OculusGraphy: Description and Time Domain Analysis of Full-Field Electroretinograms Database

2023 IEEE Ural-Siberian Conference on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT) | 979-8-3503-3605-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/USBEREIT58508.2023.10158887

Faisal B. Albasu
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia

Subhankar Dey
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia

Anton Yu. Dolganov
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia

Oussama EL Hamzaoui
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia

Wisam M. Mustafa
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia

Aleksei E. Zhdanov
Engineering School of Information Technologies, Telecommunications and Control Systems
Ural Federal University
Yekaterinburg, Russia
Machine Learning and Data Analytics Lab
University of Erlangen–Nuremberg
Erlangen, Germany

2023091296

***Abstract*—Electroretinography is an established electrophysiological technique for clinical investigation of visual health function. The test involves the non-invasive assessment of the retinal function using light stimulation. This study presents a comprehensive database of five types of signals, including Scotopic 2.0 ERG response, Photopic 2.0 ERG response, Maximum 2.0 ERG response, Photopic 2.0 EGR Flicker response and Scotopic 2.0 ERG Oscillatory Potentials. The database includes 1975 signals from 323 patients, consisting of both adults and children. This study seeks to evaluate and analyze the classical parameters of three of the five signals, specifically Scotopic 2.0 ERG response, Photopic 2.0 ERG response, and Maximum 2.0 ERG response, using time-domain analysis. Correlation analysis was conducted in order to gain insights into the potential relationship between a patient's age and the classical parameters. However, the results suggest little to no correlation between these factors. The database presented in this study will serve as a useful resource for further research in the field of electrophysiology. Future research in this area could explore the use of other advanced analysis methods, such as frequency and time-frequency domain analyses, in order to gain further insights into the nuances of these signals and to better differentiate between healthy patients and those with pathologies. Additionally, further research is needed to establish norms for pediatric signals in order to better understand retinal health in children.**

Keywords—Electroretinography, ERG analysis, full-field ERG, database, Oculusgraphy, time-domain analysis.

I. INTRODUCTION

Electroretinography(ERG) is the measurement of electrical impulses from the functional parts of the retina by means of light stimuli. These responses come from different parts of the retina that respond to the stimulus based on the type of cell that is excited by the light. Some of these cells include the rod and cone photoreceptors, which function in dark(scotopic) and light (photopic) environments, respectively, bipolar cells, amacrine cells, ganglion cells, and Müller cells[1]–[5]. The responses given back by these cells are recorded in the form of signals by means of an electroretinogram and are used by doctors for the diagnosis of various retinal pathologies predominantly cone and rod dystrophies as well as diabetic retinopathies[6], [7].

The ERG signal has a very shot duration, usually about 200 milliseconds long, with the majority of its components appearing with the first 80 milliseconds[1].

There are 2 main ERG components as recommended by the International Society for Clinical Electrophysiology of Vision(ISCEV)[6], these are the a-wave which is the initial negative amplitude in the signal and represents response from both the cone and rod cells, the b-wave which is the positive inflection that comes immediately after the a-wave and represents responses from the ON- and OFF-bipolar cells. These two components appear as low frequency components, often within the range of 20-40Hz[1], [8]. Other components that might appear in the signal are the i-wave which appears to originate from an OFF-pathway situated away from the point of attachment to the retinal ganglion cells, the photopic negative response(PhNR) situated as a negative deflection directly after the i-wave and the d-wave that appears as a response to the offset of long duration flashes[9]. Oscillatory Potentials are high-frequency components of the ERG signal that often appear after the b-wave and have more oscillations and less amplitude that other components[1], [10].

