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EOG Measurement Analysis Under Different Lighting Conditions

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***Abstract*—Exposure to different wavelengths of light has been demonstrated to have an impact on the human physiological parameters. This work tests such influence in electrooculograms (EOGs). An experimental data and analysis associated with the recording of the EOG for six healthy volunteers under five different lighting conditions is considered in the article. Natural light (at midday and in the afternoon), incandescent, fluorescent, and LED artificial light conditions were considered. The EOG measurement system is based on a bioamplifier and five electrodes and acquisition module. The experimental protocol is following presented. The participants were exposed to eight minutes of each light condition after eight minutes of darkness. EOG was acquired and stored during the final four minutes of each light period. The experimental results obtained from the examination of the volunteer's EOG in the time and frequency domains show significant differences in the considered parameters.**

Keywords—electrooculogram, fluorescent light, incandescent light, light-emitting diode (LED), natural light, wavelength

I. Introduction

The human body's physiological processes are influenced by light in terms of its nature, intensity, wavelength, and duration [1]. Most reports of light's effects come from psychological research, which suggests that light induces different behavioral reactions, mental attitudes, and overt behaviors. Physiological, emotional, and cognitive responses to the different wavelengths of light shown in Fig. 1 have been extensively studied in recent years. Among the findings of this research is that shorter-wavelength light induces relaxation, while longer-wavelength light induces awakening [2]–[4]. Furthermore, the Theory of Colors states that color categories (such as yellow, red yellow, yellow red) and the corresponding emotional reactions (such as warmth and enthusiasm) have a relationship, which is especially relevant in artificial light. Various investigations on the impact of light on heart rate variability (HRV) under different light scenarios can be found in the literature [5]–[7]. Exposure to different colors has been shown to influence heart rate within minutes. There are significant effects of blue light on HRV. Compared to red wavelengths, blue wavelengths that predominate in fluorescent light showed an increase in parasympathetic activity [1]. Choi et al. presented a study analyzing HRV responses to red, green, and blue light exposure in healthy adults. Since colored light modulates such effects, the emotional state of the subjects is an important factor [3]. Under the same three different colored illuminations, Yuda et al. reported some ECG and respiration measurement results.

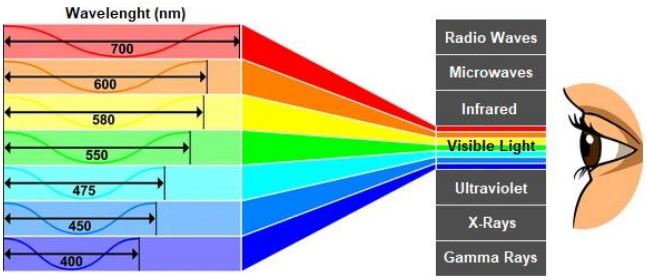


Fig. 1. The spectrum of natural light and wavelength decomposition of the visible light.

A greater impact was observed with blue light as compared to red and green light [7].

Most research on the effects of light on eye function is superficial and theoretical [8], [9]; therefore, empirical approaches are required. It is of great interest to measure how light conditions affect electrooculogram (EOG) measurement, especially in clinical settings. Vision begins with the arrival of light on the retina, where the rod and cone photoreceptors are electrically excited, subject to the light's intensity and the wavelength received. Retina cones are color-sensing cells, while rods are sensitive to light intensity. During an EOG, the corneal and retinal potential differences are registered, considering the eyeball as an electrical dipole. Diagnostic tests such as the equilibrium sense test or polysomnogram use this record of ocular activity to detect pathologies [10], [11]. Furthermore, a unique relationship can be established between gaze direction and actions with EOG as a reliable source of commands. EOG allows control of human-computer interfaces without speech or hand movements [12].

The rest of the paper is structured as follows: The methodology followed is presented in the next section. The experimental setup and results are exposed and discussed in Sections III and IV, respectively. Lastly, a conclusion is given in Section V.

II. Methods

A. Ligthting Conditions

Natural light is dynamic, varying in spectrum, intensity, number of hours, and directionality throughout the day and

year. In contrast, traditional electric artificial light is fixed and constant throughout the day, with little or no regulation capacity. In addition to losing the perception of natural time, constancy in intensity and spectrum can be negative for our health and cognitive functions. In contrast to daylight, artificial spectra are restricted to the visible region and have a spectral component ranging between 280 nm and 4,000 nm.

