



Universitatea
Transilvania
din Braşov

INTERDISCIPLINARY DOCTORAL SCHOOL

Faculty of Product Design and Environment

Eng. Alexandra-Maria LAZĂR

**Theoretical and experimental research on
visual function monitoring
SUMMARY**

Scientific supervisor:

Prof.Dr.Eng. Mihaela Ioana BARITZ

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CONTENTS

INTRODUCTION	4
1. RESEARCH PURPOSE AND OBJECTIVES, HYPOTHESES AND PROBLEM STATEMENT	9
1.1. PROBLEM STATEMENT	9
1.2. PURPOSE	9
1.3. OBJECTIVES.....	9
1.4. CONCLUSIONS	11
2. CURRENT STATE OF RESEARCH IN THE FIELD OF VISUAL SYSTEM STRUCTURES	12
2.1. CURRENT STATE OF RESEARCH THROUGH SCIENTOMETRIC ANALYSIS	12
.....	14
3. THEORETICAL BACKGROUND	16
3.1. MATHEMATICAL MODEL	16
3.2. GEOMETRIC MODEL	16
3.3. OPTICAL MODEL.....	17
3.4. MECHANICAL MODEL.....	17
3.5. MOVEMENT MODEL.....	18
3.6. CONTRIBUTIONS TO OPTICAL AND BIOMECHANICAL MODELING AND SIMULATION OF THE HUMAN VISUAL SYSTEM	18
4. TYPES OF EYE-TRACKING SYSTEMS.....	21
4.1. BRAIN ACTIVITY MONITORING EQUIPMENT	21
4.2. COGNITIVE EVALUATION METHODS – "D2" ATTENTION TEST, STROOP TEST, AND T.O.V.A. TEST.....	22
5. RESEARCH METHODOLOGY, INSTRUMENTS, MATERIALS	23
5.1. EXPERIMENTAL RESEARCH OBJECTIVES	23
5.2. RESEARCH HYPOTHESES	23
5.3. EXPERIMENTAL METHODOLOGY	23
6. EXPERIMENTAL RESEARCH DEVELOPMENT	26
6.1. IMPLEMENTATION AND CALIBRATION OF THE EYE-TRACKING SYSTEM	26
6.2. EXPERIMENTAL SETUP FOR VISUAL TRACKING IMPLEMENTATION	27
6.3. EMOTIONAL STIMULATION IN CONTROLLED ENVIRONMENT	28
6.4. ATTENTION EVALUATION THROUGH STANDARDIZED COGNITIVE TESTS	28
6.5. SIMULTANEOUS EEG AND EYE-TRACKING RECORDING	29
6.6. POST-EXPERIMENTAL EVALUATION.....	31
6.7. DEVELOPMENT OF SOFTWARE TOOLS FOR SACCADIC ANALYSIS.....	31
6.7.1. <i>Implementation of binocular saccade detection and analysis algorithm</i>	31
6.7.2. <i>Modelarea comportamentului saccadic în contextul stărilor emoționale</i>	32
7. RESULTS AND DISCUSSIONS	34
7.1. RESULTS OBTAINED THROUGH THE EXPERIMENTAL SYSTEM FOR CALIBRATION AND OCULAR MOVEMENT TRACKING	34
7.2. RESULTS OF THE VISUAL STIMULATION AND VIDEO PROCESSING STAGE	34
7.3. KINEMATIC ANALYSIS OF OCULAR MOVEMENTS UNDER CHROMATIC STIMULATION.....	35
7.4. RESULTS OF THE ATTENTION EVALUATION STAGE THROUGH STANDARDIZED COGNITIVE TESTS	36
7.5. RESULTS OF EEG MEASUREMENTS BASED ON ATTENTION AND MEDITATION INDICATORS.....	40
7.6. RESULTS OF THE POST-EXPERIMENTAL EVALUATION STAGE	41
7.7. AUTOMATIC ANALYSIS OF BINOCULAR SACCADIC	41
7.8. SIMULATION OF SACCADIC EFFECT ON GAZE DIRECTION IN RELATION TO EMOTIONAL STATE	43
8. CONCLUSIONS, ORIGINAL CONTRIBUTIONS, FUTURE RESEARCH DIRECTIONS	46

8.1. CONCLUSIONS	46
8.2. ORIGINAL CONTRIBUTIONS	48
8.3. FUTURE RESEARCH DIRECTIONS	49

INTRODUCTION

Vision is the dominant human sense [1], playing a crucial role in perception, spatial orientation, and interaction with the environment. Visual impairments significantly affect quality of life and can lead to safety issues, particularly among the elderly population [2]. Recent technological advances in visual monitoring [3] - especially the development of eye-tracking systems and their integration with EEG analysis and cognitive testing—open new avenues for the objective evaluation of visual function and associated psychophysiological responses.

This doctoral thesis, entitled "*Theoretical and Experimental Research on Visual Function Monitoring*", developed within the field of **Mechanical Engineering**, has a strong interdisciplinary character, incorporating elements from optics, biomechanics, cognitive psychology, and neuroengineering.

The thesis proposes an integrated approach that combines eye movement analysis, exposure to colored visual stimuli, and interpretation of brain responses in order to understand how the visual system reacts under conditions of controlled emotional stimulation. Through the proposed methodology and the developed tools, original contributions are brought to the design of adaptive visual analysis systems and to the definition of biomechanical parameters relevant to the user's visual and emotional state.

The work integrates a series of theoretical and experimental contributions, developed progressively in accordance with the stated objectives. These are systematically presented in each chapter, as follows:

The first chapter defines the general framework of the research by presenting the aim of the thesis, its general and specific objectives, and the working hypotheses. Research questions guiding the scientific endeavor are formulated, outlining the current issues related to visual function monitoring. The necessity and relevance of an interdisciplinary approach are also justified, combining methods from mechanical engineering, biomechanical analysis, cognitive psychology, and neuroscience to enable a comprehensive and integrated evaluation of the human visual system.

Chapter 2 provides a solid theoretical foundation for the research topic, through a comprehensive scientific analysis of the specialized literature. The first part is dedicated to a scientometric analysis conducted using the Web of Science database and the VOSviewer tool. The results indicate a steady increase in interest in eye-tracking technologies applied to the study of visual perception, emotions, and cognition. The generated semantic maps confirm the interdisciplinary nature of the field, located at the intersection of neuroscience, cognitive psychology, artificial intelligence, and medicine.

Furthermore, the analysis reveals a lack of applied research in integrated clinical contexts, which supports the original direction of this thesis and highlights the need for methodologies tailored to practical applications. This approach provides a robust basis for defining original contributions and identifying future research directions.

The second part of the chapter presents the structure and functionality of the human visual system, analyzing key concepts such as visual field, visual acuity, and color perception. The influence of colored light on visual performance and cognitive responses is emphasized.

The main ocular dysfunctions—myopia, hyperopia, astigmatism, and presbyopia—are detailed, along with modern correction methods, with a focus on orthokeratology as a non-invasive alternative. The importance of early diagnosis and personalized interventions for maintaining visual health is highlighted.

Finally, the role of visual training in children is addressed as a preventive strategy and a means of optimizing visual development. The chapter supports the need for a holistic approach that integrates clinical, technological, and educational perspectives to promote visual health.

Chapter 3 is dedicated to the development of mathematical models and biomechanical simulations that describe ocular behavior, focusing on two main directions: the quality of the retinal image affected by optical defects, and the modeling of eye movements and pupil size variations as a function of external stimuli and internal states.

Well-established optical models are included, such as those of Gullstrand, Emsley, and Navarro, used to describe the optical components of the eye, along with the statistical model of the normal eye. From a biomechanical perspective, rigid-body, muscular, elastic (FEM), and integrated neuro-musculo-biomechanical models are analyzed, including the Komogortsev model designed to simulate saccadic movements. Additionally, the chapter addresses various types of eye movements such as saccades, fixations, smooth pursuit, convergence, and the vestibulo-ocular reflex.

The optical models are implemented in OSLO and MATLAB to simulate retinal image degradation by analyzing the Modulation Transfer Function (MTF), optical aberrations, and various correction methods. In parallel, MATLAB simulations reproduce three-dimensional eye movements using Euler angles (yaw, pitch, roll), enabling visualization of trajectories and tracking of moving targets.

Pupil diameter is modeled using empirical functions correlated with emotional states (active, neutral, calm), based on EEG data used to generate oscillatory curves with neurophysiological significance. A composite model is proposed to integrate parameters such as movement speed and trajectory, refractive errors, and emotional state, providing a unified view of visual function.

The Komogortsev model is implemented to describe the dynamics of forces, inertia, and damping involved in generating saccades, through differential equations that simulate realistic eye trajectories.

