Electronystagmography,
virtual reality,
optokinetic stimulation.

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RESEARCH ON UTILIZATION OF VIRTUAL REALITY AS OPTICAL STIMULATION IN ELECTRONYSTAGMOGRAPHY

The paper presents a research on the utilization of an up-to-date virtual reality set as a stimulation during an electronystagmography examination. The main aim of the research was to test whether an optical stimulation generated by means of virtual reality presented in a helmet-mounted display is comparable with the same methods of stimulation generated in a human natural environment. The experiments were conducted using an amplifier of electronystagmography signals, an acquisition software and the Oculus Development Kit 2 virtual reality set. As traditional stimuli were used animations displayed on the LCD monitor screen. The electronystagmograms registered with a virtual optokinetic stimulation were compared with results obtained using traditional stimulating methods. Additionally, a questionnaire on comfort was conducted among participants of the experiment. To asses the similarity of signals registered using both methods the Pearson correlation coefficient was calculated and the standard deviation. The results of tests showed that electronystagmograms registered during the virtual stimulation were consistent with the records registered during the traditional stimulation. Moreover, the results of the questionnaire on comfort while using a virtual reality headset are very encouraging showing that headset is at least neutral for participants.

1. INTRODUCTION

Dizziness and disturbance of equilibrium are ambiguous symptoms that may occur in the process of many diseases [7] [13] [14]. Clinical symptoms that indicate disturbances of the human equilibrium system include dizziness (a subjective symptom) along with objective indicators such as nystagmus (i.e. rapid involuntary movements of eyeballs) as well as unbalanced posture that result from alterations in various groups of muscles. The analysis of the nystagmus effect that has been induced by strictly defined sets of stimuli is considered as one of most reliable methods for evaluation of the equilibrium system [7] [13] [2]. The electronystagmography examination includes different types of stimulation to induce a nystagmus. The standard electronystagmography test battery consists of three parts: an oculomotor evaluation, a positioning and positional testing [7] [13] [2] [24] and a caloric stimulation of the vestibular system [26] [9] [12].
In this research authors focused on oculomotor evaluation using computer-generated stimuli only. The main aim of the presented research was to test whether an optical stimulation generated by means of the virtual reality (VR) presented in a helmet-mounted display (HMD)

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is comparable with traditional methods of the stimulation presented in the human natural environment (not virtual). In this case the traditional stimuli were presented on LCD monitor screen. Moreover, among the participants of the experiment a questionnaire on comfort was conducted before, during and after tests. Furthermore, an additional aim was to verify hardware performance of contemporary computers to produce animations presenting required stimuli.
Early research on the usage of the virtual reality were conducted in the field of vestibular rehabilitation in late '90s and in early 2000s [22] [27] [1]. Recently researchers returned to this studies [15] [25] [3] in view of a big comeback of the virtual reality technology in many different fields of science as well [16] [18][17] [19] [10] [30] [31]. However, application of the virtual reality animations as a stimulation in electronystagmography was not found.

2. MATERIALS AND METHODS

To test the usefulness of the virtal reality stimulation in electronystagmography a set of the equipment was utilised. It consisted of a two-channel amplifier of the electronystagmography signals with declaration of conformity according to the Medical Device Directive 93/42/EEC, an acquisition software and the Oculus Rift Development Kit 2 virtual reality headset [21]. The applied equipment is presented in the Fig.1.

In presented tests traditional stimulation methods were used. Three traditional animations were prepared: a calibration animation, a pendulum tracking test and moving vertical stripes mimicking a striped rotatory drum for optokinetic test. All these animations were presented on the 30" LCD monitor screen. The participant sat 1 m away from the screen. In order to register eye movement reactions based on vestibulo-oculomotor reflex three virtual animations were worked out. There were following animations: a calibration pre-test animation, a pendulum movement animation and an animation simulating equipment with rotatory chair using optokinetic stimulus superimposed upon round walls. Each of the participants was tested two times in periods of couple days. All data were analysed fully anonymously.