Standardized protocols for ERG analysis and research are published and frequently updated by the International Society for Clinical Electrophysiology of Vision(ISCEV) for various types of Electrophysiological research including Full-Field ERG, Multi-focal ERG, Pattern ERG, Visual Evoked Potentials(VEP), and Electrooculography(EOG)[6], [11]–[14]. There are six standard response protocols according to the ISCEV Full-Field ERG standard, these are: (1) Dark Adapted 0.01(DA 0.01) ERG; (2) Dark Adapted 3(DA 3) ERG; (3) Dark Adapted 10 (DA 10) ERG; (4) Light Adapted 3 (LA 3) ERG; (5) Light Adapted 30 Hz flicker (LA 30Hz) ERG and (6) Dark Adapted oscillatory potentials (DA OPs)[6]. These protocols are named based on their adaptation state and light intensity($cd \cdot s \cdot m^{-2}$).

The primary objective of this study is to analyze and assess the classical parameters of the ERG database utilizing time-domain analysis. This is the initial investigation in a series of studies that seeks to analyze the ERG signals database by means of different techniques, including time-domain, frequency domain and time-frequency domain analyses, and

MK-1262.2022.1.6

contrast these techniques with the current state of the art in order to gain a better comprehension of these signals.

II. Materials and Methods

A. Patient Preparation

The signals in the database were recorded using the Tomey GmbH EP-1000 Multifocal computerized electrophysiology workstation situated at the IRTC Microsurgery Yekaterinburg Center. Patient preparation was conducted in accordance with the ISCEV standards with the administration of 0.05ml of Midrimax eye drops for pupil dilation, 20 minutes of dark adaptation before recording dark adapted ERG signals and 10 minutes of light adaption before recording light adapted ERG signals as well as a minimum of 30 minutes recovery period for eye restoration for optical coherence tomography (OCT). Signal recordings were done based on the Tomey standard protocols though flash intensity replacements were routinely regulated by the ISCEV standard[6].

B. Parameter Extraction

Data storage and decryption were carried out in accordance with standard research protocols. Python numerical libraries including NumPy and SciPy were used to extract the signals from the raw database and to identify the peaks and troughs of the signals. The a- and b-amplitudes and their latencies were measured and calculated for each signal based on the extracted peak and trough points. The parameters were calculated according to standard norms of adult signals. Fig. 1 outlines the pipeline process from signal acquisition to parameter extraction and signal categorization. Fig. 2 shows the 3 main types of signals analyzed.

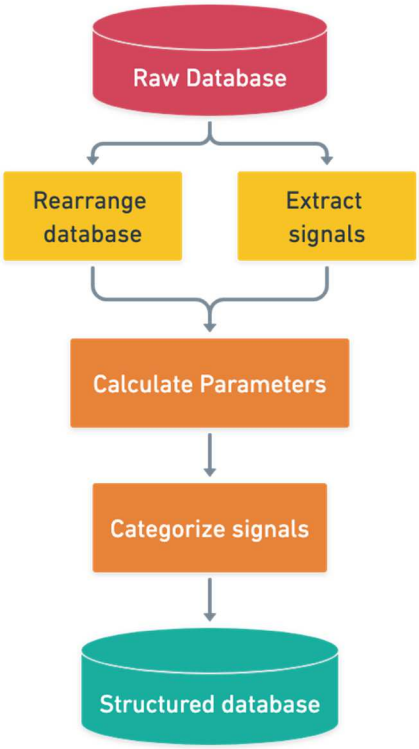

Fig. 1. Parameter extraction process

$$a = P_2 - P_1 \quad (1)$$

$$la = t_2 - t_1 \quad (2)$$

$$b = P_3 - P_2 \quad (3)$$

$$lb = t_3 - t_1 \quad (4)$$

1) Scotopic 2.0 ERG Response

This type of signal is usually the first one taken during the experiment and has 2 waves, the a-wave which is a response from the patient's photoreceptors and the b-wave which is a response from the patient's on- and off-bipolar cells and the main physiological driver of the signal. The a-wave represents cone activation which is not clearly defined and thus usually not measured. The b-wave amplitude is measured from the trough (P_2) of the a-wave to the peak of the b-wave(P_3) while the latency is computed from the mean baseline(t_1) to the peak of the b-wave(t_3). Equations (3) and (4) show the formulae for calculating the amplitude and latency for the signal.

