High-speed video-oculography applied to assess pupil light reflex

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Eye response to light exposure is usually described through the pupillary light reflex, which controls the pupil diameter and allows for testing the sensory and motor functions of the eye. We have arranged an experimental setup and developed a procedure in order to improve the video-oculography experiment through high-speed imaging. The technique has been applied over eleven people distinguishing between consensual and direct pupillary light reflexes and analyzing the eye dominance. We found no significant differences. Moreover, obtained time parameters describing the pupil light reflex agree with those from literature.

Keywords: pupillary light reflex, high-speed imaging

1. Introduction

The size of the eye's pupil automatically determines the amount of light arriving to the retina, so it plays an important role in the system of the eye. The pupil diameter is regulated by two antagonistic muscles of the iris, which are controlled by sympathetic and parasympathetic pathways. The last one controls the sphincter responsible of the contraction of the pupil (myosis) whereas the sympathetic controls the dilation (mydriasis).

Pupillary reflexes are classified in two types: direct and consensual response. The difference lies in the stimulus. We talk about direct response if the pupil receives light and contracts, whereas, if the pupil contracts because the light stimulates only the opposite eye, it is called a consensual response. Both consensual and direct responses in humans have been considered equal [1], whereas an unequal response is attributed to neurological pathology. Nevertheless, some studies found that the amplitude was smaller for the consensual response than for the direct one [2].

Cameras used in the literature to register PLR have a temporal resolution of 15 ms, which are in the limit for proper registering fast eye movements. The latest works used eye trackers, like the Eyelink II [3] or one eye tracker from SensoMotoric [4], sample at 500 Hz or even 1000 Hz, like the Eyelink 1000 [5]. Sampling rates of those devices could detect, in principle, reflexes in the order of milliseconds. However, eye trackers are directed to track eye movements rather than pupil size variations and one must take into account the spatial resolution too. The device from SensoMotoric has a resolution of 200 microns. Regarding Eyelink 1000 and Eyelink II, although pupil size resolution is 0.2 % of the pupil diameter, the measurements are affected by up to 10% due to the optical distortion of the cornea of the eye, and camera-related factors.

Recently, the authors used a high-speed camera and video image processing to record and analyze different eye movements [6,7]. The main advantages of those experimental setups are that are able to sample data up to 1000 Hz and a spatial resolution of 3 microns. In this work, we try to reproduce the typical video-oculography experiment but focusing two high-speed cameras simultaneously on both eyes. With an acquisition speed of 500 fps, the aims of the study were to look for observing any small discrepancy between the direct and consensual responses or even seeing any effect of eye dominance.

2. Methods

Basically, the assessment of pupil light reflex (PLR) involves the recording of time and pupil size characteristics. Hence, the pupil is usually illuminated with infrared light and a video camera working at 30-60 frames per second (fps) records pupil activity. During the recording, a flash is shot and the PLR is captured. Then, the sequence is analyzed to obtain different parameters like the latency time for contraction, the duration and the velocity of contraction, the radius-ratio pupil/iris in darkness [8, 9], etc. The experimental setup schematized in Fig. 1 consisted of a halogen projector that provides uniform illumination over the face, a headrest with an opaque vertical screen that separates eyes, two flash units and two digital video cameras (AOS Technologies AC). These cameras can be synchronized to take measurements following the options specified by manufacturer. They are situated at 34 cm from the eye and acquire video sequences at a speed of 500 fps with a spatial resolution of 800×600px. Each one was focused on one of the subject's eyes and was connected to a different computer. Ambient illuminance in the plane of the headrest was 2170±50 lux. Each of the flash units points to one eye and the screen avoids light to pass the other side.

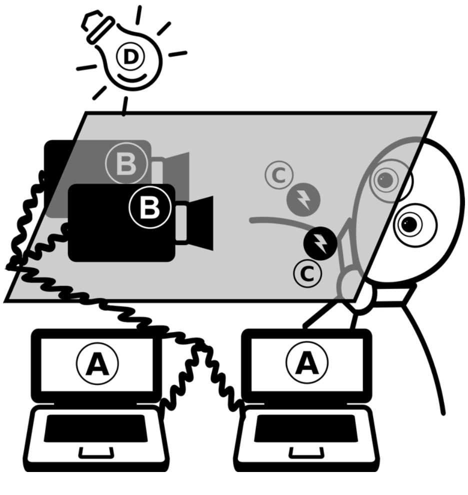

Figure 1. General experimental setup. A) Computers B) Cameras C) Flash units D) Halogen projector.

One sequence of 4,20 seconds was registered at 500 fps for each subject's eye. After the first second and without previous warning, we shot one of the flash units so that it illuminates only one eye. Illuminance in the plane of the headrest reached a peak of 4100±200 lux at that moment. The experiment was repeated but with the flash unit illuminating the other eye.