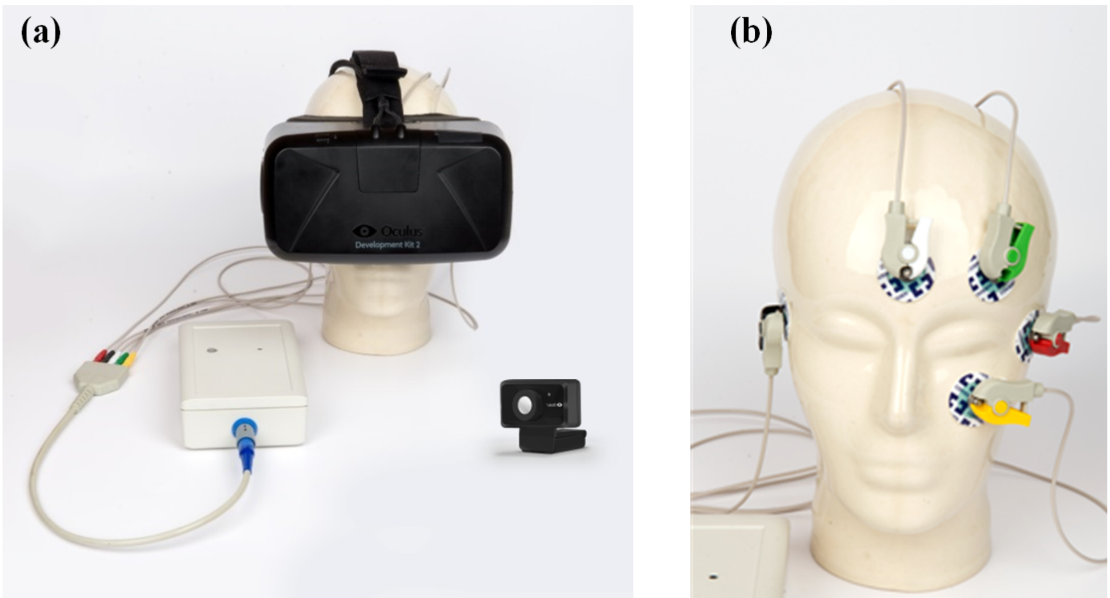

Fig. 1. The amplifier, the Oculus Rift Development Kit 2 virtual reality set (virtual reality headset and 3D positional sensor) (a), electrodes placement (b).

A human interpupillary distance mostly varies from 50 to 75mm. However, Dodgson [8] recommends to widen this range into 45 to 80mm. Due to this fact, before virtual tests the individual interpupilary distance was determined. The interpupilary distance determination process uses dedicated software provided by a virtual reality set manufacturer (Oculus). Determination of this distance significantly improves a visual perception of a three-dimensional (3-D) animations eliminating artefacts produced during 3-D animation generating. The information about an individual interpupilar distance enables to adjust an angle of generated images to a real personal angle of view. Additionally, a 3-D positional tracker was also enabled to track the head movements in the third dimension. The tracker was placed in front of a participants head.

The tests were carried out in accordance with the procedure:

- a calibration - a determination of an eye angle deflection from the primary position,
- a pendulum tracking test,
- an optokinetic test.

The whole procedure was conducted using traditional stimuli generated in a natural environment (without a virtual reality set) as well as using virtual stimuli generated in a virtual reality. Traditional tests included the calibration, the pendulum tracking and the tracking of moving vertical stripes. They were displayed on 30” LCD monitor screen. Virtual tests were conducted using stimuli animations prepared for the virtual reality set. All animations for the virtual reality were created with the Unity 3D editor and Blender software [11] [28] [29].

2.1. Preparation for tests

Before each virtual test it was necessary to set a participant’s head in a correct position in the virtual space where an animation was displayed. A participant of the experiment fitted two coaxial circles displayed in a virtual reality space in order to set his correct head position (as shown in the Fig.2). One of the circles was static in the virtual space. The second one was a kind of gaze pointer that followed the movement of the participant’s head until it covered the static circle. The correct position of the head was established by the coverage of both circles. After the participant’s head had been placed in the correct position it was stabilized not to move.