As can be seen in Fig. 2, electric light has not been able to fully emulate natural light. Artificial light from incandescent, fluorescent, and light-emitting diode (LED) bulbs does not provide the right combination of electromagnetic waves to mimic those of the sun. Likewise, the human response to artificial light is not natural. In recent years, it has become increasingly clear that the disproportionate percentage of blue wavelengths from electrical light sources hurts health, including the formation and progression of breast cancer, diabetes, obesity, and cancer metabolic syndrome [13]. Moreover, the color temperature of the source of light within the Kelvin scale shown in Fig. 3 must be considered. It indicates the type of color that the light will have. Depending on this value, the three basic types of commercial lights can be obtained: warm white, neutral white, and cold white. The main characteristics of the lighting sources considered in this work are detailed below and summarized in Table I [14].

- **Natural** light reaches its peak intensity in the wavelength range of 380 nm to 780 nm in the visible spectrum. In this frequency band, there is a continuous spectrum that is constant and without gaps. The proportion of the short-wave colors (blue) is greater than the proportion of the broad-wave colors (red). However, there are also small amounts of shortwave (ultraviolet) radiation and substantial amounts of broad wave (infrared) radiation in addition to visible light. The two components of natural light, direct and diffuse, have opposite color dynamics. On the one hand, direct sunlight generates its warmest light color (3,000 K) at sunset and sunrise and its coolest light color (6,000 K) at midday. In contrast, with diffuse irradiance, the highest color temperatures are seen at sunrise and sunset, while the lowest values occur at noon. From a photometric perspective, the sun is like a 5,800 K heat radiator or light bulb.
- The wavelength range of an **incandescent** light bulb is between 400 and 700 nm. However, it presents a peak of light very close to 550 nm. A tungsten electrical conductor is heated by an electric current until it glows white. Filaments are enclosed in glass bulbs under a vacuum or inert gases to prevent them from oxidizing. Its color temperature typically ranges from 2,600–2,700 K. Due to its ineffectiveness in several countries, its manufacture and sale are forbidden, but not in as many countries as halogen light sources.
- The **fluorescent** spectrum contains wavelengths of light produced by the phosphor coating. Light in typical fluorescent peaks is strongly blue violet at 435.8 nm, rather yellowish green at 546.1 nm, and red at wavelengths of 628 nm. At 3,500 K and up to 6,500 K, it is possible to find fluorescent lamps or tube lamps. Some types of fluorescents are banned in a limited number of regions of the world in favor of the use of more sustainable alternatives.

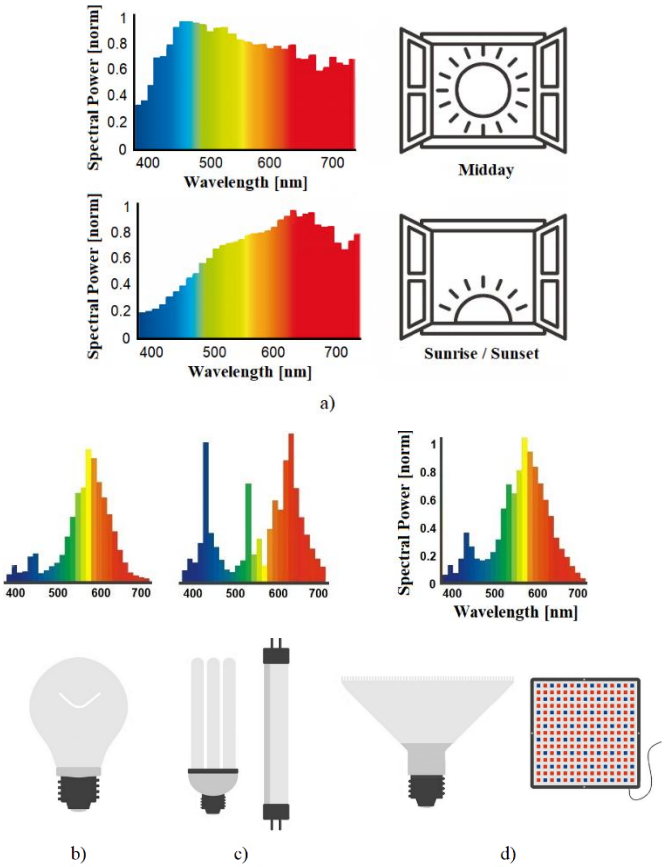


Fig. 2. a) The spectrum of sunlight at midday and sunset or sunset; b) Incandescent; c) Fluorescent; and d) LED ligths.