The chapter concludes with an analysis of the interaction between stimulus color, emotional state, and oculomotor behavior, using mathematical equations that link visual characteristics to physiological eye responses, as well as a causal diagram that synthesizes the influence relationships among these variables.

Chapter 4 highlights the interdisciplinary nature of eye-tracking technologies by analyzing their main fields of application—from medicine and scientific research to marketing, education, sports, UX/UI design, ergonomics, the automotive industry, and military contexts. A comparative analysis of eye-tracking devices is included, classifying them based on accuracy, mobility, applications, and cost, ranging from high-end professional solutions (Tobii, HMDs, retinal cameras) to portable and affordable options (MyGaze, webcams, NeuroSky).

The chapter also addresses the integration of brain activity monitoring using the NeuroSky EEG headset, as well as the cognitive evaluation tools employed (the D2 test, Stroop test, and T.O.V.A.), emphasizing the benefits of combining these methods for a comprehensive analysis of attention, emotion, and visual processing.

The conclusions underline the versatility of these technologies, their adaptability to various application contexts, and their essential role in developing innovative solutions in both research and practical domains.

Chapter 5 describes the methodology used in the research, with the objective of investigating how the color of visual stimuli influences ocular responses and brain activity. The formulated hypotheses focused on the correlations between stimulus color, oculomotor reactions, and the level of cognitive activation.

The study was conducted on a sample of 8 participants under controlled experimental conditions, using accessible equipment such as a webcam, RGB LEDs for visual stimulation, and the NeuroSky EEG headset for brain activity monitoring.

Validated cognitive tests (D2, Stroop, and T.O.V.A.) were applied to assess attention and executive functions. In parallel, an experimental platform was developed in MATLAB, allowing for the generation and control of colored stimuli, recording of responses, and correlation with EEG data. Although functional, this MATLAB platform is exploratory in nature and has not yet been scientifically validated.

Chapter 6 details the implementation of experimental stages, with the objective of analyzing visual, cognitive, and emotional responses. Applications and scripts were implemented in MATLAB and LabVIEW for eye tracking, controlled visual stimulation, EEG data processing, and administration of cognitive tests (D2, Stroop, T.O.V.A.). The developed systems enabled real-time monitoring of pupillary position, detection of binocular

saccades, and analysis of responses to chromatic stimuli. An analytical model was integrated that correlates saccadic parameters with emotional states, simulating ocular behavior as a function of the degree of affective activation. The final stage included the application of a subjective questionnaire, and the results were correlated with the recorded data to evaluate the impact of colored visual stimulation on attention and emotional control.

Chapter 7 presents the results obtained following the application of experimental protocols developed for investigating visual behavior and neurocognitive responses. Data collected through eye-tracking and EEG systems were analyzed, correlated with performances in standardized cognitive tests and subjective responses obtained post-experiment.

The eye-tracking system, previously calibrated and tested, enabled the evaluation of ocular trajectories under varied background color conditions (white, blue, green, red) and stimulus movement patterns (linear, zigzag, sinusoidal). Kinematic analysis revealed individual differences and variations related to chromatic context, particularly regarding trajectory stability and movement amplitude.

Cognitive performances were measured through D2, Stroop, and T.O.V.A. tests, implemented in MATLAB. These provided a complementary perspective on attention level, inhibitory control, and resistance to cognitive stress. EEG values (attention and meditation) were automatically extracted from video recordings of the NeuroSky interface, temporally correlated with each task.

Binocular saccade analysis was performed automatically for each subject and each experimental condition, with results presented synthetically and extensive details provided in appendices. Additionally, the influence of emotional states on gaze direction was simulated using a model developed in MATLAB, without integrating the theoretical mathematical models from Chapter 3.

The results support the idea that visual parameters – particularly color – can influence visual and cognitive responses, with significant differences observed between stimulation conditions. The conducted analyses demonstrate the utility of the proposed experimental platform and contribute to a more detailed understanding of the interaction between visual stimulation and attention and ocular control mechanisms.

Chapter 8 synthesizes the research conclusions regarding visual function monitoring and oculomotor behavior under controlled conditions. The study highlighted the significant influence of colored visual stimuli on attention and emotional state, demonstrating the applicability of eye-tracking technologies in biomedical engineering and experimental psychology.

Original contributions were formulated related to the development of a flexible experimental model, integration of opto-biomechanical simulations, analysis of ocular synergy, and correlation of EEG data with cognitive performance. The research proposed

innovative methods for visual evaluation and laid the foundation for intelligent psychophysiological monitoring systems.

Future directions aim at extending the system toward portable formats, integrating evaluations in clinical contexts, and adapting tests for varied populations, with the goal of developing robust interdisciplinary standards for visual function analysis.

1. RESEARCH PURPOSE AND OBJECTIVES, HYPOTHESES AND PROBLEM STATEMENT

Based on the analysis of specialized literature and the current context of research in the field of visual function, the need for an integrated approach to monitoring ocular movements in relation to visual and emotional stimuli has emerged. Visual impairments and problems related to ocular function represent significant challenges for global public health, affecting quality of life and performance in various daily activities. Although eye-tracking technologies have evolved considerably in recent years, there are still numerous insufficiently explored aspects regarding the interaction between emotional stimuli and visual behavior, as well as virtual modeling of these processes.

This chapter establishes fundamental research directions, starting from the identification of existing gaps in specialized literature and culminating in the formulation of specific objectives and hypotheses that guide the scientific endeavor. The clear structuring of purpose and objectives allows the research methodology to be oriented toward concrete and measurable results, thus ensuring the coherence and scientific relevance of the entire investigative approach.

1.1. Problem Statement

Despite the considerable evolution of eye-tracking technologies, numerous studies are primarily focused on monitoring visual function in the context of neurological conditions, such as Alzheimer's disease or Parkinson's disease. Thus, an insufficiently explored niche appears regarding the monitoring and modulation of ocular and cerebral responses in relation to visual stimuli. This research conducts an exploratory analysis to find answers to these needs, integrating an approach that investigates the interaction between visual perception, ocular responses, external stimuli, and psycho-sensory responses

1.2. Purpose

The main purpose of this work is to develop and validate a theoretical and experimental model for analyzing ocular movements in relation to visual stimuli, thus contributing to the improvement of visual function monitoring methods and to extending the applicability of eye-tracking technologies in the study of human behavior beyond the field of neurological pathologies.

1.3. Objectives

Within this doctoral work, the research is oriented toward a deep understanding of the functional and behavioral mechanisms of the human visual system, in the context of monitoring and experimental analysis. Considering the interdisciplinary complexity of the field — which brings together elements from optics, biomechanics, psychomotricity, and

cognitive sciences — the formulated objectives reflect an integrative approach, both theoretical and applied.

The general objectives (numbered 1-6) and specific objectives (OS) aim to coherently structure the research stages, from the analysis of specialized literature and evaluation of used equipment, to the proposal of models, methods, and experimental solutions with direct applicability in visual behavior evaluation. Each objective is correlated with a clear research direction, with the purpose of bringing relevant contributions to the development of knowledge in the field of visual systems and associated technologies.

O1. Analysis of the current state of research in the field of monitoring and analysis of visual system evolution.

OS1.1. Highlighting the role and relevance of human visual system analysis, with emphasis on current and potential applications.

OS1.2. Identification of main research directions through scientometric analysis of specialized literature.

O2. Development and implementation of theoretical aspects (optical, biomechanical, and psycho-motor) in highlighting human visual system behavior through monitoring and eye-tracking.

OS2.1. Conception and extension of theoretical aspects through digital modeling in the opto-mechanical domain.

OS2.2. Contributions to the development of applications for analyzing visual system behavior under the influence of specific stimuli.

OS2.3. Correlation of ocular motricity aspects with emotional valences.

O3. Comparative study and hierarchization of equipment used in human visual system analysis.

OS3.1. Identification, classification, and comparative evaluation of human visual system monitoring equipment, based on performance and applicability.

O4. Original contributions to the experimental development of methodologies and equipment used for human visual system monitoring.

OS4.1 Conception and development of experimental research methodology.

OS4.2. Acquisition, processing, and interpretation of experimental data, ensuring their compatibility and integrity.

OS4.3. Conception and development of robust and validated mechanisms for correlating the effects of human visual system stimulation with objective and subjective responses.

O5. Development of unitary methods for quantifying experimentally obtained data

OS5.1. Elaboration and implementation of empirical equations for specific evaluations in visual system analysis.

OS5.2. Quantification of the synergy level in human ocular biomechanics, with the purpose of understanding the complexity of ocular movements.

O6. Development of interdisciplinary research for human visual system analysis.

