Electrooculography: A Proposed Methodology for Sensing Human Eye Movement

G. de Melo and Sílvio Leão Vieira

Abstract

Bioelectric signals are emanations from living biological systems and have their origin in various electrical potentials in cells. In this context, electrooculography (EOG) is defined as a specific biopotential is generated by the eye and eyelids' muscular movement. Here, we are dedicated to developing a methodology and an appropriate environment to detect the human eye's movement by acquiring bioelectric signals. The study was conducted in 40 healthy individuals using the 4/5 configuration consisting of four main electrodes and an additional fifth reference electrode. The methodology is following standards and guidelines for data acquisition of ECG signals. During the acquisition, the volunteer remains seated and with his head comfortably sustained on a support of a tailored Ganzfeld box. On the back wall of the box were fixed five light-emitting devices (LEDs) in the form of a plus sign symbol positioned at a distance opposed and at the center. The LEDs were turned-on or turned-off according to a pre-established sequence protocol synchronized with data acquisition while the volunteer performed eye movements. As a result, were obtained 18 samples of EOG signals per subject of 60 s. A dedicated algorithm was used to separate the data by group according to the established methodology.

Keywords

Electrooculography (EOG) • Eye movement • Bioelectric signals • Ganzfeld

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1 Introduction

Electrooculography (EOG) biosignals are electrical signals generated by the eye's biopotentials from a retina-cornea constant voltage source [1, 2]. The EOG biosignals are an eye angle-dependent, which is the central concept that makes voltage measurements possible. EOG signals can be studied and applied to diagnose eye diseases and the interaction of people with limited movements. Indeed, in the last decade, a plethora of new applications have been proposed in the area such as Robotics [3–5]; Human–Computer Interaction (HCI) [6–13]; Noise reduction by digital signal processing techniques [14, 15]; Healthcare [1, 16]; Machine Learning [2, 17, 18].

EOG is classified as bioelectric signals. EOG is a signal that measures and records the resting potential of the eye retina. The human eye functions as a dipole in which the frontal cornea represents the anode and the rear the cathode [19]. Such signals are acquired through electrodes positioned at an external angle to the eyes, both vertically and horizontally. The eyeball movement approaches the cornea of an electrode. Its corresponding potential increases, and the potential of the opposite electrode decreases. According to [7], many experiments considered part of the cornea as a positive pole and the retina a negative pole. These two poles are responsible for generating a small amount of electric field. It is detected on the forehead, temple, and upper part of the cheek when placing some electrodes.

Typically, the EOG signal has a differential potential ranging from 50 to 3500 mV in amplitude and frequency from 0.1 to 20 Hz [7]. Other authors present different values of this potential for both amplitude and frequency: 30 mV–50 mV and 7 Hz–20 Hz [19]; 10 mV–100 mV and 0.1 Hz–15 Hz [20]; 0.4 mV–1.0 mV and 0.5Hz–30 Hz [21]; and 10 mV–100 mV and 0.1 Hz–38 Hz [15], respectively.

In the field of diagnosis and treatment of vision, the most crucial step in the study of EOG is signal acquisition. To accomplish it is necessary to develop an enabling

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environment, quality devices and materials, and very objective methodologies so that the acquisition can be carried out in a way that is within the standards.

There are several methodologies for acquiring EOG signals, and the acquisition equipment, in most cases, is expensive [7, 15, 19–21]. Herein, we proposed to create an environment with an excellent cost–benefit and a new methodology according to standards guidelines for data acquisition of EOG signals.

2 Materials and Methods

This section describes the methodology for carrying out the acquisition of EOG signals. First, the acquisition device is configured to capture EOG signals. After this configuration, the procedures to accomplish the data acquisition defined. The data acquisition used the bioelectric instrument Miotool (200/400 USB, Miotec Equipamentos Biomédicos Ltda, RS, Brazil). It allows data acquisition of surface electromyography signals with the support of Miograph USB software. According to the equipment manual, the system meets all safety standard records for electromedical equipment NBR IEC 601.1/1994 and EMENDA (1997), NBR IEC 60601.1.2:2006, and Particular Standard NBR IEC 60601.2.40/1998 [22].