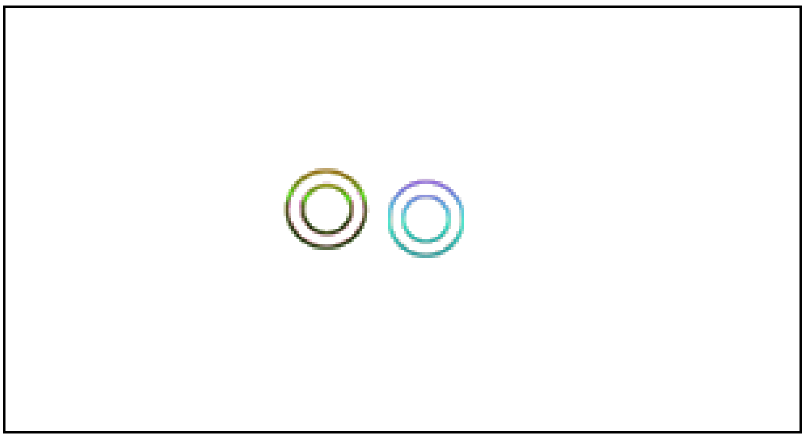

Fig. 2. Setting a correct head position in the virtual space before the tests (circle pointers in the filed of view presented in inverted colours).

2.2. Calibration

Before the tests, a calibration procedure had been run in order to determine an angle of eyes deflection for further analysis. The traditional calibration was conducted using 30" LCD monitor screen in a darkened room. A calibration was based on tracking points on the Madox cross. In both animations (in a "traditional" and in a virtual one) the calibrating points were lit for 1 second in a sequence: left-centre-right-centre-top-centre-bottom-centre (C - 0 - B - 0 - D - 0 - E - 0) as shown in the Fig.3.

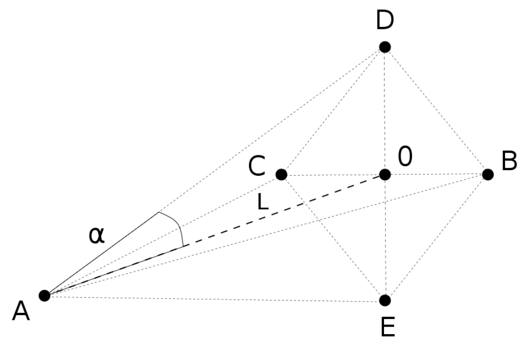

Fig. 3. The coordinates points placement in the three dimentional space. Gaze focused on the position "0" is a primary position.

Participant's eyes were situated in the A point. Gaze focused on the position "0" was a primary position. The coordinates of calibration points were given by the formulas:

$$O(x, y) = (0, 0), \quad (1)$$

$$B(x, y) = (L \cdot sin(\alpha), 0), \quad (2)$$

$$C(x, y) = ((-1) \cdot L \cdot sin(\alpha), 0), \quad (3)$$

$$D(x, y) = (0, L \cdot sin(\alpha)), \quad (4)$$

$$E(x, y) = (0, (-1) \cdot L \cdot sin(\alpha)), \quad (5)$$

where:

– α - is an angle between points A and B, A and C, A and D as well as A and E;

– L is a distance between participant's eyes and Madox cross.

During the experiment, the parameters were as follow:

- an angle $\alpha = 10°$,
- the distance $L = 1m$,
- distances $OB = OD = 17.37cm$,
- distances $OC = OE = 17.37cm$.

The real distances between a particular objects in the virtual space were mapped to elicit required eyes deflection angle as it had been done in the natural environment. In the Unity 3D editor the distances are represented in Unity units. The default value of 1 Unity unit is 1m for the virtual reality objects creation. Consequently, the object was placed in the distance of 1 Unity unit.