OS6.1. Conception and implementation of theoretical and experimental research for the development of opto-biomechanical systems.

1.4. Conclusions

The objectives of this doctoral thesis reflect a systematic, progressive, and interdisciplinary approach in human visual system research. Structured into six main objectives, each with detailed specific objectives, they outline a logical pathway: from theoretical foundation and in-depth literature analysis to experimental implementation and methodology standardization.

This structure ensures comprehensive research, harmoniously integrating optical, biomechanical, and psycho-motor aspects. The emphasis on quantification, standardization, and correlation between objective data and subjective responses underlines scientific rigor and applicative relevance.

The interdisciplinary character of the thesis – at the intersection of optics, biomechanics, neurosciences, and technology – reflects the complexity of the field and the necessity of a holistic approach for understanding and monitoring visual behavior in varied contexts.

Achieving these objectives will contribute to advancing knowledge through the development of new research methodologies, analysis tools, and innovative solutions, providing a solid methodological and applicative framework. These contributions have potential for extension both in fundamental research and in practical applications in medicine, biomedical engineering, psychology, or other related fields. Overall, the objectives establish the foundation for the investigative, analytical, and developmental endeavors of the thesis.

2. CURRENT STATE OF RESEARCH IN THE FIELD OF VISUAL SYSTEM STRUCTURES

2.1. Current state of research through scientometric analysis

Scientometric analysis represents an essential method for evaluating and quantifying scientific publications, based on quantitative indicators such as the number of works, authors, involved institutions, and other relevant characteristics of research activity. Through this approach, trends in various fields can be examined, contributions of researchers and institutions can be highlighted, the impact of academic works can be analyzed, and representative statistics or graphics can be generated. Additionally, scientometric analysis allows for the identification of thematic areas that are less addressed or insufficiently developed research directions, offering valuable support for orienting future studies. Within this thesis, this method is used to highlight global trends in visual function monitoring research, with emphasis on eye-tracking technologies, ocular movement analysis, and their correlations with cognitive and emotional processes. Thus, scientometric analysis contributes both to justifying the choice of research topic and to identifying existing gaps in specialized literature.

Methodology

For conducting the scientometric analysis, the following resources and methods were used:

- ↳ **Database:** Web of Science™ Core Collection
- ↳ **Time interval:** 2002–2024
- ↳ **Keywords:** eye tracking, emotions, eye movement, gaze
- ↳ **Analysis tool:** VOSviewer [4] (online version)
- ↳ **Data format:** Text export from Web of Science [5], imported into VOSviewer for generating semantic networks and co-citation maps.

General Results

The search generated a total of **183 relevant scientific articles**, distributed over a period of 22 years. A constant increase in interest for the analyzed topic can be observed, especially in the last decade, in the context of eye-tracking technology development and their applicability in neurosciences, psychology, and medicine.

Author Analysis and Geographic Distribution

Out of the total articles, only **20 authors** form an interconnected research nucleus, which indicates an emerging but specialized scientific community. Research has been conducted

primarily in the following countries: USA, Germany, England, Canada, France, China, Sweden, Japan, South Korea, Italy, but also in less represented countries such as Monaco, Malaysia, Northern Ireland.

Keyword Network Analysis

The semantic network generated by VOSviewer highlighted significant connections between the analyzed terms. For example:

- ↪ „Eye tracking” is associated with terms such as *visual attention, emotion, perception, stimuli, social anxiety, autism.*
- ↪ „Gaze” (gaze direction) is connected with communication, social cognition, schizophrenia, prejudices.
- ↪ „Eye movement” has a more restricted but relevant semantic network, including *emotions, attention, autism spectrum disorders, threat.*

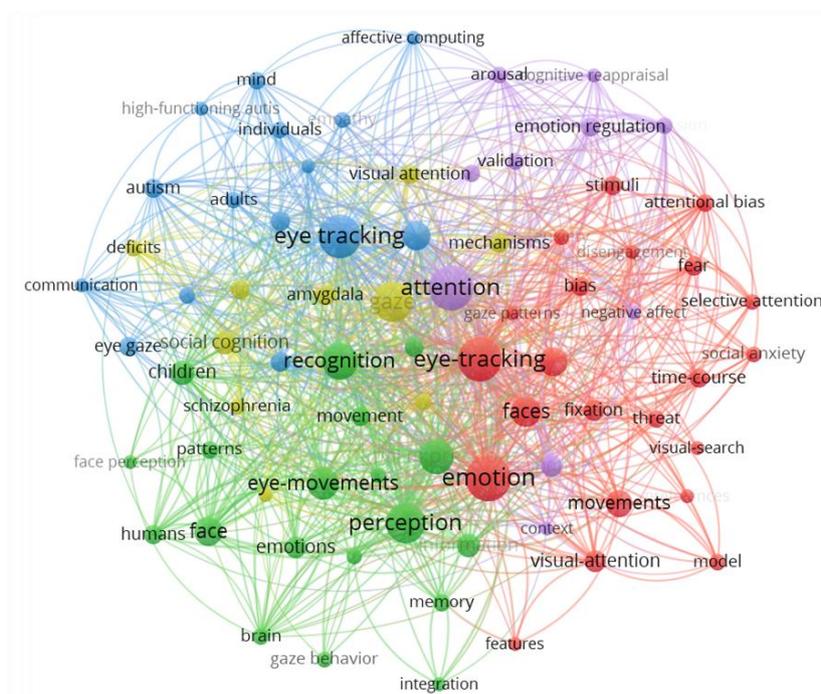


Figure 1 – Research network map in the field of eye-tracking and social cognition: thematic clusters and emerging directions

Figure 1 represents a **network visualization** generated with VOSviewer, in which:

- ↪ **Nodes** correspond to keywords extracted from scientific articles.
- ↪ **Node size reflects** the frequency of term occurrence.
- ↪ **Color** indicates belonging to a thematic cluster.
- ↪ Links (edges) signal the co-occurrence of terms in the same scientific context.

Figure 2 presents a **semantic network map** generated with VOSviewer, having the term "gaze" as the central node. This illustrates how the concept of "gaze" is connected with

3. THEORETICAL BACKGROUND

Understanding the functioning of the human visual system requires a multidimensional approach, in which theoretical models – mathematical, geometric, optical, biomechanical, or neural – play a central role. These models allow not only the exploration of physiological and cognitive mechanisms of vision, but also the development of advanced technological solutions, useful in optics, ophthalmology, artificial intelligence, and human-machine interfaces. Through the integration of anatomical, biometric, and dynamic data, researchers can accurately simulate visual behavior and can contribute to optimizing the performance of optical systems and medical devices. Thus, theoretical models become indispensable tools both for fundamental research and for practical applications in vision science and engineering.

3.1. Mathematical model

The development of different types of models for eyes and human visual systems involves constructing an ideal model, as close as possible to the real system, to minimize inaccuracies [6]. However, perfect simulation is improbable due to certain limitations, such as the high complexity of ocular anatomy, current technology restrictions in calculating extremely complex modeling equations, and the difficulty of obtaining a unique solution [6]. To simplify these obstacles, mathematical models are often accompanied by various hypotheses, such as the one proposed by [6], which suggests working in a two-dimensional plane.

The analyzed studies highlight the complexity of modeling the human eye and visual system, as well as the necessity of balancing accuracy and computational feasibility. Although three-dimensional models offer better representation of anatomical reality and allow detailed analysis of thermal or optical processes, results indicate that, under certain conditions, two-dimensional models can provide sufficiently precise estimates with reduced computational effort. Additionally, research on the refractive index profile of the crystalline lens and on neural mechanisms involved in ocular movements underlines the importance of integrating experimental data and mathematical modeling for understanding visual functions and for optimizing clinical and technological applications in ophthalmology. Thus, the continuous development and validation of multifactorial mathematical models remains essential for progress in research and practical application of vision science.

3.2. Geometric model

Geometric modeling of the human eye, with emphasis on the shape and curvatures of the cornea, offers important perspectives on how the pupil image is perceived and distorted. The study based on mathematical simulations [7] demonstrates that corneal geometry

contributes significantly to the magnification effect and apparent positioning of the pupil image, without significantly influencing the elliptical shape observed in some cases. Corneal astigmatism has a minor impact on image shape, and cornea-induced dispersion limits the precision with which the pupil image can be rendered, regardless of optical system quality. The integration of mathematical models with realistic 3D simulators, such as the one proposed by Adamo-Villani and collaborators [8], highlights the interdisciplinary potential of research in this field, with relevant applications in education, virtual reality, and human-computer interaction. However, for the most faithful representation of human ocular behavior, it is necessary to improve the synchronization of ocular movements with facial expressions and integrate knowledge from various domains such as biomechanics, artificial intelligence, and cognitive sciences.