The device has the following specifications [22]:

- 14 bits of resolution;
- Channel acquisition rate of 2000 samples per second;
- Low noise level;
- Common 110 dB rejection mode;
- Security isolation 3000 Vrms.

The connection between the electrodes and the Miotool 200/400 USB was used as a Differential Surface Sensor (SDS500) with a claw connection. This type of connection is suitable for fixed electrodes in places that are not flat and difficult to fix, such as the face. Thus, the claw-type SDS500 allows the electrodes' placement adjustments, facilitating the signals' acquisition [22].

The Miograph USB software has previously configured to acquire EOG signals. For the type of acquisition, the sEMG S option was chosen, referring to the skin surface's EMG signals. Two acquisition channels were used to measure the horizontal and vertical eye movements. Two sensing electrodes connect each channel. Besides, was used a fifth reference electrode connected to a specific input of the equipment. The main settings for both channels are:

- 0.1 Hz high pass filter (HPF) of fourth-order;
- 40 Hz low pass filter (LPF) of fourth-order;
- Notch filter 60 Hz of fourth-order;
- Maximum Voluntary Contraction (MVC) set to a maximum of 900 mV.

Completed the device configuration task, initiated the methodological procedures and data acquisition of EOG signals. The measurements accomplished by observing the Clinical Standards Methods for analysis of electrooculogram, recommended by ISCEV [23].

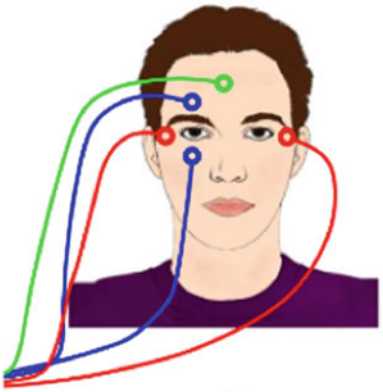
In the literature, there are many descriptions regarding the placement of electrodes to acquire EOG signals [15, 19–21]. Bharadwaj and colleagues [24] explain that the number of electrodes for acquiring EOG signals can be 2/3, 3/4, 4/5, or 7/8, where the first number denotes the number of active electrodes and the second number denotes the total electrodes, including the reference electrode. Such differences will depend on the application involving the research. This work was used the 4/5 configuration based on characteristics of the device used. Figure 1a shows the electrode arrangement in the configuration described.

The electrode used was the disposable ECG electrode (2223BRQ, 3 M, Sumaré, SP, Brazil). The electrode consists of a polyethylene foam back, covered with hypoallergenic acrylic adhesive on one side and laminated with polypropylene tape printed on the other side; conductive adhesive gel; stainless steel pin and polymer counter pin covered with Silver/Silver Chloride treatment with size 4.5 × 3.8 cm [25].