2) Maximum 2.0 ERG Response

This signal is usually recorded after the Scotopic 2.0 ERG Response has clearly defined a- and b-waves. The a-wave is formed as a response from the photoreceptors and post-receptor pathways while the b-wave is formed as a response from the rod bipolar cells. The a-wave amplitudes and latencies are measured from the mean baseline to the trough of the a-wave. B-wave amplitude is measured from the trough of the a-wave to the peak of the signal, while its latency is computed from the mean baseline to its peak. Equations (1) – (4) show the formulae for calculating the amplitudes and latencies for the signal.

3) Photopic 2.0 ERG Response

Photopic 2.0 ERG Response is often recorded after the Maximum 2.0 ERG Response or the Scotopic 2.0 ERG Response. In order to achieve stable and reproducible ERGs as well as maximum cone response, the patient undergoes a 10-minute light adaptation. This signal is generated by the rods and the off- and on-post receptor pathways. The a-wave amplitude and latency are measured from the mean baseline to the trough of the wave while the b-wave amplitude is measured from the trough of the a-wave to the peak of the b-wave and its latency from the mean baseline to its peak. Usually, there is some noise at the beginning of this signal before the mean baseline which is discarded during measurement. The equations for calculating the amplitudes and latencies for this signal is the same as the one for calculating the parameters for Maximum 2.0 ERG Response shown in Equations (1) – (4).

4) Scotopic 2.0 ERG Oscillatory Potentials

These signals can either be recorded by an ophthalmic recording system or retrieved by filtering the Maximum 2.0 ERG Response signal using high pass filters of 75Hz and below. Their cellular origin still remains partially unknown but seem to be a reflection of inner retinal activity from the amacrine cells and retinal ganglion cells[6]. The recommended technique for the digital filtering of such signals is by removing Fourier components with frequencies less than 75Hz[15].

5) Photopic 2.0 EGR Flicker Response

In order to ensure stable test conditions in this experiment, the initial flicker response due to temporal response of the light-adapted rods is dropped, as this signal only indicates the activity of the cone system due to its brief duration. The primary physiological drivers of this signal are the cone response and the on- and off-post receptor pathways.