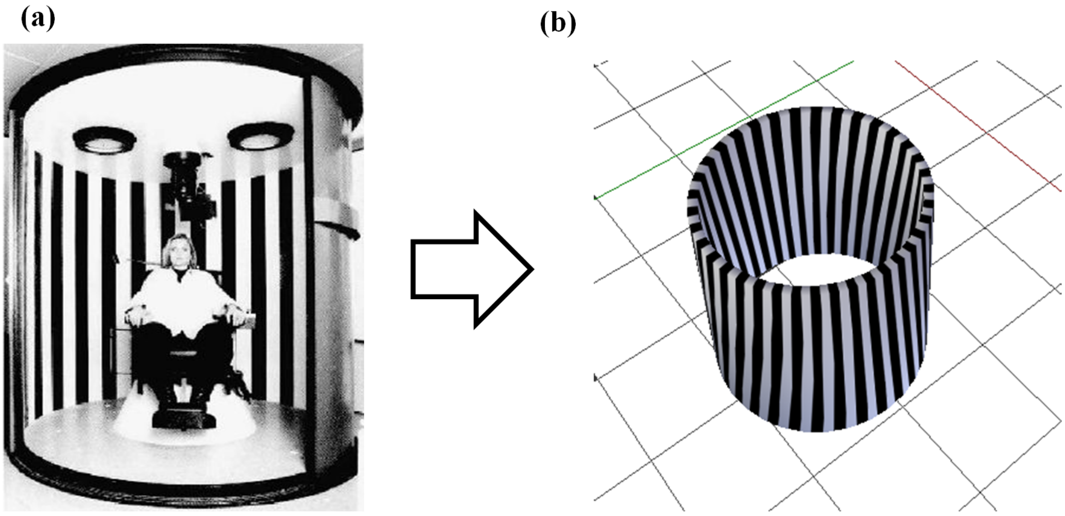

Fig. 4. The simulation of a real equipment with revolving chair (a) [5], a simulation in the virtual reality space (b).

2.3. Pendulum tracking tests

The pendulum tracking test was based on a linear pendulum movement following in the range of angles $< -\beta, \beta >$. The angle β was changed from 5° to 10° . A moving object (a sphere) was placed 1m from participant's head at the height of eyes. The frequency of the pendulum ranged from 0.5 to 2Hz. During each test mentioned parameters were constant.
The traditional pendulum tracking test was carried in the same conditions as in calibration process. In the virtual space the coordinates of the sphere position in three dimensional space (x, y, z) were given as follows:

$$x = sin(\beta), \tag{6}$$

$$y = 1, \tag{7}$$

$$z = cos(\beta), \tag{8}$$

where: β - the angle of deflection of the sphere from the three dimensional position $(x, y, z) = (0, 1, 0)$.
As well as during the calibration process the moving object was placed 1m away from the participant's head.

2.4. Optokinetic tests

The traditional optokinetic test was carried out under the same conditions as in the previous tests. The participant sat 1m from the monitor. The parameters of an optokinetic test were as follows:

- an angular speed of stripes rotation ranged from 30° to 60°/s,
- a stimulus frequency ranged from 0.5 to 4Hz.

The speed, the direction and the stimulus frequency were changed during the test. The virtual simulation of the real equipment used for an optokinetic tests was prepared as a striped cylinder as shown in the Fig.4(b). A person wearing virtual reality headset was situated inside a virtual rotating striped cylinder.

2.5. Questionnaire on comfort

All participants were asked to describe their comfort during the usage of the virtual reality headset. The assessment scale was as follows:

- 1 I feel a large discomfort,
- 2 I feel a discomfort,
- 3 The usage of the virtual reality headset is neutral for me,
- 4 I feel comfortable,
- 5 I feel very comfortable,
- 6 I am excited.

The questionnaire was conducted in two trials spaced in time by couple of days. According to the research [6] and [20] on visual perception depending on the background of the presentation both in natural and virtual environments, static and dynamic images were displayed on two different backgrounds: a solid colour background and a landscape background.

2.6. Platform performance test

According to the Oculus Rift Development Kit 2 manufacturer's recommendations a realistic animation presenting a smooth movement of objects should be generated at a speed 75 frames per second (FPS) or higher. To asses the hardware platform performance for abilities of generating the virtual reality animation five different hardware-software computer configurations were tested. The criterion was the number of frames per second in the animation mode that can be generated by each configuration. Additional question was whether the speed of animation lower then 75FPS could be sufficient for generating the electronystagmography stimulation. The specification of each configuration and achieved number of frames per second while playing the animation using a computer screen and a virtual reality headset is given in the Table 1.

Table 1. Hardware-software configurations used in the performance test.

	Procesor	RAM [GB]	Graphics card	Graphics card RAM [GB]	Operating system	FPS average value / FPS generated in VR HMD
1	Intel Core Duo E7500	2	Nvidia GeForce 9300 GE	1	Windows 7 Pro 32-bit	100/75
2	Intel Core Duo T 6500	2	ATI Mobility Radeon HD 4570	1	Windows Vista Ultimate 32-bit	59/59
3	Intel Core i5-2400	4	AMD Radeon HD 6450	2	Windows 7 Pro 64-bit	242/75
4	Intel Core i7-4790	32	Nvidia GeForce GTX 960	4	Windows 8.1 Pro 64-bit	996/75
5	Intel Core i7-6700HQ	16	Intel HD Graphics 530	4	Windows 10 Pro 64-bit	60/60

2.7. Technical aspects

Each frame of the animation is generated in a different time depending on its complexity. A required speed of the animation (e.g. the pendulum movement with the frequency 0.5Hz etc.) was achieved by generating the adequate movement of the sphere determined by the strict time between the successive frames. During the virtual stimulation an angular field of view of a scene equalled 100 ° . All real distances were mapped in the virtual space.