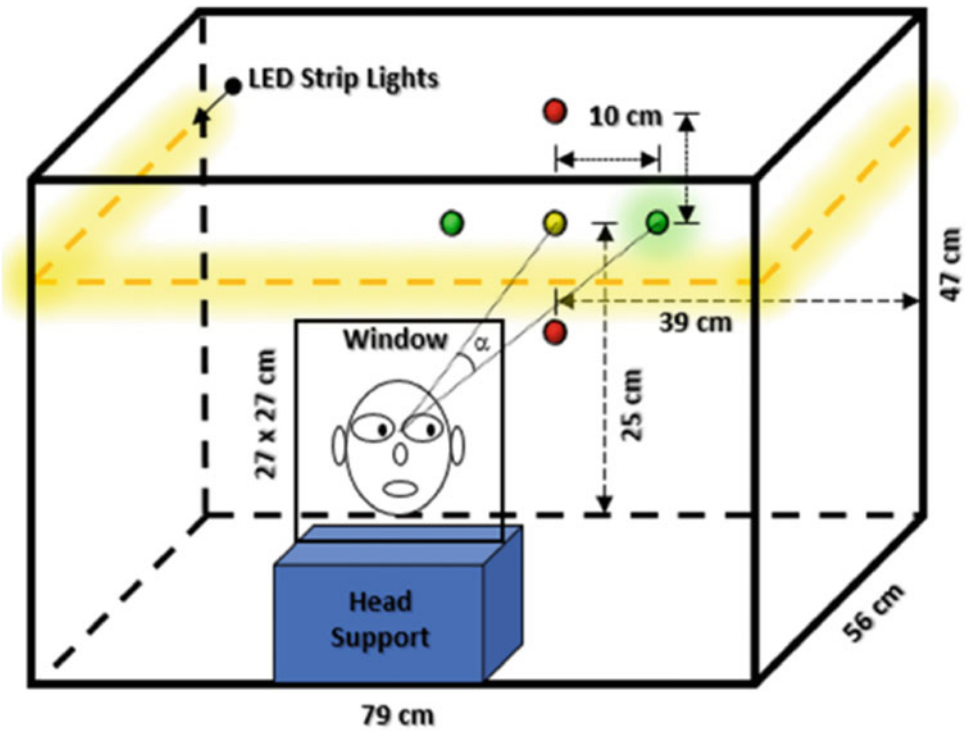
The acquisition of EOG signals carried out in two phases. The first with the volunteer exposed to light and the second with an absence of light. According to the ISCEV [24] standard, a record ranging from 7 to 12 min increases the eye's bioelectric potential, thus reaching Lighting Peak (LP). In the second phase, between 10 and 15 min of the absence of light, there is a drop in potential, thus reaching what can be called Dark Valley (DV).

Thus, according to the presented standard, the acquisition test was performed between 10 and 12 min for each phase. To attempt control of luminosity and the stimulus environment described in the International Society for Clinical Electrophysiology of Vision (ISCEV) [24] standard was necessary to use a closed and insulating external light during signal acquisition. Specifically, this environment is a place where there will be internal control of luminosity (the specific standard 100 cd/m^2, equivalent to 100 lx) and stimulating the volunteer's eye movement (LEDs at the bottom of the container). This environment is known as Ganzfeld, as illustrated in Fig. 1b.

The environment was designed following the guidelines and essential concerns established by the standard. A Ganzfeld was based on a 79 × 56 × 47 cm sized cardboard box with a square window opening on its front surface



(a)



(b)

Fig. 1 **a** Electrode arrangement on the face for acquiring EOG signals, 4/5 configuration. **b** Illustration of the internal LEDs for illumination (yellow bands) and support for the volunteer's head support (blue)

of 27 × 27 cm. These measures were chosen based on box material available at that moment, once there is no standardization about Ganzfeld box dimensions. However, specific rules remark on the internal luminosity and layout of the light-emitting diodes (LEDs).

Inside the Ganzfeld, a LED ruler was adapted to control lighting following the ISCEV Standard. At the edge of the square opening, soft foam support was placed to support the volunteer's head.

The previous figure illustrates the Ganzfeld prototype's spatial dimensions for this research, the dispositions of the LED strip that were installed, the support bracket, and the LEDs on Ganzfeld's bottom.

Five LEDs have been installed inside the box on the rear surface in the shape of a plus sign symbol. They were configured to light according to three predefined sequences to stimulate the volunteer's eye movement.

Four light emitters are arranged on the plus sign's extremity and one in the center of the cross. The central LED is 25 cm from the bottom edge of the box and 39 cm from the side edges. Each of the other four LEDs is 10 cm straight from the center LED.

The central LED was arranged so that it was approximately straight with the eyes of the volunteer. The movement of the volunteer's eyes towards the other LEDs accomplish an angle, α, of about 11.31 degrees.