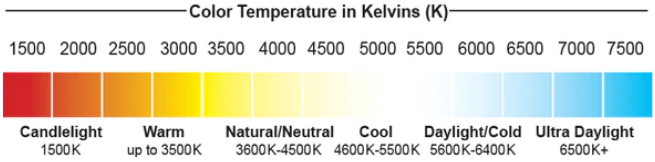


Fig. 3. Color temperatures whitin the Kelvin scale.

TABLE I. WAVELENGTH AND COLOR TEMPERATURE RANGES OF THE DIFFERENT LIGHT CONDITIONS CONSIDERED.

	Wavelength (nm)	Color temperature (K)
Midday	380–780	6,000
Incandescent	400–700	2,600–2,700
Fluorescent	400–700	3,500–6,500
LED	275–950	1,500–7,500
Sunset	380–780	3,000

- Commercially available **LEDs** that have a single-element output power have wavelengths ranging from 275 to 950 nm. A specific semiconductor material family is used for each wavelength range. LED lighting does not have a specific color temperature range, unlike other light sources. With LED lighting, almost any color temperature is possible. The high reliability, efficiency, and low cost of these devices make them very affordable for both consumers and industries.

B. EOG Acquisition

The EOG was recorded by placing five disposable Ag/AgCl surface electrodes on the subject's face and connecting them to a commercial bioamplifier, as shown in

Fig. 4 [15]. The electrode model used was the Ambu® Neuroline 700, which provides an impedance of less than 3 kΩ. Two pairs of these positive-negative electrodes allow for recording the vertical and horizontal eye movements separately. A reference electrode was placed on the subject's

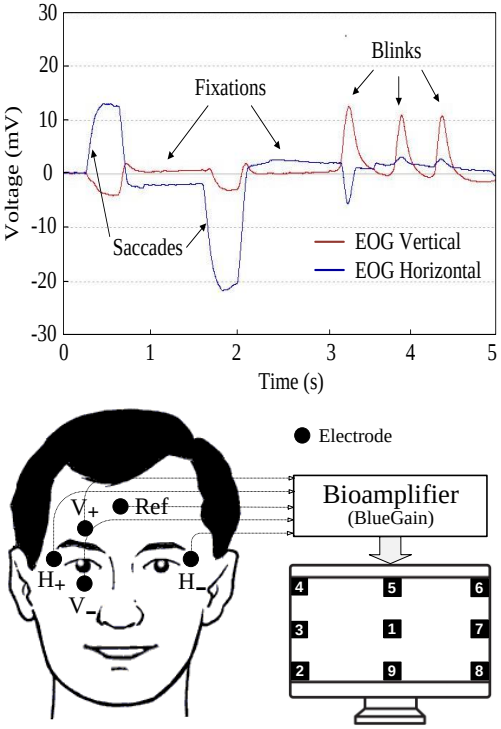


Fig. 4. Typical electrooculogram recorded by the BlueGain bioamplifier and setup to register the vertical and horizontal eye movements independently.

forehead to establish a reference potential and reduce the common-mode voltage. Using this electrode, it is possible to compensate for any unwanted signals on the active electrodes in the acquired signal. At a rate of 1 kHz, the bioamplifier digitizes the signal recorded by the electrodes with a 16-bit analog-to-digital converter. The Bluetooth protocol transmits the signals to a computer. The commercial device also includes the EOGtest software application that allows viewing and storing the registered signal, as well as applying 0.1-Hz and 30-Hz high-pass and low-pass filters.

C. Subjects

After informed consent, six healthy volunteers (two women and four men without any known visual pathology) aged 24 to 63 years were enrolled in this study. Participants did not consume alcohol or caffeine during the day, and their vision was normal. All volunteers were seated upright and breathing normally. In each lighting condition, participants were asked how comfortable they felt. Their common criteria for determining visual comfort and its level were used to decide the light intensity.