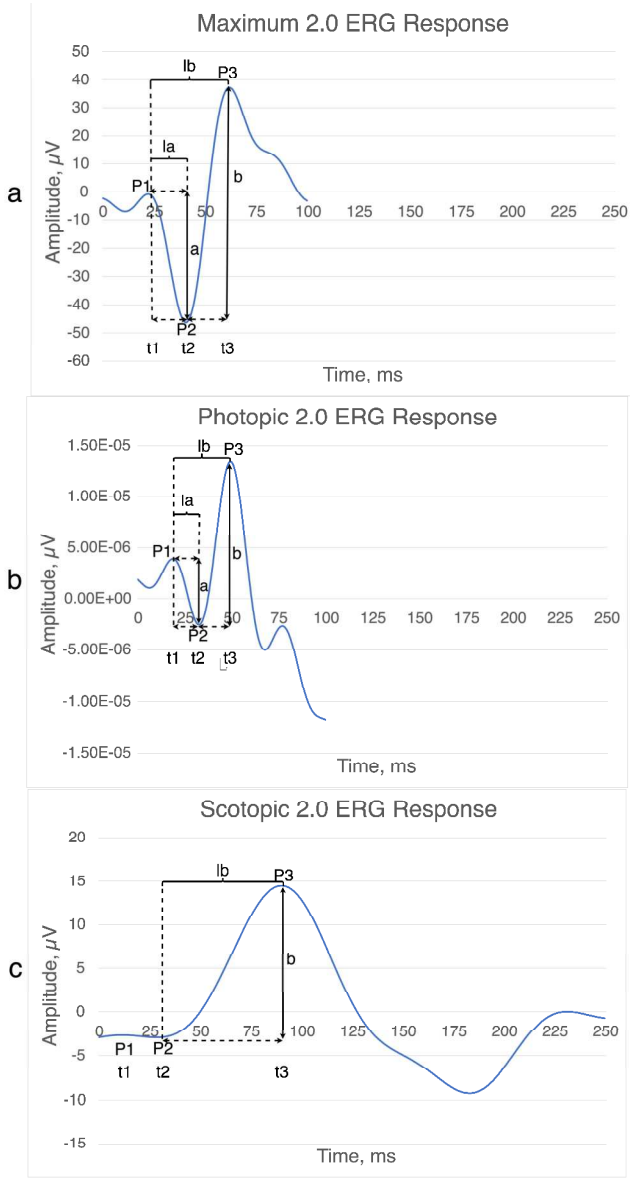

Fig. 2. ERG Signals: Maximum 2.0 ERG Response(a); Photopic 2.0 ERG Respsonse(b); Scotopic 2.0 ERG Response(c).

III. Results and Analysis

The database in the appendix this study contains 1975 signals from 323 total patients of which 182 were kids and 141 were adults. Fig. 3 shows the number of signals based on their types while Table I shows the age distribution of both signal groups.

TABLE I. PATIENT AGE DISTRIBUTION

Group	n	Mean	Median	STD	Q5%	Q95%
Adult	130	36.59	31.75	14.74	21.13	62.43
Pediatric	158	10.35	9.88	3.95	4.23	17.24

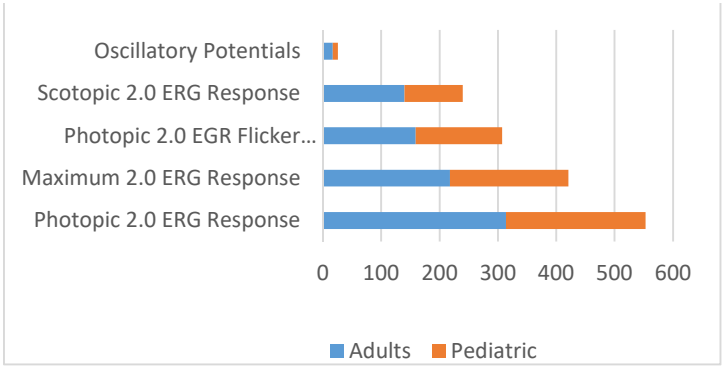

Fig. 3. Number of signals by type.

Tables II, III and IV demonstrate the correlation between the age and the classical parameters of the signals. It can be observed that there is a stronger correlation between the parameters than between the age and any of the other parameters, though some cases display a negative correlation between these features. Table III demonstrates a higher prevalence of negative correlations for pediatric patients than for adult patients.

TABLE II. CORRELATION MATRIX FOR MAXIMUM 2.0 ERG RESPONSE

Pediatric (Adults)	**Age**	**Ia**	**a**	**Ib**	**b**
Age	1.000 (1.000)	**0.018 (0.141)**	**0.065 (0.011)**	**0.038 (0.203)**	**0.102 (0.134)**
Ia	**0.018 (0.141)**	1.000 (1.000)	**-0.081 (-0.032)**	**0.892 (0.815)**	**-0.102 (-0.007)**
a	**0.065 (0.011)**	**-0.080 (-0.032)**	1.000 (1.000)	**-0.136 (-0.097)**	**0.929 (0.835)**
Ib	**0.038 (0.203)**	**0.892 (0.815)**	**-0.136 (-0.097)**	1.000 (1.000)	**-0.118 0.048**
b	**0.102 (0.134)**	**-0.102 (-0.007)**	**0.929 (0.835)**	**-0.118 (0.048)**	1.000 (1000)

TABLE III. CORRELATION MATRIX FOR PHOTOPIC 2.0 ERG RESPONSE: PEDIATRIC PARAMETERS

Pediatric (Adults)	**Age**	**Ia**	**a**	**Ib**	**b**
Age	1.000 (1.000)	**-0.026 (0.055)**	**-0.095 (-0.024)**	**-0.002 (0.057)**	**-0.120 (-0.037)**
Ia	**-0.026 (-0.055)**	1.000 (1.000)	**0.102 (0.123)**	**0.793 (0.784)**	**0.001 (0.018)**
a	**-0.095 (-0.024)**	**0.102 (0.123)**	1.000 (1.000)	**0.026 (0.012)**	**0.887 (0.878)**
Ib	**-0.002 (0.057)**	**0.794 (0.784)**	**0.263 (0.012)**	1.000 (1.000)	**-0.003 (0.035)**
b	**-0.120 (-0.037)**	**0.001 (0.018)**	**0.887 (0.878)**	**-0.006 (0.035)**	1.000 (1.000)