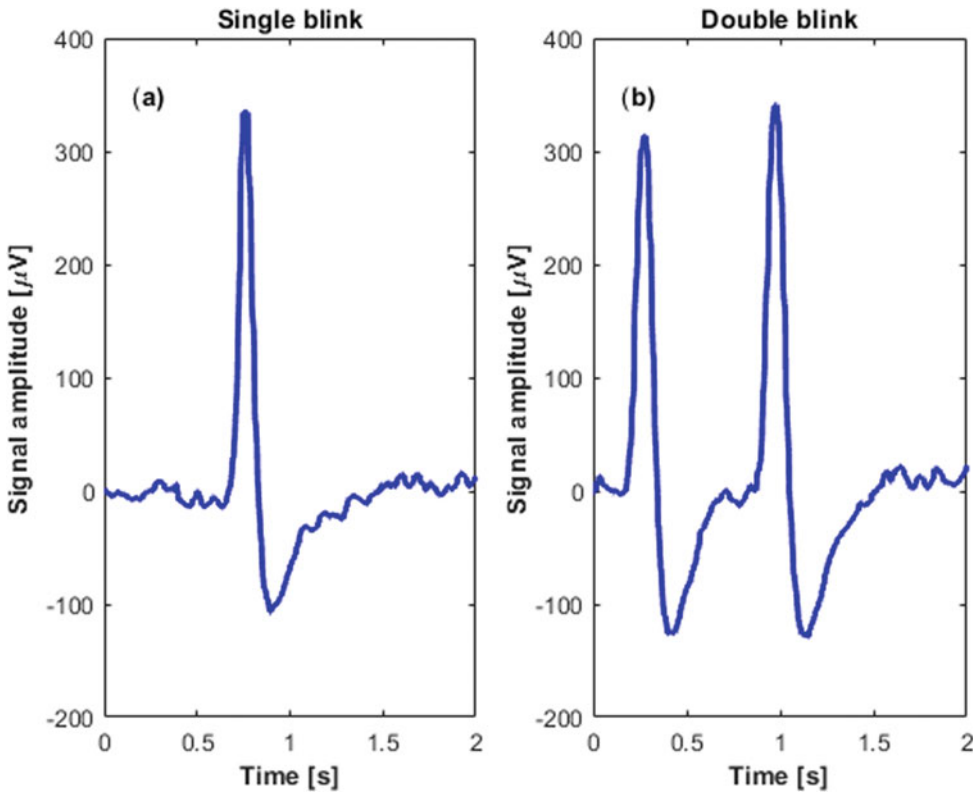


Fig. 2 Expected bioelectric signal from a single blink and a double blink obtained on channel 2 (Vertical)

A microcontroller ATmega328 (Arduino Uno R3, Ivrea, Italy) is used to control the LED's on–off sequences, as it is an easy-to-program and low-cost microcontroller.

The Ganzfeld box's internal lighting is controlled by the LED strip light's intensity powered by an adjustable DC voltage source (1502DD, Yihua, China). For the internal lighting reaches 100 lx, a voltage of 10.1 V and an electrical current of 0.33 A was set up. The luminous intensity inside the box was measured using a lux meter (MLM-1332, Minipa, Joinville, Brazil).

Three different sequences of activation of the LEDs were elaborated to stimulate the volunteer's eye movement. Three sequences were elaborated and configured so that the volunteer did not try to predict what next movements of eyes would be performed during the data acquisition. Thus, these sequences served as guidance and induced what direction the individual's eyes would have to move. Such sequences are based on the following eye movements: Blink, Double blink, Right-Center, Left-Center, Up-Center, Down-Center, Right-Left-Center, Left-Right-Center, Up-Down-Center, and Down-Up-Center.