3.3. Optical model

Optical models of the human eye represent essential tools in understanding visual system functioning and in developing modern technologies in optics, ophthalmology, and neuroscience. The cornea and crystalline lens, central components of this system, contribute majorly to light refraction and image formation on the retina, and their precise modeling allows evaluation of visual performance and optimization of therapeutic interventions.

Recent studies highlight the aplanatic character of the eye, emphasizing the reciprocal compensation of corneal and crystalline aberrations and the remarkable adaptability of the human optical system. Models such as Gullstrand's [9], with detailed structure and precise refractive parameters, or Emsley's reduced model [9], [10], [11], frequently used in clinical practice for simplicity and efficiency, have laid the foundations of modern physiological optics. In contrast, Navarro's model [12] introduces a more realistic and complex description, integrating variations in asphericity, chromatic dispersion, retinal shape, and other essential anatomical parameters.

The evolution of these models reflects a clear tendency to transition from simplified representations to advanced simulations, capable of faithfully reproducing ocular optical behavior under real conditions. Although each model has its limitations, overall, they provide a valuable conceptual and applicative framework for diagnosis, research, and personalized design of visual solutions. In conclusion, optical modeling remains a dynamic field, at the intersection of science, technology, and medicine, essential for continuous progress in understanding and improving human visual function.

3.4. Mechanical model

Mechanical modeling of eyeball movements offers a rigorous perspective on ocular dynamics, treating the eye as a rigid body with a fixed point [13], subject to the laws of classical mechanics. The use of Euler angles allows complete description of ocular rotations

in the three fundamental planes (horizontal, vertical, and torsion), and Euler's equations and kinetic moment equations provide the necessary mathematical framework for analyzing forces and moments involved.

This approach highlights the biomechanical complexity of the visual system and the essential role of extraocular musculature in precise control of eye position. Integration of inertia parameters and reactions from the spherical joint allows realistic simulation of ocular movements and prediction of their behavior under varied conditions.

Although complete integration of the equation system is possible only in certain particular cases (Euler-Poinsot, Lagrange-Poisson, Kovalevskia), the mechanical model remains a valuable tool for understanding ocular dynamics and for its application in fields such as visual robotics, neurosciences, and ocular prosthetics. Additionally, correlation of ocular rotation angles with real values of human movements contributes to practical validation of this model in visual function study.

3.5. Movement model

The human eye movement model provides essential understanding of how the visual system regulates gaze orientation and focusing, depending on sensory and motor context. The variation in types of ocular movements – from rapid saccades and smooth pursuit [14], to vergence [14], [15], [16], and vestibulo-ocular reflex – reflects the complexity of neuromuscular coordination involved in maintaining clear and stable visual perception. The differences between monocular and binocular vision underscore the importance of interaction between both eyes for depth perception and image fusion.

The role of the six extraocular muscles [17], [18], along with specific rotation axes and rest or activity positions, contributes to defining a detailed biomechanical framework of ocular function. In this context, ocular movements not only reflect visual processes, but also serve as relevant indicators for evaluating neuromotor system integrity and for applications in eye-tracking, neurosciences, and clinical ophthalmology. Thus, the ocular movement model becomes an indispensable tool in the study and simulation of human visual behavior.

3.6. Contributions to optical and biomechanical modeling and simulation of the human visual system

The integration of optical and biomechanical models in human visual system analysis offers a complex and coherent perspective on how eye structure and functioning influence visual perception. Optical modeling performed in OSLOEdu [19] allows precise simulation of retinal image formation in the presence of refractive errors, such as myopia, and highlights their impact on visual quality through graphic representations (MTF, PSF, wavefront, chromatic and geometric aberrations).

Results show that the uncorrected myopic eye produces unclear, diffuse retinal images with significant losses in contrast and acuity. By comparison, models simulated with corrective lenses (glasses or contact lenses) indicate a clear improvement in the final image, but also differences between correction types. Thus, contact lenses offer better compensation for geometric aberrations during complex movements, which supports the necessity of optimal and personalized adaptation of optical correction according to the individual.

On the other hand, modeling ocular movements in MATLAB has allowed simulation of eyeball rotation, real-time trajectories, and the influence of binocular vision. Using a kinematic model based on Euler angles and biomechanical parameters (moment of inertia, damping, muscular forces), saccadic and pursuit movements have been reproduced, as well as oculomotor variations associated with emotional states.

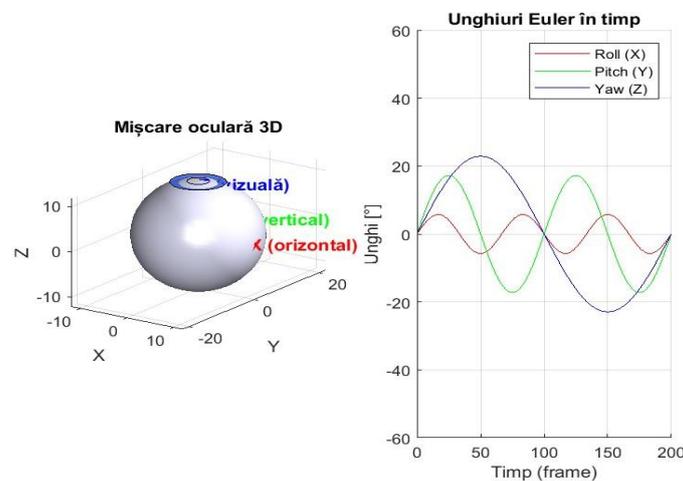


Figure 1 - Ocular movement modeling with generation of time variation of Euler angles

For example, pupil diameter values and blinking frequency correlated directly with colored visual stimuli and emotional activation level (calm, neutral, stress/active)

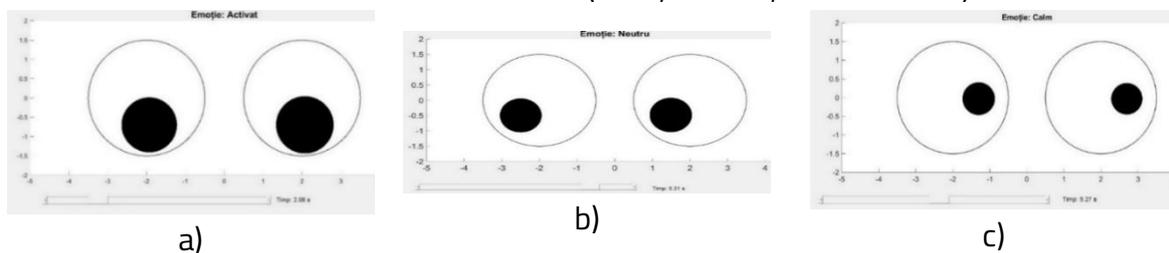


Figure 5 - Simulation of pupil diameter variation according to emotional state: a) activated emotional state, b) neutral emotional state, c) calm emotional state

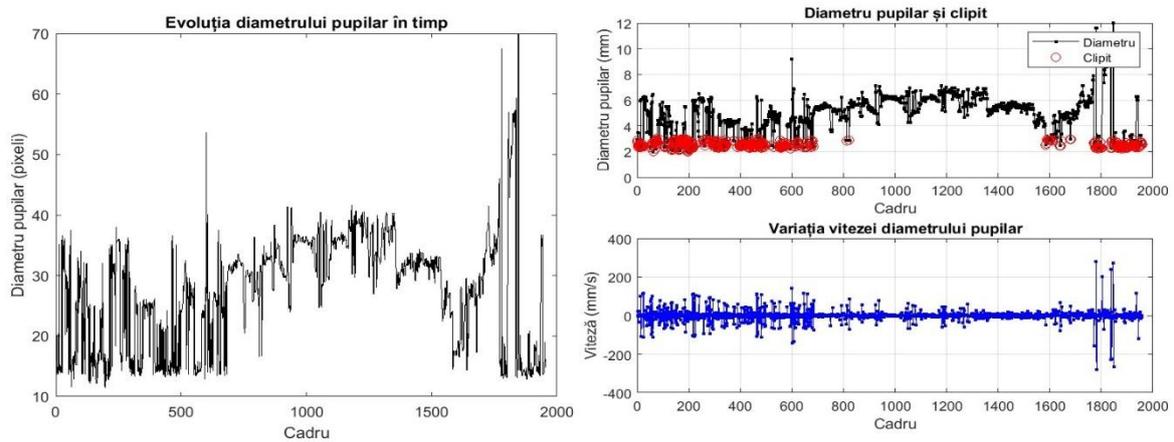
MATLAB simulations were completed by an interactive application for analyzing relationships between visual parameters (fixation, saccades, pupillary dilation) and

stimulus characteristics (color, contrast, emotional intensity). This allowed the generation of simplified linear models that describe significant relationships between sensory factors and observable ocular behaviors.