3. RESULTS

The tests were conducted involving 20 healthy participants aged 31 to 65 years. Each participant underwent traditional and virtual tests. To assess the usefulness of recordings of oculomotor movements acquired during virtual stimulation they were compared with signals recorded using traditional stimulation.

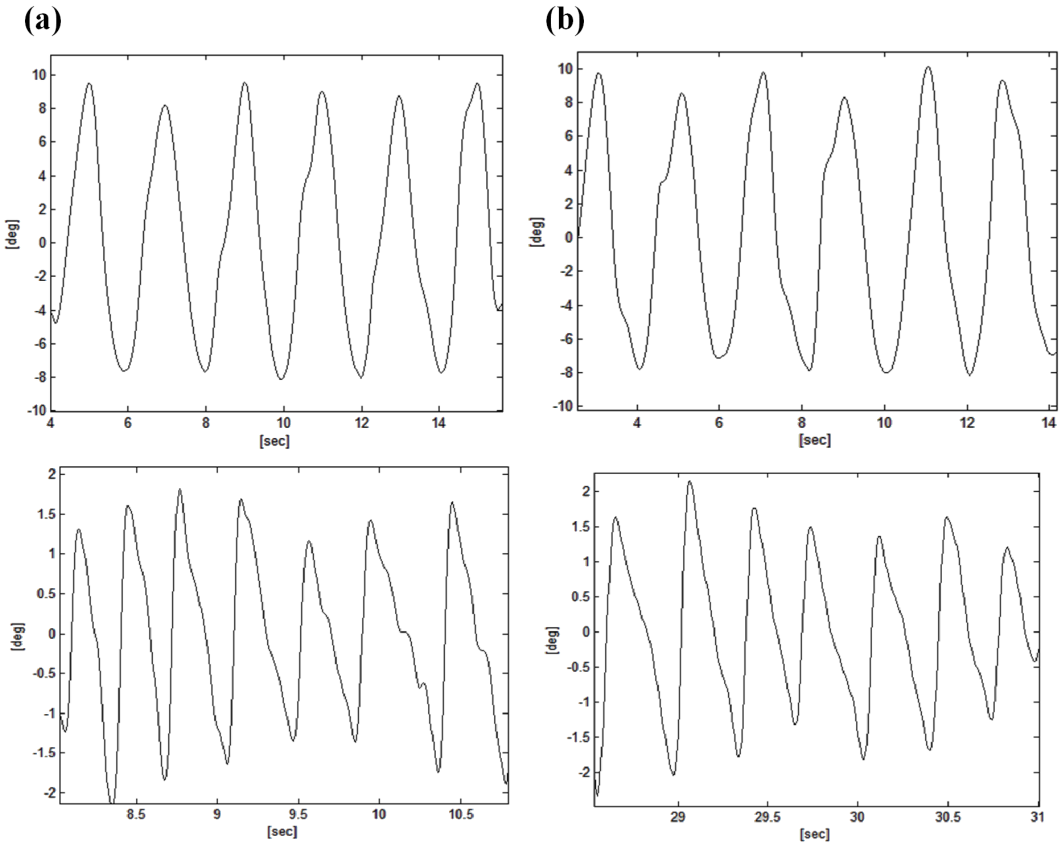

Fig. 5. The horizontal eyes deflection during the pendulum tracking test and optokinetic test using a 30" LCD monitor (a) and using a virtual reality animation (b).

3.1. ELECTRONYSTAGMOGRAPHY TESTS RESULTS

Charts presented in the Fig.5 show samples of acquired signals of oculomotor responses (an eye position in angles as a function of time) registered during the pendulum tracking test (upper graphs) and the optokinetic test (lower graphs). The section(a) of the chart presents a horizontal eyes deflection line graph presenting eyes position changes registered during using traditional stimulation while the section (b) depicts signals obtained during the virtual stimulation.

After the analysis of aquired signal it was found that corresponding fragments of the electronystagmograms which were registered in the same conditions (i.e. stimulus angles, speed) were compared with. Registered signals were filtered with the zero phase Savitzky-Golay filter [23]. Filter parameters were as follows: the polynomial order equaled 3 and the frame size was 5. As a result of the comparison Pearson correlation coefficients were calculated $(p < 0.05)$ between electronystagmograms registered using a traditional and virtual stimulation [4]. The results of the comparison are presented in Table 2.

