \cdot l - d_{c1} \cdot n_1)}{n_2 \cdot (1 + l \cdot F_R) - d_{c1} \cdot x + x \cdot (n_2 - d_{c1} \cdot F_{cornea}) \cdot l}\right)^2 \cdot \left(\frac{d_R \cdot (n_2 \cdot (1 + l \cdot F_R) - d_{c1} \cdot x + x \cdot (n_2 - d_{c1} \cdot F_{cornea}) \cdot l)}{2 \cdot n_2 \cdot ((n_2 - d_{c1} \cdot F_{cornea}) \cdot l - d_{c1} \cdot n_1)}\right)^2$$

$$S = S_R + S_{min}$$

$$P_0 = P \cdot \frac{S_0}{S}$$

$$P_{out} = P_0 \cdot \rho \cdot f = P \cdot \frac{S_0}{S} \cdot \rho \cdot f$$

$$l_{focus} = \frac{n_2 \cdot d_{1r} - n_2 \cdot d_{c1} - d_{1r} \cdot d_{c1} \cdot x}{n_2 \cdot (n_2 + d_{1r} \cdot x) + (n_2 \cdot d_{1r} - n_2 \cdot d_{c1} - d_{1r} \cdot d_{c1} \cdot x) \cdot F_{cornea}}$$

$$S_{fda} = S_z \cdot \left(\frac{abs(l_{focus} - l_{fd})}{l_{focus}}\right)^2$$

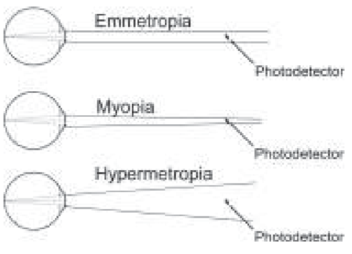
$$P_{fd} = P_{out} \cdot \frac{S_{fd}}{S_{fda} + S_{fdam}}$$

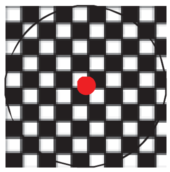
$$q = I \cdot t = P_{fd} \cdot PS \cdot t$$

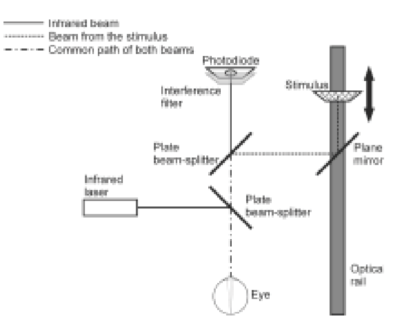
$$\boxed{U = y_o + k \cdot \frac{P_{fd} \cdot PS \cdot t}{c}}$$

Parameters explained
S_r - size of the retinal spot according to the geometrical optics [m^2]
S - the real size of the retinal spot [m2]
P_0 - the incident power on the area from which light reaches the photodiode [W]
P_{out} - power of the outgoing beam at the corneal level [W]
ρ - reflectance at the wavelength 850 [nm]
P - power of the ingoing beam at the corneal level [W]
S_0 - the area from which light reaches the photodiode [m^2]
l_{focus} - the distance at which the outgoing beam is focused [m]
S_{fda} - area of the spot focused at the region of photodiode according to the geometrical optics [m^2]
PS - photosensitivity of the photodiode [A/W]
t - integration period [s]
U - voltage across the capacitor [V]
y_0 - bias voltage [V]
k - scaling parameter
c - capacitance of the capacitor [F]

Brightness of the retinal reflex depends on the refractive state of an eye. Depending on the refractive state of the eye the photodetector captures different amount of light. This phenomenon is frequently observed by ophthalmologists and optometrists.

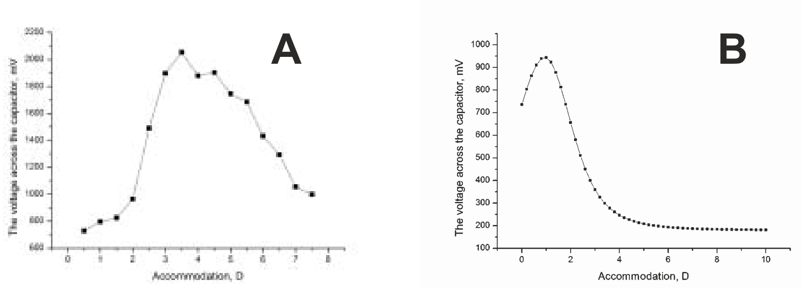


A


B


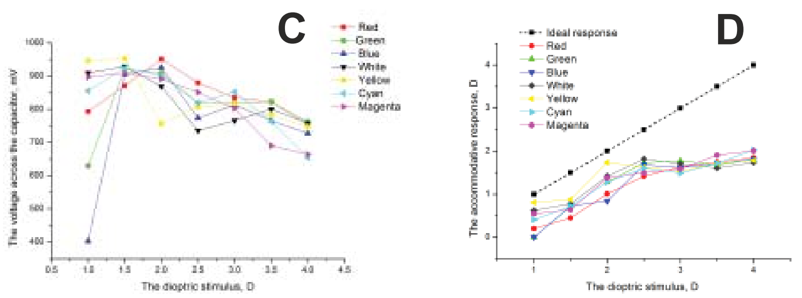
A - the stimulus used in the experiment was a chechkerboard onto which a spot formed by an infrared beam was projected.
B - the scheme of the optical setup used in the experiment.
C - the optical layout on the optical table.

Results.



A - The voltage across the capacitor vs the accommodation of the artificial eye. This figure clearly demonstrates the effect of accommodation on the brightness of the retinal reflex. The peak is located very close to the near-point, i.e., the dioptric distance of the photodiode.

B - The modelled photodiode response according to equation given in the 'Methods' section.



C - the voltage across the capacitor vs the dioptric stimulus shown to the subject. The relationship is shown for stimuli in all seven colours.

D - the accommodative response curves for stimuli in all seven colours based on the modelled response. A large accommodative lag was obtained. However, the value of the accomodative response was ascending as the dioptri stimulus was increased.

Conclusions.
The results suggest that this method and the designed prototype of the device may have potential for measuring the accommodative response of a living human eye. Similar results were demonstrated by Jaskulski et al. during the VPO-2014 conference [4]. One of the advantages of this method is that it is fast and the only requirement for the subject is to fix the gaze at the stimulus.Preliminary results suggest that chromatic effects on accommodation may be more pronounced when looking at distant objects.
The main challenge is to ensure that in the case when there are two possible accommodation values for a given voltage level the correct accommodation value is selected. The method is also sensitive to head and eye movements. Unfortunately, the calibration procedure can't be done in a living eye because it is required to know a precise value of accommodation but determining this value is the goal of this study.

References.
1. E. Gambra, L. Sawides, C. Dorronsoro, S. Marcos. Accommodative lag and fluctuations when optical aberrations are manipulated. J Vis., 9, 1-15 (2009).
2. H. Bossong, M. Swann, A. Glasser, V. E. Das. Applicability of Infrared Photorefraction for Measurement of Accommodation in Awake-Behaving Normal and Strabismic Monkeys. Invest Ophthalmol Vis Sci., 50, 966–973 (2009).
3. http://www.optotune.com
4. M. Jaskulski, L. Thibos, D. R. Iskander, N. L. Gil. Modeling of the effects of chromatic aberration on accommodation response. VPO-2014, Wrocław, Poland, 24th - 27th august, 2014.

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