3. Results

We study the temporal dynamics of the pupil radius of 11 subjects following parameters used in previous studies [8, 9] related to time, like latency from flash exposure to the start of contraction (T_1), which is located at a minimum of the second time derivative, latency to the smallest size of the pupil (T_2) and latency to a plateau (T_3). This last one stands for the end of the contraction process and, here, we define it as the instant after T_2 when the second derivative has a peak. In Table 1, we present the obtained average values. The statistic has been done distinguishing between direct and consensual reflexes and between dominant and non-dominant eyes. Comparison between direct and consensual reflex times does not lead to find any noticeable difference ($p>0{,}05$), in accordance with bibliography [1]. Similarly, there is no significant difference related to the eye dominance ($p>0{,}05$).

Table 1. Temporal parameters of the PLR. We distinguish between direct and consensual reflex, and dominant and non-dominant eye.

	All (s)	**Pupillary light reflex (s)**			**Eye (s)**		
		Direct	**Consensual (s)**	**p-value**	**Dominant (s)**	**Non-dominant (s)**	**p-value**
T_1	0,206±0,027	0,205±0,026	0,207±0,027	>0,05	0,206±0,027	0,202±0,027	>0,05
T_2	0,632±0,087	0,641±0,081	0,623±0,092	>0,05	0,623±0,087	0,628±0,088	>0,05
T_3	1,335±0,206	1,234±0,200	1,347±0,216	>0,05	1,337±0,191	1,338±0,251	>0,05

Time parameters describing the PLR determined in [9] are $T_1=0{,}17\pm0{,}03$ s; $T_2=0{,}64\pm0{,}07$ s and $T_3=1{,}86\pm0{,}24$ s; and those measured in [8] are $T_1=0{,}20\pm0{,}078$ s; $T_2=0{,}90\pm0{,}147$ s and $T_3=1{,}63\pm0{,}559$ s. We observe that obtained T_1 agrees with them. Regarding T_2, it is similar to that from [9] but not to [8] and T_3 does not agree with any one. These disagreements can be due to different parameter definitions or experimental characteristics. In fact, it is difficult to compare results between different studies because of differences in the systems used and the experimental conditions. First, the flash shot characteristics were different. Additionally, we performed the experiment under photopic conditions, so the initial pupil radius was smaller and this could affect the duration of constriction. Obtained T_3 is lower than that measured in [8] and [9]. It is reasonable if we consider equal muscular reaction but smaller initial size.

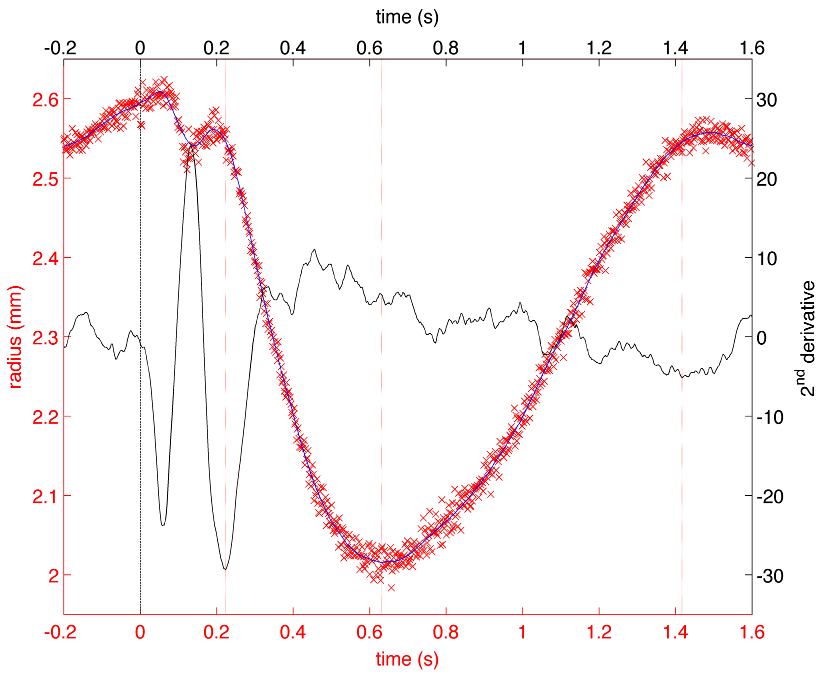

Figure 2. Pupil radius (red crosses and blue line) and its second derivative (black line) variations in time after a flash shot ($t=0$ s). Vertical red lines consecutively represent T_1, T_2 and T_3.

An example of the pupillary reflex analysis can be seen in Figure 2. We represent the dynamics of pupil radius (crosses) in time. Time zero is the moment the flash is shot. The continuous blue line is obtained from the radius by applying a Savitzky-Golay filter to remove the salt-and-pepper noise. The black line represents the second derivative computed from the filtered radius and the vertical lines mark the times T_1, T_2 and T_3, consecutively.

4. Conclusions

We present a method to analyze the eye light reflex under photopic illumination tracking the pupil size. Although pupil light reflex was studied before, we did not found any work that use high-speed imaging under photopic conditions or simultaneously track size and position. Eleven subjects participated in the experiment. We studied the pupil radius contraction distinguishing between direct and consensual PLR as well as dominant and non-dominant eye. Results agree with those from literature and we have not found differences between direct and consensual PLR or related to dominance.

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