System of vestibular assessment using video-oculography and electroencephalography data

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Abstract. This paper presents a new system for combined analysis of video-oculography and electroencephalography data during vestibular testing. The experimental setup consists of electroencephalography amplifier using 9EEG system of electrode placement and a low-cost, head-mounted device for video-oculography. The developed system has simple implementation and provides the possibility of simultaneous analysis of the nystagmus and bioelectrical activity of the brain during positional maneuvers, that can be used for differential diagnosis of dizziness and epilepsy.

1. Introduction
Epilepsy and dizziness are common neurological diseases that can be accompanied by nystagmus [1-7]. In the United States, 7.5 million patients with dizziness are examined in the ambulatory care setting each year [8].

Dizziness is much more commonly caused by inner ear disease [4]. But in many cases dizziness can be a manifestation of an attack in epilepsy [1-6]. Determination and description of vestibular abnormalities in patients with epilepsy is important for a better understanding of the disease [2]. Dizziness in epilepsy, when the patient has no psychomotor symptoms (generalized or localized attacks), is particularly difficult in differential diagnosis [4]. In such cases, dizziness can be a symptom of many other conditions, including benign paroxysmal positional vertigo, vestibular neuralgia and Meniere's syndrome [4]. Therefore, diagnosing of a patient with dizziness often the complex examination, which includes analysis of electroencephalographic data and eye movements. However, nowadays there are no medical systems for complex assessment of vestibular function and bioelectrical activity of the brain.

Attempts to combine electroencephalography (EEG) systems and video recording of eye movements have been made before [9, 10]. However, in these cases, remote eye tracking systems or infrared video cameras used to record eye movements. Application of such systems requires to fixate the head during examination, which excluded the possibility of analysis of the nystagmus during positional maneuvers.

The main aim of this research is to develop combined system of synchronous analysis of eye movements and electroencephalography data during vestibular testing, which includes different positional maneuvers.

2. Methods and materials
Diagnosis of dizziness in suspected epilepsy includes analysis of the bioelectrical activity of the brain (EEG) and video-oculography (videonystagmography). It must be taken into account that eye
movements can cause artifacts on the EEG, so it is important to analyze brain activity synchronously with eye movements [9].

EEG measures brain electrical activity, allowing doctors to identify any unusual patterns. In conventional systems, EEG signals record from 21 electrodes (International 10-20 system). To simplify the process of EEG registration and analysis, we used 9EEG system based on our previous research and described in [11]. Thus, minimizing the number of electrodes makes positional vestibular testing more convenient. The following electrodes were chosen from the international 10-20 system and placed symmetrically sagittal line head: Fp1, F7, T5, Fp2, F8, T6, O1 and O2 as shown on figure 1 [11].

![Figure 1](image1.png)

**Figure 1.** International 10-20 system on the left, 9EEG system on the right.

Otherwise, the NVX24 EEG system, that was used for recording brain activity has a typical schematic (figure 2).

EEG recordings were made under the following conditions:
1) Electrode cap was used to make it easier to affixing electrodes;
2) Before and after the calibration has been carried out the registration;
3) The sensitivity of the EEG amplifier was 5-10 μV/Mm;
4) The data were recorded at a sampling rate of 1000Hz;
5) The data were band-pass filtered between 5.3Hz and 15Hz;
6) 50 Hz line filter (50 Hz – in Europe);
7) The used speed was 30 mm/s;
8) Background recording, eye opening test, eye closing test, hyperventilation test, background after hyperventilation for at least 2 min were recorded;
9) Recording was analyzed in monopolar and bipolar leads.

![Figure 2](image2.png)

**Figure 2.** Block diagram of NVX EEG amplifier.
Videonystagmography (VNG) nowadays is the gold standard for diagnosing vestibular disorders. The method is based on video recording of the movements of one or both eyes using infrared cameras fixed in a special opaque mask. VNG can differentiate between a central and a peripheral vestibular lesion. Vestibular examination includes analysis of spontaneous nystagmus, Dix-Hallpike test, oculomotor tests (saccade and pursuit), gaze test and caloric test [1].

Videonystagmography software is possible to quantify the amplitude, speed and other parameters of eye movements. VNG can distinguish between central and peripheral vestibular lesions, which is certainly important for differential diagnosis.

However, existing VNG systems tend to be very expensive, so many clinics are not able to use it. It is also often necessary to pay extra for the ability to store the results of VNG on a computer.

The proposed solution to the problem is the eye movement recording device (figure 3) that we developed with available, low-cost hardware [12]. The device was based on VR headset for mobile devices and made of opaque plastic. A USB video camera was mounted inside the goggles.

Specifications of the camera:
1) Sensor: OmniVision OV2710;
2) Matrix resolution is 2.0 megapixels;
3) 3.6 mm focal length;
4) Aperture 2.0;
5) Infrared filter is missing;
6) Two 3mm IR diodes (940 nm) for the backlight;
7) Resolution and frame rate (fps): 1920 x 1080 (30fps), 1280 x 720 (60fps), 640 x 480 (120fps)
8) Compression format: MJPEG.

![Figure 3. The device for recording of eye movements.](image)

It is possible to install one or two cameras in the device case. It is also possible to adjust pupillary distance. The lenses were removed to reduce noise in the video.

