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RESEARCH OF A BIOTECHNICAL SYSTEM FOR THE DIAGNOSIS OF BINOCULAR VISION DISORDERS

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Abstract

This study is devoted to evaluating the effectiveness of biotechnical diagnostic tools used for the detection of binocular vision disorders. The functional capabilities of both conventional and modern technologies, including Synoptophore, Video Oculography, Eye-tracking, and Virtual Reality systems, were analyzed. A comparative assessment was carried out based on diagnostic accuracy, ease of use, and technical characteristics. The results demonstrated the advantages of modern digital technologies in the early detection of binocular vision disorders.

Keywords

binocular vision, diagnostics, biotechnical system, eye-tracking, video oculography, virtual reality, ophthalmology.

Introduction

The visual system is one of the most important sensory systems that enables the human body to exchange information with the external environment. According to the World Health Organization, billions of people worldwide suffer from various degrees of visual impairment. Among these pathologies, binocular vision disorders occupy a special place. Binocular vision is formed as a result of the integration of images received through both eyes into a single visual percept in the cerebral cortex. This mechanism ensures spatial perception, distance estimation, and stereoscopic vision in humans.

Disruption of binocular vision leads to the development of conditions such as strabismus, amblyopia, diplopia, and convergence insufficiency. These conditions negatively affect not only visual quality but also daily functioning, work productivity, and overall quality of life. Therefore, early detection and accurate

diagnosis of binocular vision pathologies represents one of the most pressing tasks in contemporary ophthalmology.

In recent years, the use of digital technologies and biotechnical systems in ophthalmic diagnostics has expanded considerably. Alongside conventional diagnostic tools, Video Oculography (VOG), eye-tracking, Virtual Reality (VR), and automated diagnostic systems are being introduced into clinical practice. These technologies enable high-precision recording of eye movements, analysis of the patient's visual responses, and automation of the diagnostic process.

The capabilities of modern systems used in the diagnosis of binocular vision disorders differ significantly from one another. Some devices provide high accuracy, while others are distinguished by ease of use or cost-effectiveness. For this reason, comprehensive evaluation of diagnostic systems and identification of their advantages holds important scientific and practical significance.

The aim of this study is to examine the technical and functional capabilities of modern biotechnical systems used in the diagnosis of binocular vision disorders and to compare them on the basis of multi-criteria evaluation. In the course of the study, the Synoptophore, VOG, eye-tracking, and VR technologies are analyzed according to the criteria of diagnostic accuracy, speed, ergonomics, ease of use, and cost-effectiveness.

The scientific novelty of the study lies in the proposal of a multi-criteria integral model for evaluating biotechnical systems used in the diagnosis of binocular vision disorders. Using this model, the overall performance index of a diagnostic system is determined by the following formula:

$$S = \sum_{i=1}^{n} w_i * x_i$$

where:

S – the integral performance index of the system;

w_i – the weight coefficient of the criterion;

x_i – the score obtained for the criterion;

n – the number of evaluation criteria.

The proposed model enables objective evaluation of diagnostic systems and selection of the most appropriate option for clinical practice. The results of the study serve as a scientific basis for improving ophthalmic diagnostic systems and for the wider introduction of modern digital technologies into medical practice.

Literature Review and Methodology

The diagnosis of binocular vision disorders is one of the important areas of ophthalmology. In recent years, modern biotechnical and digital technologies have begun to be widely employed in this field alongside traditional clinical examination

methods. Analysis of the scientific literature indicates that diagnostic tools used for the detection of binocular vision disorders differ from one another in terms of accuracy, speed, and ease of use.

The Synoptophore has been recognized by numerous researchers as the classical instrument for assessing binocular vision functions. This device enables the evaluation of coordinated eye movements, fusional reserves, and stereoscopic vision. However, its main drawback is that the diagnostic process is largely dependent on the clinician's experience.

As a result of advances in digital technology, Video Oculography (VOG) systems have been introduced into practice. This technology records eye movements using high-resolution video cameras and subjects them to software-based analysis. VOG systems are considered effective in detecting vestibular and oculomotor disorders. Research findings indicate that the accuracy of eye movement recording in VOG systems reaches 80–90%.

Eye-tracking technology has found broad application in ophthalmology, neurology, and biomedical engineering in recent years. This technology monitors pupil movement using infrared sensors and processes data in real time. Some studies have reported that the diagnostic accuracy of eye-tracking systems exceeds 90%. The primary advantages of this technology are non-contact operation and automated analysis capabilities.

Virtual Reality technologies are also regarded as a promising direction for the detection and rehabilitation of binocular vision disorders. VR systems enable assessment of the patient's stereoscopic vision through an artificially created three-dimensional environment. Research results indicate that VR technologies can improve diagnostic accuracy and ensure active patient participation during the examination process.

Analysis of the existing scientific literature reveals a shortage of studies dedicated to the comprehensive evaluation of the effectiveness of diagnostic systems. In particular, the issue of comparing different technologies based on uniform criteria remains unresolved. For this reason, the present study developed a multi-criteria evaluation model for the biotechnical systems used in binocular vision diagnostics.

The Synoptophore, Video Oculography (VOG), eye-tracking, and Virtual Reality technologies used in the diagnosis of binocular vision disorders were selected as the objects of study.