Therefore, this interdisciplinary approach — combining optics, biomechanics, numerical analysis, and psychophysiology — has demonstrated a robust and applicable methodology in visual function study. The contributions of this section validate the potential of advanced simulations for improving visual correction devices, human-machine visual interfaces, as well as for understanding visual processes in cognitive and emotional contexts.



a)



a)

Figure 2 - Real evolution of pupil diameter in a subject under the influence of red light radiation (variation of speed and pupil diameter, blinking process)

4. TYPES OF EYE-TRACKING SYSTEMS

4.1. Brain activity monitoring equipment

Within this research, visual function monitoring was achieved through an integrated approach that combines eye-tracking technology with brain activity recording (electroencephalography – EEG). This multimodal method allows simultaneous analysis of ocular movements and neuronal activity, offering a complex perspective on how visual perception interacts with cognitive processes.

For EEG monitoring, the NeuroSky MindWave headset [20] was used, a portable, non-invasive, easy-to-apply device suitable for exploratory studies. It captures frontal electrical activity through a sensor positioned on the forehead and a reference electrode mounted on the ear, allowing real-time recording of cognitive indices such as attention, relaxation level, or concentration state.

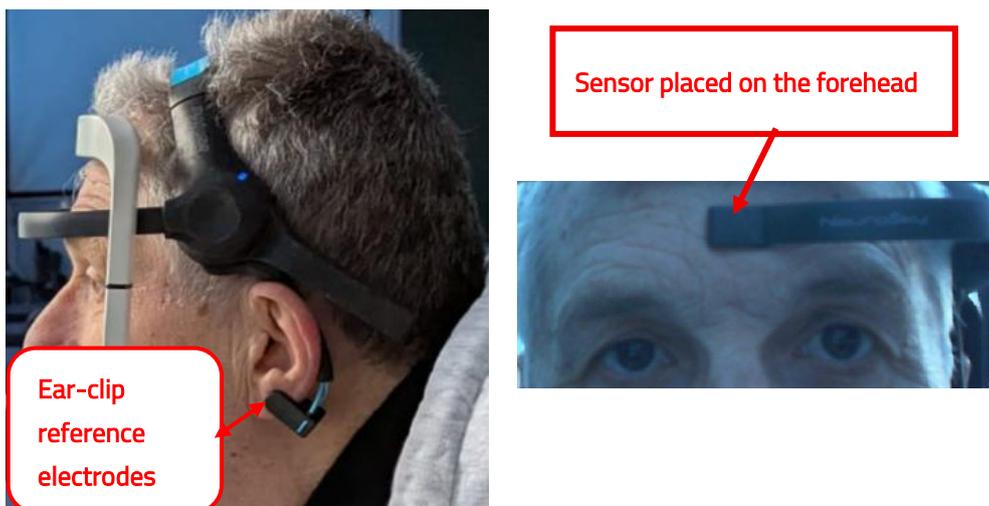


Figure 4 – Proper placement of the NeuroSky headset on the participants' heads

The EEG device used is notable for its increased mobility, reduced cost, and easy integration in educational contexts or simple experiments, being suitable for research focused on rapid cognitive reactions or general functional evaluations. To contextualize the technology used, Table 9 in the thesis presents a comparative synthesis of the main technical characteristics of equipment involved in research, including sampling frequency, latency, precision, application domain, typology of eye-tracking systems (desktop, glasses,

VR HMDs), as well as possible error sources. This analysis facilitates understanding of the advantages and limitations of the equipment used.

Through the integration of EEG and eye-tracking data, it was possible to analyze the relationship between gaze direction and the participant's cognitive state in real time. This correlation provided valuable information about:

- maintaining attention on visual stimuli,
- reactions to changes in color, position, or luminance,
- cognitive state fluctuations according to task.

This combined method offers a solid framework for simultaneous interpretation of visual behavior and cognitive processes, allowing not only performance measurement, but also understanding of internal mechanisms involved in the process of perception, decision, and visual adaptation.

4.2. Cognitive evaluation methods – "D2" attention test, Stroop test, and T.O.V.A. test

The application of D2 [21], [22], [23], Stroop [24], [25], [26], [27], and T.O.V.A. [28] tests, validated and frequently used in neuropsychology, allowed objective evaluation of selective attention, inhibitory control, and sustained vigilance. The D2 test measured concentration capacity and visual selection, Stroop highlighted cognitive flexibility and automatic response inhibition, while T.O.V.A. provided standardized data regarding sustained attention and impulsivity. To simplify the testing and interpretation process, dedicated MATLAB scripts were developed for each test, facilitating their integration with EEG and eye-tracking data and contributing to a more complete understanding of visual function in cognitive context.

p--- p- ---d- p---- p-- -p-- --p-- -d d---- p- --p- ---d -d --p- -p

Figure 3 – Sample item from the D2 Attention Test

5. RESEARCH METHODOLOGY, INSTRUMENTS, MATERIALS

5.1. Experimental research objectives

This experimental research aims to investigate how multisensory stimuli (visual - light intensity, color), combined with the induction of emotional states, influence ocular movements and brain activity. The main purpose is to analyze correlations between biomechanical responses of the eyes, cognitive and emotional reactions, and EEG signals, in the context of visual tracking tasks. Through this analysis, the development of a model that can be implemented in various applications related to human-computer interaction, behavioral analysis, ergonomics, or optometry is pursued.

5.2. Research hypotheses

Starting from these general principles and from bibliographic analysis and preliminary research, the following hypotheses are formulated:

- ↳ Geometric and mechanical theoretical models of eyeballs can accurately predict oculomotor behavior under emotional stimulation conditions.
- ↳ Virtual geometric models of the eye based on parameters extracted from visual trajectory tracking predict ocular movements under similar conditions.
- ↳ There are differences between ocular responses generated by the virtual model and those observed in real human eye behavior when tracking the same visual trajectories.
- ↳ Emotional stimuli based on colored light induce different ocular movement patterns compared to neutral stimuli, manifested through modifications in fixation time, saccade amplitude, and their velocity.
- ↳ There is a significant relationship between ocular movement patterns and brain wave values associated with attention and concentration, measured with the NeuroSky headset, under various stimulation conditions.
- ↳ Specific brain waves measured with the NeuroSky headset during the execution of cognitive attention tests (D2, Stroop, and T.O.V.A) present distinct correlations with various cognitive performance parameters.
- ↳ There is a predictive relationship between brain wave values recorded by the NeuroSky headset and visual information processing efficiency measured through D2, Stroop, and T.O.V.A tests.

5.3. Experimental Methodology

The research methodology was built upon a rigorous experimental protocol conducted in a controlled environment, involving a sample of healthy volunteer participants. The hardware

and software components were integrated into a complex system for the acquisition and processing of ocular, EEG, and cognitive data, with custom implementations developed in MATLAB and LabVIEW.

The technical system incorporated several devices: a webcam for recording eye movements, an RGB LED panel for visual stimulation, the NeuroSky EEG headset for monitoring brain activity, and MATLAB and LabVIEW applications developed for data control and processing. The eye-tracking system was calibrated using both static and dynamic LEDs, and the algorithm was designed to accurately detect the pupil, including error correction and validation of fixation positions.

The experimental protocol consisted of four main stages:

1. Visual tracking of a moving stimulus (following linear, sinusoidal, and zigzag trajectories);
2. Chromatic background stimulation to induce emotional responses;
3. Administration of standardized cognitive tests (D2, Stroop, and T.O.V.A.) with synchronized EEG and eye-tracking recordings;
4. Post-experimental subjective evaluation through a questionnaire.