According to the established sequences, the signal acquisition procedure was performed to stimulate the eye to look horizontally, vertically, or blink. The three sequences were first performed with the indoor box light turned-on. In this procedure, three samples were obtained from each sequence, in the following order: Sequence 1, Sequence 2, Sequence 3. Then, three more samples were obtained from each of the sequences with the interior light off.

The microcontroller LEDs controller and the bioelectric monitoring instrument were synchronized to data acquisition. The LEDs were turned-on or turned-off according to a pre-established sequence protocol while the volunteer per-formed eye movements.

Signals were acquired of 40 healthy individuals formed by men and women, providing 720 samples. They were then arranged in two groups of 360 samples obtained in the lighted environment and the dark. The time to take all raw data was about 12 h being 18 min for each person.

3 Results and Discussions

EOG signal results from many factors, including eyeball rotation and movement, eyelid movement, electrodes placement, head movements, and luminance influence. Those EOG systems are easily contaminated with drift in long-term measurements. The drifts can be reduced by applying Ag/AgCl electrodes and filling them bubble-free with electrode-gel.

The separation and extraction of the movements of interest from EOG signals were done through a custom algorithm. The aggregate data from one volunteer has 120.000 sampled points. The row data was windowed with a duration of 60 s,

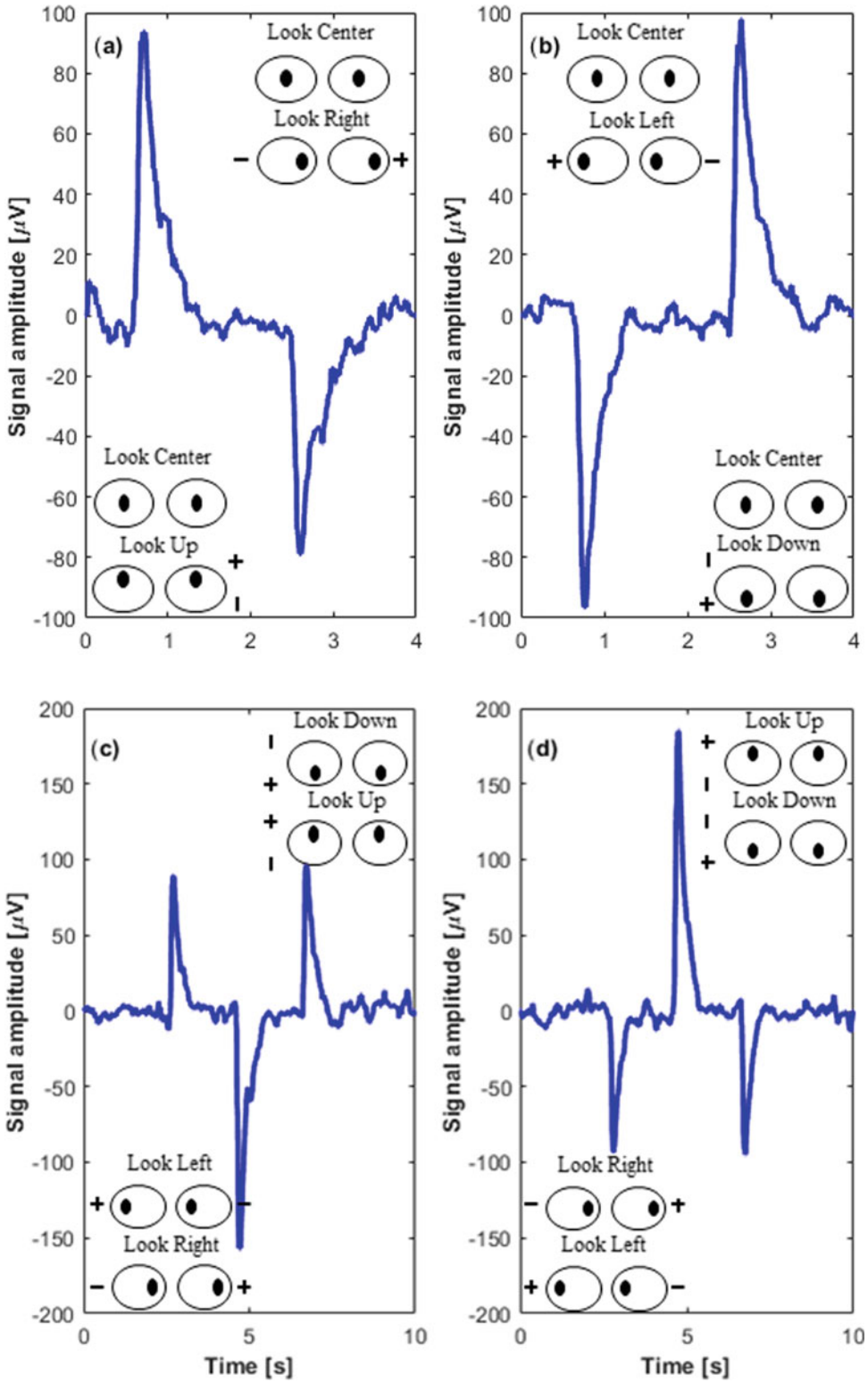


Fig. 3 Evoked potential recorded from channels 1 (horizontal) and 2 (vertical) as the response of the eyeball movement

which corresponds to 2.000 sampled points. The methodology used to detect eye movement is based on extracting the sum of the mean amplitude for each second of the analyzed sample. For example, if the average amplitude in that second is greater than the global signal's average amplitude, the algorithm identifies it as an eye movement signal.

Finally, the algorithm generates a graph of the eye movement signals taken from the initial raw signal. As illustrated in

Fig. 2, we can see the signal produced by one single blink (Fig. 2a) of the eye, depicted on the left, and a double blink (Fig. 2b) of the eyes shown on the right of the picture. These two movements typically have a higher response in amplitude compared to the other emanated movement, such as they look to the horizontal and vertical direction. The eye blink amplitude is almost four times greater than those found representing the right to center or up to center movement, as illustrated in Fig. 3. This figure are illustrated a sequence of bioelectric responses of the eyes. All sequence of movement has the look center of the eye as reference.