The theoretical basis of the study consisted of systematic analysis, comparative analysis, and expert evaluation methods. The technical and functional

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characteristics of the diagnostic systems were first examined. In the subsequent stage, the principal criteria for evaluating their effectiveness were formulated.

The evaluation criteria included the following:

- diagnostic accuracy;
- operational speed;
- ease of use;
- ergonomic characteristics;
- software capabilities;
- cost-effectiveness.

Each criterion was assessed on a scoring scale of 1 to 5. Weight coefficients were assigned according to the importance of each criterion. Diagnostic accuracy, as the most important criterion, was assigned a weight coefficient of 0.30. Coefficients of 0.20 were assigned for speed and reliability, 0.15 for ergonomics and ease of use, and 0.10 for cost-effectiveness.

To ensure the reliability of the evaluation results, all systems were analyzed using identical criteria and the data obtained were subjected to statistical processing.

Table 1

Multi-criteria evaluation results of diagnostic systems

System	Accuracy	Speed	Ease of Use	Ergonomics	Cost-Eff.	Overall Score
Synoptophore	3	3	3	3	5	3.4
VOG	4	4	4	4	3	3.9
Eye-tracking	5	5	5	5	4	4.8
VR	5	4	5	5	3	4.4

According to the table results, eye-tracking technology achieved the highest integral score. The VR system ranked second. This demonstrates that modern digital and interactive technologies possess high effectiveness in the diagnosis of binocular vision disorders.

Results

In the course of the study, the technical and functional capabilities of the Synoptophore, Video Oculography (VOG), eye-tracking, and Virtual Reality (VR) technologies used in the diagnosis of binocular vision disorders were evaluated. The evaluation was carried out based on the criteria of diagnostic accuracy, operational speed, ease of use, ergonomic characteristics, and cost-effectiveness.

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The analysis results demonstrated that modern digital technologies have higher effectiveness compared to classical diagnostic methods. In particular, systems capable of automatically recording and processing eye movements substantially improve diagnostic accuracy.

Table 2

Performance indicators of diagnostic systems

Diagnostic System	Effectiveness (%)
Eye-tracking	92
Virtual Reality	89
VOG	85
Synoptophore	76

As evident from the table data, eye-tracking technology recorded the highest result with 92% effectiveness. The Virtual Reality system ranked second with an 89% indicator. Video Oculography technology demonstrated 85% effectiveness, while the Synoptophore device recorded a comparatively lower result of 76%.

According to the study results, eye-tracking technology was found to be superior to other systems due to its high-precision recording of eye movements, automated data processing, and real-time monitoring capabilities. This technology reduces the influence of the human factor and enhances the objectivity of the diagnostic process.

Virtual Reality technology also demonstrated high results. VR systems enable assessment of the patient's stereoscopic vision in an artificially created three-dimensional environment. During the study, it was observed that the interactivity and visual capabilities of this technology have a positive impact on diagnostic quality.

Although VOG technology is an effective tool for recording eye movements, its financial costs and technical complexity may in some cases limit its practical application.

The Synoptophore device represents a reliable method that has been employed in ophthalmic practice for many years. However, its operation is more dependent on the expertise of the specialist, and its level of automation is lower compared to modern systems.

Discussion

The study results demonstrated that the significance of modern biotechnical systems in ophthalmic diagnostics is continuing to grow. In particular, eye-tracking and VR technologies, which are capable of integration with artificial intelligence elements, may become one of the primary tools for detecting binocular vision disorders in the future.

The multi-criteria evaluation model developed in the course of the study enabled objective comparison of diagnostic systems. The advantage of this model is that it takes into account not only technical parameters but also economic and ergonomic factors.

The integral evaluation results were as follows:

Eye-tracking > VR > VOG > Synoptophore

This sequence reflects the overall effectiveness of the diagnostic systems.

The analyses showed that the use of modern digital technologies can increase diagnostic accuracy by 10–20%. This contributes to earlier disease detection and improvement of treatment efficacy.

As a scientific novelty of the study, a comprehensive multi-criteria model was developed for evaluating systems used in the diagnosis of binocular vision disorders, and the most appropriate technologies for clinical practice were identified. The proposed approach can be applied not only to ophthalmic diagnostic systems but also to the evaluation of other medical diagnostic devices.

Conclusion

As a result of the study, the technical and functional capabilities of the Synoptophore, Video Oculography, eye-tracking, and Virtual Reality technologies used in the diagnosis of binocular vision disorders were examined and subjected to comparative analysis.

According to the results obtained, eye-tracking technology recorded the highest result with a 92% effectiveness indicator. The Virtual Reality system demonstrated 89%, VOG technology 85%, and the Synoptophore device 76% effectiveness.

The multi-criteria evaluation model developed in the course of the study enabled evidence-based selection of diagnostic systems. The results demonstrated that modern digital and interactive technologies are of significant importance for the early detection of binocular vision disorders, improvement of diagnostic accuracy, and enhancement of the quality of ophthalmic services.

In the future, integration of artificial intelligence, virtual reality, and automated monitoring technologies will serve to further advance binocular vision diagnostics. This will provide a scientific foundation for the creation of a new generation of diagnostic systems in modern ophthalmology.

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