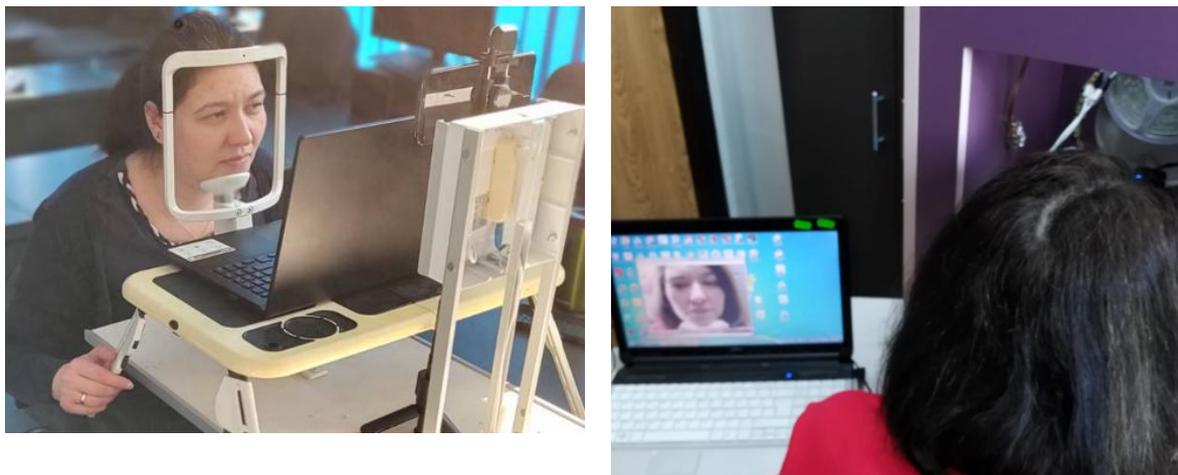


Figure 5 – Arrangement of participants in the experimental testing areas

The cognitive tests were implemented and digitized in MATLAB, allowing automated application and easy integration with EEG and eye-tracking data. This approach ensured standardization of procedures and reduced variability associated with classical evaluation. Overall, the methodology allowed obtaining a complex set of neurovisual and behavioral data, useful for integrative analysis of the relationship between attention, emotion, ocular response, and brain activity in multisensory contexts.

In addition to recording ocular movements and brain activity, a MATLAB application was developed for simulating the effects of emotions on ocular movements, with the purpose of validating experimentally obtained data through computational modeling. The

application allowed comparison between real data and generated theoretical models, through analytical relationships that quantify the influence of colored light on oculo-motor responses.

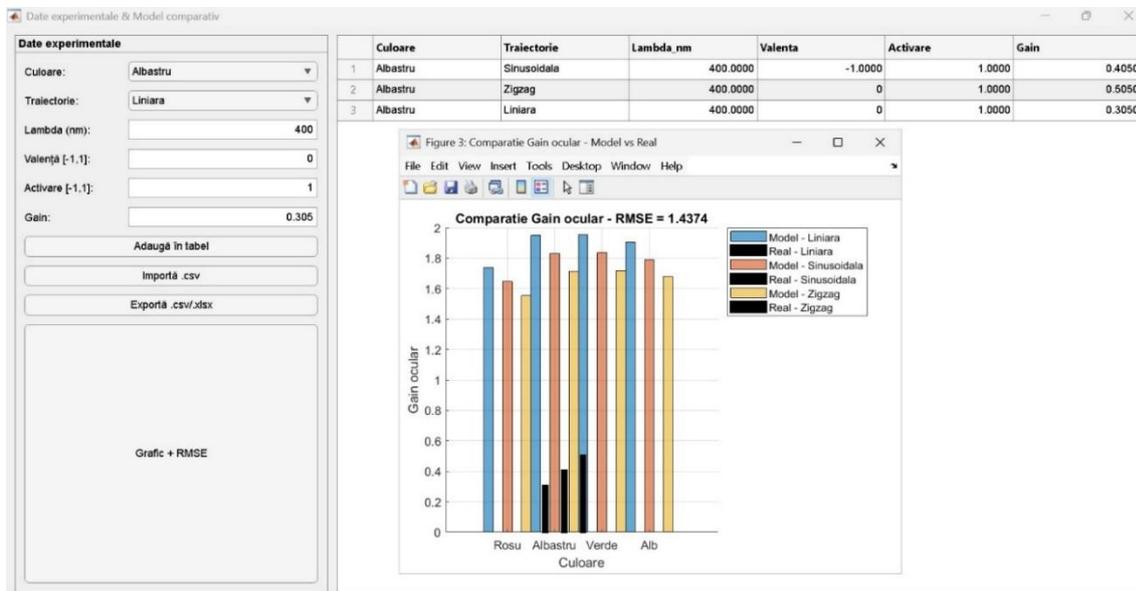


Figure 6 - CGO Application (CGO=ocular gain comparison) for experimental data analysis

To ensure the validity of results, the experiment was conducted under strict control of variables: illumination, distance, temperature, random order of stimuli, fixed durations, and standardization of instructions. Individual calibration of the eye-tracking system and verification of EEG connectivity were performed for each participant, and system synchronization was based on common time markers.

This multimodal approach, combined with careful control of variables and computational simulation, provided a solid foundation for integrated analysis of visual function, cognitive processes, and emotional influence.

6. EXPERIMENTAL RESEARCH DEVELOPMENT

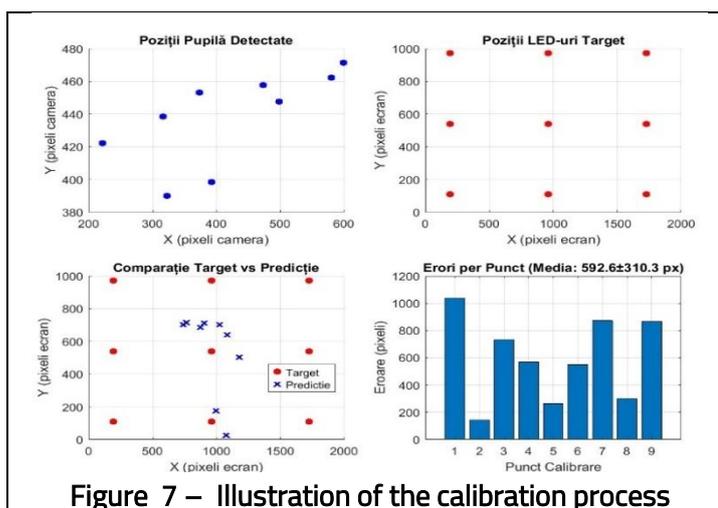
This chapter is dedicated to presenting the experimental stages and technical instruments used for integrated investigation of visual function in relation to cognitive and emotional states. The research combined eye-tracking technologies, EEG, and standardized cognitive tests in an experimental protocol, conducted in a controlled environment, with the general objective of evaluating bio-mechanical responses to colored visual stimuli, correlated with oculomotor performances and cognitive parameters.

Eye movement tracking was used as a method for recording real and subjective participant behavior, offering relevant perspectives for fields such as optics, biomechanics, and psycho-motor analysis. In this context, various monitoring and data interpretation systems were implemented, intended to support investigation of the research's specific objectives. Data processing was structured on several modules: ocular movement analysis with **cvMob** software, EEG value extraction from video clips using **MATLAB scripts**, as well as cognitive performance interpretation through automated **D2**, **Stroop**, and **T.O.V.A.** tests, all reproduced in MATLAB for rapid testing with easily quantifiable results.

The following sections describe each component in detail, following the logic of research development, with emphasis on methodological coherence and relevance of obtained results, for the purpose of investigating visual behavior and approaches for its evaluation and interpretation.