TABLE IV. CORRELATION MATRIX FOR SCOTOPIC 2.0 ERG RESPONSE: PEDIATRIC PARAMETERS

Pediatric (Adults)	**Age**	**lb**	**b**
Age	1.000 (1.000)	**0.313 (0.227)**	**0.060 (-0.054)**
lb	**0.313 (0.227)**	1.000 (1.000)	**0.305 (-0.027)**
b	**0.060 (-0.054)**	**0.305 (-0.027)**	1.000 (1.000)

IV. Conclusion and Discussion

Based on tables II, III, and IV for the adult's correlation, there appears to be little to no correlation between age and the four classical parameters. This could indicate that a patient's age does not necessarily dictate their retinal health, although the high correlation between latencies and amplitudes is an indication of how the parameters influence each other.

Due to the lack of clear norms that can be referenced for the kids' correlation, the correlation between age and the parameters is limited. However, some repeating patterns can still be observed.

Correlation and time-domain analysis alone, however, are not adequate to understand the nuances of these signals and accurately differentiate between healthy patients and those with pathologies. In order to determine healthy and unhealthy signals it's necessary to analyze all classical parameters as a group based on the signal norms[16]. Results from [17] which was conducted using Wavelet scalogram processing showed that patients with pathologies tended to have lower amplitudes and higher latencies than healthy patients, although it was noted that some "overlaps" make it infeasible to diagnose using a single feature.

This and the fact that time-domain analysis is highly susceptible to noise has motivated further research in the literature using other advanced analysis methods, such as frequency and time-frequency domain analyses.

Although, Photopic 2.0 EGR Flicker Responses and Scotopic 2.0 ERG Oscillatory Potentials were recorded in the database, analysis of these two types of signals won't be done for this study due to the level of care and details required for their study.

Appendix

Aleksei Zhdanov, Anton Dolganov, Vasilii Borisov, Mikhail Ronkin, Vyacheslav Ponomarev, Dario Zanca, September 16, 2022, "OculusGraphy: Ophthalmic Electrophysiological Signals Database", IEEE Dataport, doi: https://dx.doi.org/10.21227/r1wb-pg25.

Acknowledgement

Aleksei Zhdanov executed the study design and manuscript editing within the Bi-nationally Supervised Doctoral Degrees/Cotutelle DAAD Research Grant.

References

[1] S. Behbahani, H. Ahmadieh, and S. Rajan, "Feature Extraction Methods for Electroretinogram Signal Analysis: A Review," *IEEE Access*, vol. 9, pp. 116879–116897, 2021, doi: 10.1109/ACCESS.2021.3103848.

[2] S. M. Saszik, J. G. Robson, and L. J. Frishman, "The Scotopic Threshold Response of the Dark-Adapted Electroretinogram of the Mouse," *J. Physiol.*, vol. 543, no. 3, pp. 899–916, 2002, doi: 10.1113/jphysiol.2002.019703.

[3] J. Wu, A. D. Marmorstein, P. Kofuji, and N. S. Peachey, "Contribution of Kir4.1 to the mouse electroretinogram," *Mol. Vis.*, vol. 10, pp. 650–654, Sep. 2004.

[4] J. G. Robson and L. J. Frishman, "The rod-driven a-wave of the dark-adapted mammalian electroretinogram," *Prog. Retin. Eye Res.*, vol. 39, pp. 1–22, Mar. 2014, doi: 10.1016/j.preteyeres.2013.12.003.