Table 2. The results of the comparison of electronystagmograms registered using traditional and virtual stimulation (the average value of Pearsons correlation coefficient and the standard deviation).

Test	Average value of Pearson correlation coefficient	Standard deviation
Calibration	0.89	0.04
Pendulum tracking	0.89	0.06
Optokinetic test: at a speed 30 ° /s	0.84	0.05
Optokinetic test: at a speed 60 ° /s	0.81	0.05

Table 3. The results of the participants' comfort questionnaire.

Test phase	Average value ($\overline{x}$)	Standard deviation (σ)	Average value ($\overline{x}$)	Standard deviation (σ)
	First attempt		After couple of days attempt	
Before the test	4.05	0.22	4.2	0.41
During static image presentation (a solid colour background)	3.25	0.44	3.35	0.49
During static image presentation (a landscape background)	5.05	0.22	5.05	0.22
During dynamic image presentation (a solid colour background)	3.15	0.37	3.30	0.47
During dynamic image presentation (a landscape background)	4.25	0.44	4.30	0.47
After the test	3.65	0.44	4.30	0.67

The comparison of test results showed that the stimulation based on the virtual reality is significantly comparable (the Pearson correlation coefficient ranged from 0.81 to 0.89) with the traditional stimulation. Acquired signals registered under corresponding to each other conditions were considerably correlated. Amplitudes of compared signals depicting a deflection of eyes were also comparable.
Finally, expected oculomotor movements as a response to presented stimuli registered during virtual stimulation agreed to records registered during traditional stimulation.

3.2. Qestionnaire results

Additionally, the anonymous questionnaire was conducted before, during and after tests. The mean values of the questionnaire results in each phase of the examination show that the virtual reality headset was at least neutral for participants. A subjective image perception and a feeling of comfort was significantly better while static and dynamic images were presented on a landscape background. The lowest score in the questionnaire can be found mainly in assessment of the comfort during the presentation of the static object on solid colour background (black colour). None of the participants felt a discomfort. The results of the questionnaire are shown in the Table 3.

3.3. Platform performance results

The test of hardware platform performance of different hardware-software configurations showed that the required 75 frames per second animation can be reached using a typical contemporary computer with the dedicated mid-range graphics card. The interesting fact was that sufficient quality of the nystagmografic animation could be displayed even using an embeded chipset Intel Graphics HD 530. In this case the animation was presented with 60 FPS. The displayed animation was smooth and the stimulus required for the electronystagmographic test was displayed properly due to the low complexity of nystagmographic animations. Unfortunately, using Intel Graphics HD 530 there was not a feedback information from the virtual reality headset. Consequently, there was not any information about current participant's head position.

4. SUMMARY AND CONCLUSIONS

The research on the utilization of the virtual reality as the stimulation in electronystagmography showed that morphology of recordings in the time domain registered during virtual stimulation corresponded to records obtained during traditional stimulation. Oculomotor responses registered during virtual stimulation corresponded to records registered during traditional stimulation. The average value of the Pearson correlation coefficient ranged from 0.81 to 0.89 with the standard deviation value ranging from 0.04 to 0.06.
It must be emphasized that virtual reality headset did not influence the quality of the electronystagmographic signals.
The hardware platform performance test of up-to-date computers showed that tested platforms used for generating a stimulus animation were sufficient and they reproduce natural conditions in a specific section of scene (an angular field of view equalled 100 °). The animation generated at a speed 75 frames per second or higher was smooth and satisfying. This speed is necessary to achieve a realistic natural environment image. However, the animation generated with the speed 60 frames per second also produced a correct electronystagmographic stimulation.
Moreover, the questionnaire results show that virtual reality headset was at least neutral for participants.
The research shows that an optical stimulation generated in a virtual reality space can be sufficient for utilization in electronystagmography to the extent that was tested.
Finally, the main advantage of using VR goggles over the classic displays is the possibility of displaying nystagmus stimuli in a wide range of angles ($\pm 45°$) in contrast to the classic LCD monitor (huge 30" LCD monitor may generate stimuli in range of $\pm 10°$). Moreover, a lightweight VR goggles enable making a portable station for electronystagmographic examination based on portable computer.

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