Special mount for mobile devices allows to use a smartphone screen to show visual stimuli instead of a monitor or projector, when performing a series of vestibular tests.

Figure 4 shows the general scheme of the experimental study. Our EEG system has proprietary software, which makes it difficult to record the EEG and eye movements simultaneously. To resolve this, the simple script for capturing video using Python programming language and OpenCV library was written. Video was recorded at a resolution of 1280×720 and 60 frames per second. For synchronous recording of eye movements (VOG) and EEG we used Open Broadcaster Software. Videorecordings were accompanied by voice comments.
3. Results and discussion
The developed system has simple implementation and shows the possibility of synchronous analysis of eye movements (nystagmus) and EEG (figure 5). The proposed method of combined instrumental assessment of dizziness can be used for differential diagnosis of vertigo and diseases of the nervous system, taking into account the bioelectric patterns of the EEG.

Using this new original combined system, it is possible to assess motor activity of the eyes and bioelectrical activity of the brain during vestibular examination. Camera installed in front of the eye provides clear, high resolution image.

A frame rate of 30 frames per second allows to analyze all types of nystagmus [13]. In our system it is possible to set the frame rate up to 120 fps for more accurate analysis of fast eye movements such as quick phase of nystagmus.

The developed system is useful for vestibular testing which includes different positional maneuvers such as Dix-Hallpike test due to application of head mounted VR goggles with cameras (Video Frenzel) and compact system of electrode placement. There are no needs to fixate the head during examination in comparison to existing systems [9, 10].
It is also important to note that the patient cannot fixate the gaze inside the goggles as it is completely dark. Visual fixation may reduce nystagmus. EEG and video recordings have common timescale. Unfortunately, a lot of clinical EEG amplifiers have proprietary software. It makes difficulties to design new software for synchronous recording of EEG and eye movements.

4. Conclusion
Thus, the combined system of synchronous analysis of eye movements and electroencephalography data during vestibular testing was developed. The system allows to conduct positional maneuvers during examination as well as analyze bioelectrical activity of the brain using compact system of electrode placement. Applying of such combined systems will increase the efficiency of differential diagnostics of the vestibular and nervous systems.

In the future, we plan to improve the proposed method by adding the ability to calibrate and quantify eye movements. This will allow to conduct metrological verification of the nystagmus in combination with the analysis of EEG patterns.

References
[1] El-Gohary M, Elmously M, Esmail N, Gawwad E A, Mekki S, Nada E 2014 Videonystagmography findings in epileptic children. Advanced Arab Academy of Audio-Vestibulogy Journal 1(1) 26 https://doi.org/10.4103/2314-8667.137561

[2] Hamed S A, Tohamy A M, Oseilly A M 2017 Vestibular function in adults with epilepsy of unknown etiology. Otology & Neurotology 38(8) 1217 https://doi.org/10.1097/MAO.0000000000001513

[3] Kim K S, Kim Y H, Hwang Y, Kang B, Kim D H, Kwon Y S 2013 Epileptic nystagmus and vertigo associated with bilateral temporal and frontal lobe epilepsy. Clinical and Experimental Otorhinolaryngology 6(4) 259 https://doi.org/10.3342/coe.2013.6.4.259

[4] Miskov S, Hećimović H 2007 The Differential Diagnosis of Vertigo and Epilepsy. Epilepsia 38(4) 37

[5] Nicita F, Papetti L, Spalice A, Ursitti F, Iannetti P 2010 Epileptic nystagmus: description of a pediatric case with EEG correlation and SPECT findings. Journal of the Neurological Sciences 298 127 https://doi.org/10.1016/j.jns.2010.08.022

[6] Tarnutzer A A, Lee S H, Robinson K A 2015 Clinical and electrographic findings in epileptic vertigo and dizziness: a systematic review. Neurology 84(1) 595 https://doi.org/10.1212/WNL.0000000000001474

[7] Ma Y, Wang J, Li D, Lang S 2015 Two types of isolated epileptic nystagmus: case report. Int. J. Clin. Exp. Med. 8(8) 13500

[8] Kerber K A, Brown D L, Lisabeth L D, Smith M A, Morgenstern L B 2006 Stroke among patients with dizziness, vertigo, and imbalance in the emergency department: a population-based study. Stroke 37 2484 https://doi.org/10.1161/01.STR.0000240329.48263.0d

[9] Plöchl M, Ossandón J P, König P 2012 Combining EEG and eye tracking: identification, characterization, and correction of eye movement artifacts in electroencephalographic data. Frontiers in Human Neuroscience 6 23 https://doi.org/10.3389/fnhum.2012.00278

[10] Anisimov V N, Ermachenko N S, Ermachenko A A, Tereschenko L V, Latanov A V 2014 Experimental setup for synchronous recording of eye movements and eeg. Izvestiya SFedU. Engineering sciences 11(136) 116–120

[11] Gorbunov A 2019 Journal of Physics: Conference Series 1278 012013 https://doi.org/10.1088/1742-6596/1278/1/012013

[12] Neprokin A V 07.03.2018 Patent RU 183466 U1

[13] Nystagmus Simulating and Compensating for Eye Motion Blur with Eye Tribe (Stanford University), available at: http://stanford.edu/class/ee367/Winter2015/report_landry_lee_madduri.pdf