This work followed a specific protocol involving light and dark conditions. Two measurement sessions were performed for each participant and light condition. In each session, the volunteer was exposed to an eight-minute period of darkness, followed by an eight-minute exposure to light. An EOG recording was made during the last four minutes of light exposure. Participants were first exposed to natural light at midday, then to a fluorescent lamp, thirdly to an incandescent light bulb, then to an LED light bulb, and finally to afternoon light. Participants were instructed to follow a square on a screen with their gaze during each lighting condition, following the protocol described in the next subsection.

D. Protocol of the EOG Measurement

During each illumination period, the volunteer must perform the following sequence of actions to measure horizontal and vertical eye activity:

Let's assume T_1 = 4 s and T_2 = 2 s. Labels shown in Fig. 4: L_1 the center position, L_2 lower left corner, L_3 middle left horizontal, L_4 upper left corner, L_5 vertical upper center, L_6 upper right corner, L_7 middle-horizontal right, L_8 lower right corner, and L_9 vertical lower center.

- Look at a message on the screen with the test instructions for 15 s.
- Starting from the center, after a T_1, go to the next label, wait for a T_1, and return to the center. Visit the next label sequentially and slowly.
- Starting from the center, after a T_2, go to the next label, wait for a T_2, and return to the center. Visit the next label sequentially and quickly. Repeat three times.
- Starting from the center, after a T_1, go to the next label, wait for a T_1, and return to the center. Visit the next label sequentially and slowly.
-

III. EOG Experimental Setup and Results

A Microsoft PowerPoint file was designed by us with a series of eye movements to be performed. The monitor to project this sequence of actions was the HP Pavilion 22xi 21.5" IPS with LED backlight. The screen has a Full-HD 1920×1080 resolution and a refresh rate of 60 Hz. During data collection, the computer screen was positioned 70 cm away from the volunteer's eyes at a 90° angle to the table. To ensure repeatability and eliminate head movements, a chin rest was used to stabilize the head.

A. Light Characteristics

Participants were exposed to various intensities of artificial lights until one level of intensity was deemed sufficient to illuminate the work area without glaring based on the subject's eye distance from the lighting device. So, a luxmeter was used to assure a dose of illumination of around 30 lux, placing the artificial lights 15 cm above the screen and 75 cm away from the participant's eyes.

- **Midday** and **sunset** light: the measurements were made at 12 pm and at 5 pm in our laboratory located at the 43° 31' 22.8" N 5° 37'4 2.5" W coordinates on November 13.
- **Incandescent**: a traditional bulb with features of 60 W, 630 lm and 2700 K was used.
- **Fluorescent**: a 15 W, 800 lm, 6500 K fluorescent bulb was employed.
- **LED**: a 9 W, 806 lm, 6400 K with a globe shape and a 220º beam angle was used.

B. *Evaluation Parameters*

The analysis of how light conditions affect the subjects' EOG variability was supported by nine parameters in the time and time-frequency domains.

- **Time domain**: mean (μ), median (M), standard deviation (σ), energy (E), power (P), Hjorth activity (H_a), Hjorth mobility (H_m), and Hjorth complexity (H_c) parameters were computed for each EOG measured. H_a, H_m, and H_m compute the variance of the signal, power spectral standard deviation, and signal frequency change, respectively. The formulas to calculate these parameters are shown below.

$$H_a = var(x(t)) \tag{1}$$

$$H_m = \sqrt{\frac{var\left(\frac{dx(t)}{dt}\right)}{var(x(t))}} \tag{2}$$

$$H_c = \frac{H_m\left(\frac{dx(t)}{dt}\right)}{H_m(x(t))} \tag{3}$$

where $x(t)$ refers to the input signal and $var(x(t))$ is the variance of the signal [16].

- **Time-frequency domain**: the power spectral density (PSD) was calculated as the power distribution of the signal in the time-frequency domain, since the EOG signal is not stationary. The signal is divided into overlapping sections of the same length. To maintain a consistent frequency content within the segments, the segments must be short enough. A Kaiser window is then applied to each segment and the short-time Fourier transform is calculated. Finally, the spectra of the segments are concatenated to build the spectrogram.

IV. Results and Discussions

The results of each participant were evaluated independently, given the great variability between the values obtained by each participant, and thus be able to identify patterns due to the light condition. It has not been possible to identify patterns associated with the mean, median, and standard deviation values, presenting great variability between participants. Higher mean and median values were obtained associated with the vertical channel, mainly due to the recording of the sharp peaks of involuntary blinks. They can be identified in Fig. 5, which shows an EOG of a participant following the previously described protocol. A common pattern identified in all users is that both EOG channels present greater energy and power in natural light conditions at midday. This behavior is also observed with the LED light. Energy and power values are slightly lower with natural light at sunset respect midday and LED lighting. Both parameters present lower values with fluorescent and incandescent light. Table II shows the results of the time-domain parameters considered for one volunteer under the five lighting conditions.