At Fig. 3a are described the signal from horizontal (right-center) and vertical (up-center) movement; Fig. 3b illustrate the movement described by horizontal (left-center) and vertical (down-center); Fig. 3c presents a sequence of three movements initially beginning with horizontal (right-left-center) and vertical (up-down-center); and finally the Fig. 3d shows a horizontal (left-right-center) and vertical (down-up-center) movement of the eyeball.

It is interesting to note that some moments have similar bioelectric behavior. For example, as we can see in Fig. 1a, the response pattern to look right to center movement is equivalent to up to center performance. In other words, different movements present signals with similar characteristics, alternating the channel from which it is acquired. In other words, different movements present signals with similar characteristics, alternating the channel from which it is acquired.

4 Conclusions

In this report, we have proposed an environment and methodologies of EOG signals acquisition. The developed environment to obtain the data, called the Ganzfeld box, was easy to make. Its project presented a relatively low-cost, allowing it to use anywhere. The methodology presented is shown to successfully obtain the bioelectric response of a group of volunteers' eye movements. The specifications of the proposed make it suitable for biomedical applications. The acquired EOG signal provides different eye-related activities. Accordingly, many new systems can be designed to perform different tasks in the real world, involving, e.g., Human–Computer Interaction (HCI) and Artificial Intelligence (AI). As a promising tool, efforts have been made in such a direction to evaluate EOG signal processing using digital filters and feature extractions algorithms.

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Conflict of Interest The authors have no conflicts of interest.

Ethical Approval It was approved by the Research Ethics Committee (CEP) of the Federal University of Goiás (UFG) under the Certificate of Presentation for Ethical Appreciation (CAAE), number 15226219.2.0000.5083 and under the Number Opinion 3.521.755.

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