6.1. Implementation and calibration of the eye-tracking system

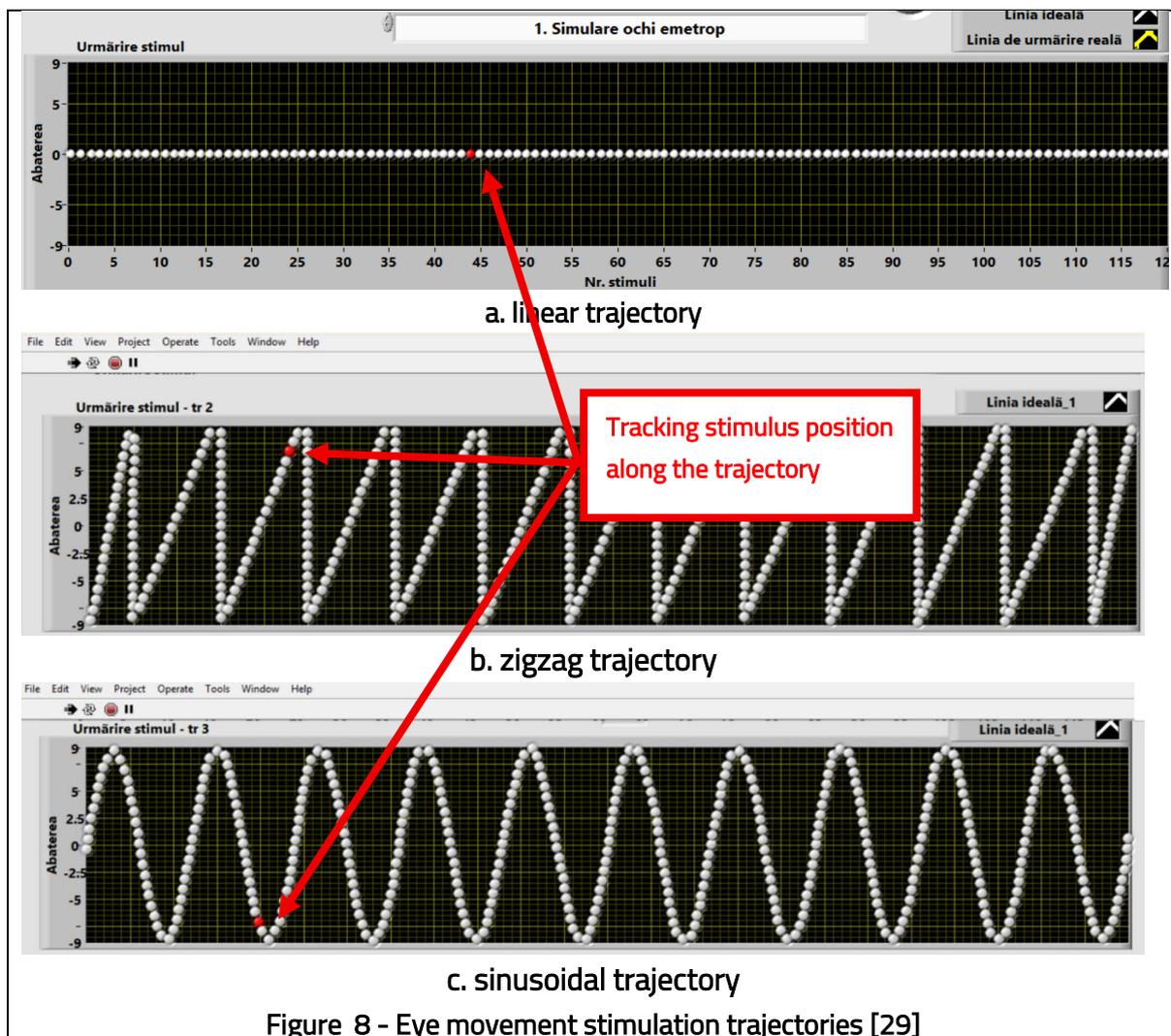
The eye-tracking system was calibrated and tested through a proprietary MATLAB application, with binocular detection of gaze position. Precision was ensured by standardizing the distance from the screen and maintaining constant illumination conditions. Ocular tracking was subsequently evaluated through comparison with trajectories generated in LabVIEW, representing classical visual movement patterns (linear, sinusoidal, zigzag).



6.2. Experimental setup for visual tracking implementation

The experimental integration required the development of an integrated visual stimulation system, built in the LabVIEW programming environment. The application developed in LabVIEW represents an experimental visual stimuli generator that serves as a "reference" for testing ocular movements. This application was designed based on the results of experimental research from specialized literature and was used for generating standard ocular movement trajectories – linear, sinusoidal, zigzag – frequently used in oculomotor system evaluation.

The workflow consists of generating, through the LabVIEW application, visual stimuli with controlled trajectories (linear, zigzag, or sinusoidal movement), which participants must visually track. Ocular movements are recorded through video cameras, synchronized with the eye-tracking and EEG systems.



6.3. Emotional stimulation in controlled environment

For this stage, participants are tested in a specially arranged stand that includes a controlled RGB LED strip and a tablet with the stimulation application. The infrared camera monitors ocular movements, and data are recorded simultaneously through EEG and eye-tracking systems. Colored stimuli (red, green, blue, white) modify the visual background, allowing investigation of affective and visual responses. The configuration is illustrated schematically in the figure below.

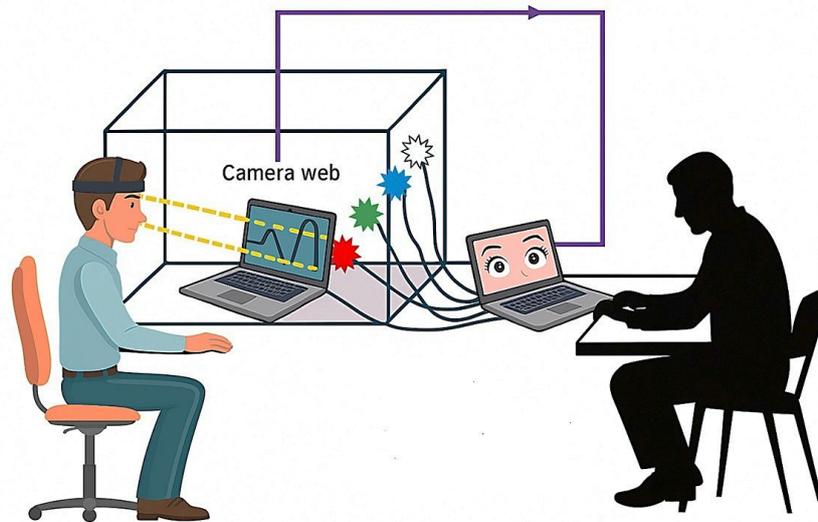


Figure 9 – Schematic representation of the experimental setup

6.4. Attention evaluation through standardized cognitive tests

Following exposure to stimuli, participants underwent a series of validated cognitive tests, developed as interactive applications in MATLAB, each synchronized in real time with EEG recordings. This integrative approach allowed obtaining objective indicators regarding attention, concentration, and reaction speed, complemented by relevant EEG parameters for evaluating subjects' mental state.

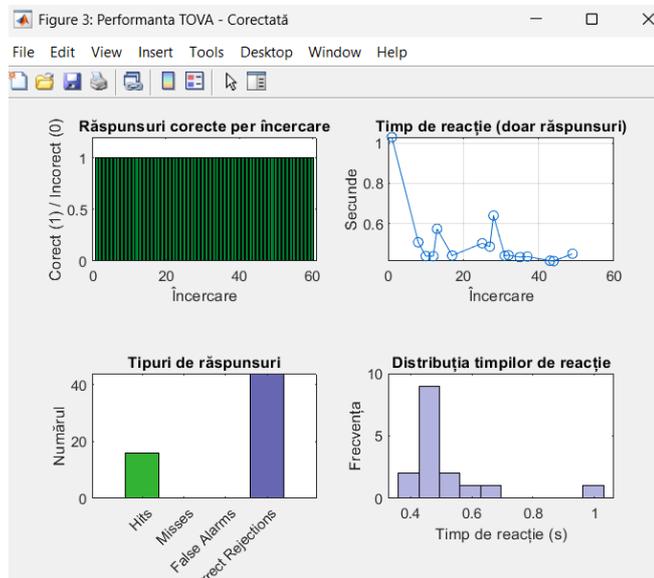


Figure 10 - Exemplification of results obtained on the T.O.V.A. test for one of the participants (S2)

6.5. Simultaneous EEG and eye-tracking recording

Concurrent with the cognitive tests, the NeuroSky EEG headset continues to record attention and meditation values, allowing correlation of cognitive performances with behavioral indicators in real time. For extraction and quantification of this data, a specialized MATLAB script was developed that processes video recordings of the EEG interface and converts visual information from analog indicators into numerical data usable for statistical analyses.

The processing script allows specification of the temporal analysis interval from the video recording and performs calibration by selecting areas corresponding to attention and meditation indicators. Through image processing techniques in HSV color space, the algorithm detects indicator position and calculates numerical values on the 0-100 scale using trigonometric transformations of the radial angle. For each second of administered tests, the system extracts instantaneous attention and meditation values, calculates averages for the entire interval, and generates temporal graphic representations with reference thresholds for experimental interpretation. Results are exported in CSV and TXT formats for integration into comprehensive statistical analyses and correlation with cognitive performances obtained from D2, Stroop, and T.O.V.A. tests.