Hjorth descriptors are a better and more efficient feature extraction technique when faced with sources of variability like EOGs. The three parameters defined by Bo Hjorth in 1970 help to obtain statistical information about the signal in the time domain that is conserved in the frequency domain. The parameter H_a tells us that the variance of the signal under LED light is significantly superior with respect to the other lighting conditions. Its value describes the amplitude characteristics of the mean signal obtained. H_m tells us that the average frequency of the spectrum of the signal under midday, LED, and sunset light is rather similar, being proportional to the standard deviation of the energy spectrum. Finally, the H_c measures the changes in frequency, giving an estimate of the bandwidth of the signal. In this case, a similar value is obtained in the horizontal channel under the five lighting conditions. In the vertical channel, similar values are again obtained in midday, LED, and sunset light conditions.

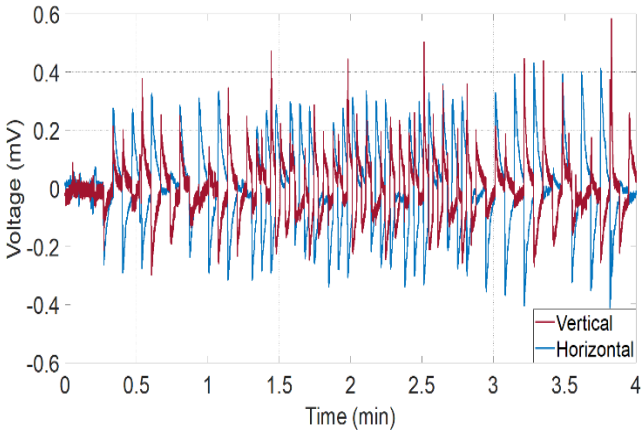


Fig. 5. Example of EOG of a participant following the described protocol.

TABLE II. Avarage Results in Time Domain for One Volunteer. H: Horizontal Channel and V: vertical Channel

Parameter		Light condition				
		Midday	*Fluorescent*	*Incandescent*	*LED*	*Sunset*
μ [μV]	H	1.54	2.49	2.77	-0.10	1.68
	V	-3.67	1.69	0.38	-5.06	0.48
M [μV]	H	1.71	0.76	1.19	-1.13	2.61
	V	5.10	0.39	-1.62	-4.68	1.08
σ [μV]	H	4.65	4.48	3.95	4.67	4.50
	V	3.38	2.96	2.87	4.00	2.72
E [J]	H	5.19	4.83	3.75	5.23	4.86
	V	2.77	2.10	1.97	3.84	1.78
P [μW]	H	10.80	6.71	5.21	7.26	6.75
	V	5.77	2.92	2.74	5.33	2.47
H_a [μV²]	H	21.60	20.11	15.61	21.79	20.26
	V	11.47	8.75	8.22	15.97	7.42
H_m [Hz]	H	5.71	14.30	11.75	6.94	6.36
	V	9.21	45.45	37.63	14.46	21.38
H_c [Hz]	H	20.47	20.36	23.99	24.20	27.24
	V	22.96	7.16	8.23	19.79	14.00

In Fig. 6 are presented the evolution of the average PSD for a participant under different lighting conditions. The results show the distribution of power between the different frequency bands for both channels. Considering the middle point of its energy distribution as a measure of the average frequency based on amplitude weighted by frequency it can be underlined the fact that signal power is concentrated in the range 0–40 Hz, ranging from 0–10 Hz at its maximum. The energy is distributed evenly across the spectrum (deep yellow vertical bars) when looking at the center, and the voltage in both channels is close to zero. This energy is associated with noise due mainly to muscle activity and, to a lesser extent, brain activity that covers the entire spectrum of EOG.