[5] R. A. Stockton and M. M. Slaughter, "B-wave of the electroretinogram. A reflection of ON bipolar cell activity.," *J. Gen. Physiol.*, vol. 93, no. 1, pp. 101–122, Jan. 1989, doi: 10.1085/jgp.93.1.101.

[6] A. G. Robson *et al.*, "ISCEV Standard for full-field clinical electroretinography (2022 update)," *Doc. Ophthalmol.*, vol. 144, no. 3, pp. 165–177, Jun. 2022, doi: 10.1007/s10633-022-09872-0.

[7] A. Balicka, A. Trbolová, and T. Vrbovská, "Electroretinography (A Review)," *Folia Vet.*, vol. 60, no. 1, pp. 53–58, Mar. 2016, doi: 10.1515/fv-2016-0008.

[8] M. Gauthier, M. Gauvin, J.-M. Lina, and P. Lachapelle, "The effects of bandpass filtering on the oscillatory potentials of the electroretinogram," *Doc. Ophthalmol.*, vol. 138, no. 3, pp. 247–254, Jun. 2019, doi: 10.1007/s10633-019-09683-w.

[9] N. V. Rangaswamy, L. J. Frishman, E. U. Dorotheo, J. S. Schiffman, H. M. Bahrani, and R. A. Tang, "Photopic ERGs in Patients with Optic Neuropathies: Comparison with Primate ERGs after Pharmacologic Blockade of Inner Retina," *Invest. Ophthalmol. Vis. Sci.*, vol. 45, no. 10, pp. 3827–3837, Oct. 2004, doi: 10.1167/iovs.04-0458.

[10] R. Granit, "The components of the retinal action potential in mammals and their relation to the discharge in the optic nerve," *J. Physiol.*, vol. 77, no. 3, pp. 207–239, Feb. 1933.

[11] M. B. Hoffmann *et al.*, "ISCEV standard for clinical multifocal electroretinography (mfERG) (2021 update)," *Doc. Ophthalmol.*, vol. 142, no. 1, pp. 5–16, Feb. 2021, doi: 10.1007/s10633-020-09812-w.

[12] M. Bach *et al.*, "ISCEV standard for clinical pattern electroretinography (PERG): 2012 update," *Doc. Ophthalmol.*, vol. 126, no. 1, pp. 1–7, Feb. 2013, doi: 10.1007/s10633-012-9353-y.

[13] J. V. Odom *et al.*, "ISCEV standard for clinical visual evoked potentials: (2016 update)," *Doc. Ophthalmol.*, vol. 133, no. 1, pp. 1–9, Aug. 2016, doi: 10.1007/s10633-016-9553-y.

[14] P. A. Constable, M. Bach, L. J. Frishman, B. G. Jeffrey, A. G. Robson, and for the International Society for Clinical Electrophysiology of Vision, "ISCEV Standard for clinical electro-oculography (2017 update)," *Doc. Ophthalmol.*, vol. 134, no. 1, pp. 1–9, Feb. 2017, doi: 10.1007/s10633-017-9573-2.

[15] A. E. Zhdanov *et al.*, "OculusGraphy: Description of Electroretinograms Database," in *2021 Third International Conference Neurotechnologies and Neurointerfaces (CNN)*, Sep. 2021, pp. 132–135. doi: 10.1109/CNN53494.2021.9580221.

[16] A. E. Zhdanov, V. I. Borisov, A. Yu. Dolganov, E. Lucian, X. Bao, and V. N. Kazaijkin, "OculusGraphy: Norms for Electroretinogram Signals," in *2021 IEEE 22nd International Conference of Young Professionals in Electron Devices and Materials (EDM)*, Souzga, the Altai Republic, Russia: IEEE, Jun. 2021, pp. 399–402. doi: 10.1109/EDM52169.2021.9507597.

[17] A. Zhdanov, A. Dolganov, D. Zanca, V. Borisov, and M. Ronkin, "Advanced Analysis of Electroretinograms Based on Wavelet Scalogram Processing," *Appl. Sci.*, vol. 12, no. 23, Art. no. 23, Jan. 2022, doi: 10.3390/app122312365.