Previous works about EOG measurement talk about the influence of ambient conditions in its measurement, such as lighting, humidity, noise, etc., but without quantifying their influence [8], [9]. This work provides evidence that the characteristics of the EOG vary in time and frequency domains under different lighting conditions. If we look at the power distribution throughout the entire EOG record, we can see that with LED lighting, there is more power across the entire frequency range, as in midday and evening light conditions. Greater power is observed in the horizontal channel due to the greater amplitude of the eye movements performed on this axis. Based on the results reported here, it is possible to review the design of EOG bioamplifiers, considering the inclusion of compensation techniques for the influence of light. The observed behavior is consistent with

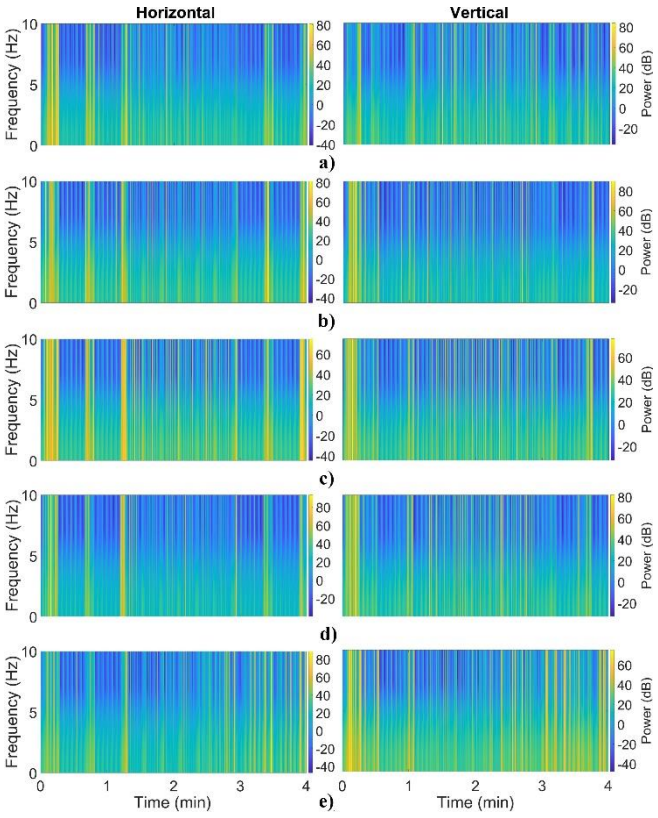


Fig. 6. Analysis of the power spectral density in the time-frequency domain of a participant during the recording period under a) midday; b) sunset; c) fluorescent; d) incandescent; and e) LED lighting conditions. Both channels are represented independently.

the fundamentals of natural and artificial light and in line with other studies that have addressed other biopotentials [1]–[7].

There is no way to eliminate the noise, but it is possible to minimize it: subjects should remain relaxed during recording, avoiding movements, and electrodes must be positioned at the base of the orbital cavity, on the orbital rim, or on the bones. Multiple factors contribute to the difficulty of the repeatability and reproducibility of measurements. One of them is that the measurements of natural light vary every day, as well as the placement of the electrodes and the general condition of the volunteers. Secondly, subjective impressions and emotional states play an important role in regulating the autonomic nervous system, which is affected by measurements. Therefore, all measurements were taken on the same day without changing the electrode positions among the volunteers. In this way, generalizable results can be obtained per day and compared with other days. The results reported in Table II and Fig. 6 correspond to a given subject as the average values of the two tests performed on one of the test days. These results are in line with the rest of the subjects and with the three days in which the measurements were carried out. In all these measurements, a standard deviation of less than 4 µV was obtained between subjects on average.

In future work, a larger sample of volunteers is needed to better understand whether different lighting conditions, color temperatures, and intensities affect the EOG measurement. A greater variety of light sources and their locations should also be considered. An additional protocol could be explored to assess the emotional state of the subject by measuring, for example, the galvanic response of the subject's skin during the test to correlate the stress state with the observed EOG values.

V. Conclusion

A novel approach regarding the EOG under different light conditions was considered. The obtained electrooculogram may vary under different lighting conditions following the same stimulus sequence. Based on LED lighting unit different type of daytime natural light conditions were simulated such as midday or afternoon light. In contrast, the use of fluorescent and incandescent light sources causes the signal to have lower energy, power, variance, and bandwidth. The center frequency of the measured signal is also significantly higher compared to using natural light or LEDs. Considering the effects of the lighting sources these findings can be very useful in signal acquisition and the design of the optimal processing of electrooculograms since they can affect the interpretation of the signal as a diagnostic tool or to control a device.

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