General statistics:

- ATTENTION: mean = 98.74
- MEDITATION: mean = 98.73

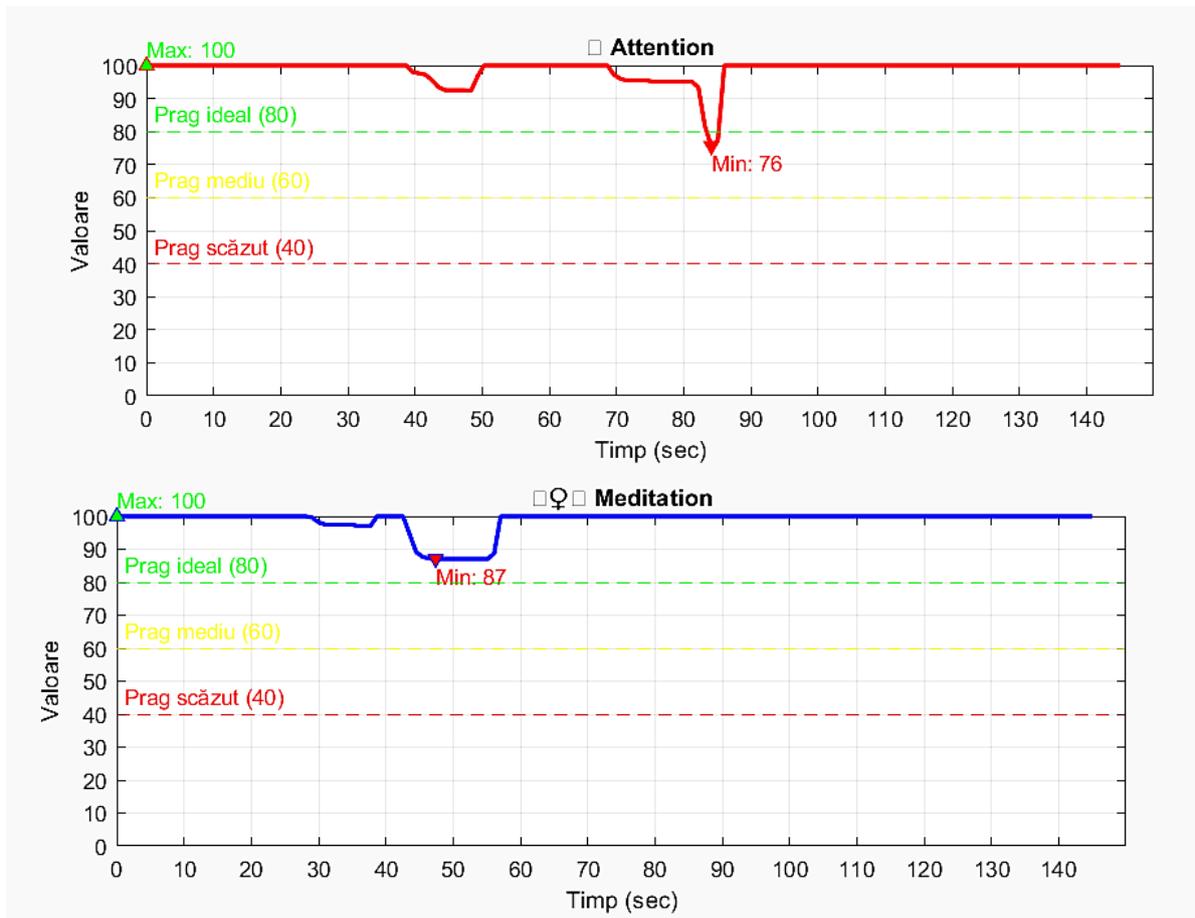


Figure 11 - Example of results generated by the script for attention and concentration/meditation value analysis

The complete individual results for each of the 8 study participants, including detailed performances on D2, Stroop, and TOVA tests, as well as attention and meditation values extracted from EEG recordings, are presented in the thesis within chapter 7 (results). Each individual sheet contains raw data exported in CSV format, performance graphs automatically generated by MATLAB scripts, and calculated scores for each administered test. These documents allow verification and replication of conducted analyses, providing methodological transparency and complete access to primary data collected within the research.

6.6. Post-experimental evaluation

At the conclusion of the experimental session, participants completed a standardized subjective evaluation questionnaire titled "Impact of Colors on Emotional States," designed specifically for this research, using the Google Forms application. The instrument is structured in four distinct sections that comprehensively evaluate participants' experience in relation to the chromatic stimulation used.

Section 1 of 4

Impactul culorilor asupra stărilor emoționale

B *I* U ↔ ~~X~~

Vă mulțumesc pentru participarea la studiul privind "Cercetări teoretice și experimentale privind monitorizarea funcției vizuale". Prin acest scurt chestionar doresc să înțeg mai bine cum a fost pentru dvs.această experiență.

Vă rog să evaluați cum v-ați simțit în momentul în care fundalul s-a schimbat în fiecare culoare menționată. Pentru fiecare întrebare, acordați un punctaj de la 1 la 5, unde:

- 1 = Deloc / Pentru niciuna
- 2 = Puțin / Rar
- 3 = Moderat / Uneori
- 4 = Mult / Adesea
- 5 = Foarte mult / Întotdeauna

Răspunsurile sunt confidențiale și vor fi utilizate exclusiv în scopul științific al cercetării la care ați luat parte în mod voluntar. Inițialele sunt colectate doar pentru corelare internă și nu permit identificarea completă a participanților de către terțe părți.

Figure 12 – Main interface of the evaluation questionnaire

6.7 Development of software tools for saccade analysis

6.7.1. Implementation of binocular saccade detection and analysis algorithm

For implementing the binocular saccade detection and analysis algorithm, we developed an algorithm in MATLAB. This is modularly organized and comprises several stages: data acquisition and preprocessing (including generation of the temporal vector), calculation of instantaneous gaze velocity, saccade detection based on velocity and duration thresholds, as well as extraction of saccadic parameters for each eye. Detection is performed in two phases: initially, rapid ocular movement segments are identified, then these are validated based on minimum acceptable duration, to eliminate artifacts and background noise.

For each eye (OS and OD), three essential parameters are calculated: saccade frequency (Hz), mean amplitude (cm), and mean duration (ms). These values allow detailed evaluation of oculomotor behavior. Additionally, absolute differences between eyes for the same parameters are automatically calculated, which allows evaluation of binocular asymmetry – a possible indicator of neurological dysfunctions.

The algorithm parameters (velocity threshold, minimum duration, sampling frequency) were optimized to ensure balance between sensitivity and specificity. The system is capable of processing large volumes of data and automatically generating detailed reports that include calculated parameter values, binocular differences, and technical configuration. These reports are exported in multiple formats (CSV, PNG, JPG, DOCX), systematically named, and can be easily integrated into research or diagnostic protocols.

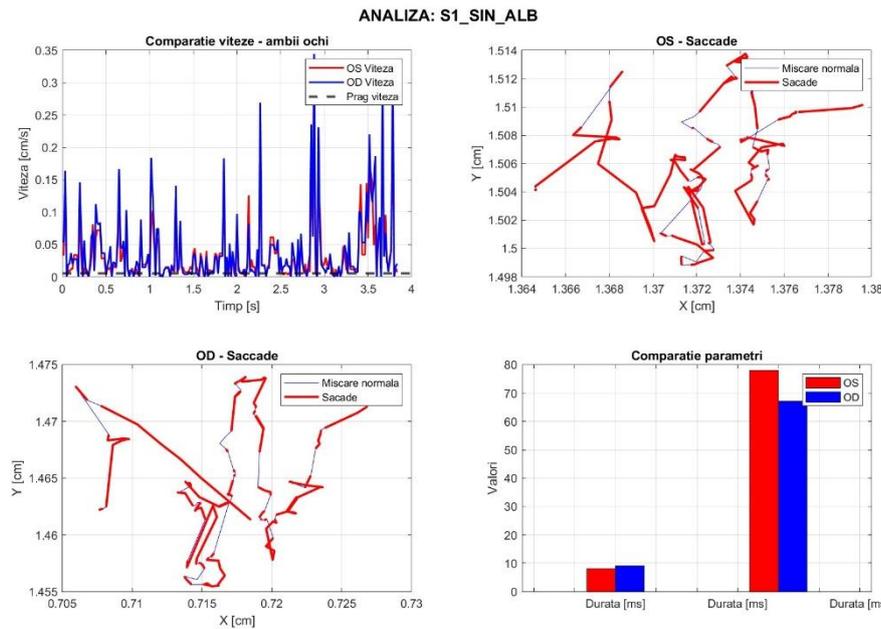


Figure 13 – Evaluation of saccadic variability and ocular movement velocity (binocular analysis)

Experimental testing has validated the system's functionality, demonstrating automatic processing capability and coherent extraction of saccadic indicators. Thus, the algorithm offers a complete and adaptable solution for quantitative analysis of ocular movements, with potential applications in evaluating neurological disorders, especially where oculomotor asymmetries are suspected.

6.7.2. Modelarea comportamentului sadic în contextul stărilor emoționale

This subchapter explores how saccadic behavior is influenced by the subject's emotional states. Thus, we developed an analytical model in MATLAB that correlates saccade parameters – amplitude, duration, frequency, and gaze direction vector – with an emotional activation index (E). The modeling is based on a Poisson-type stochastic process, which reflects the random character of saccade occurrence as a function of emotional intensity.

The model simulates three distinct scenarios: calm ($E = 0.1$), intermediate ($E = 0.5$), and stress ($E = 0.9$), each with different saccadic characteristics. In the calm state, saccades are rarer and larger in amplitude; in stress, they become more frequent and shorter, reflecting gaze fragmentation. The system graphically represents gaze trajectories and monitors in real time a set of parameters: emotional level, angle and vector of gaze direction, as well as presence or absence of saccades.

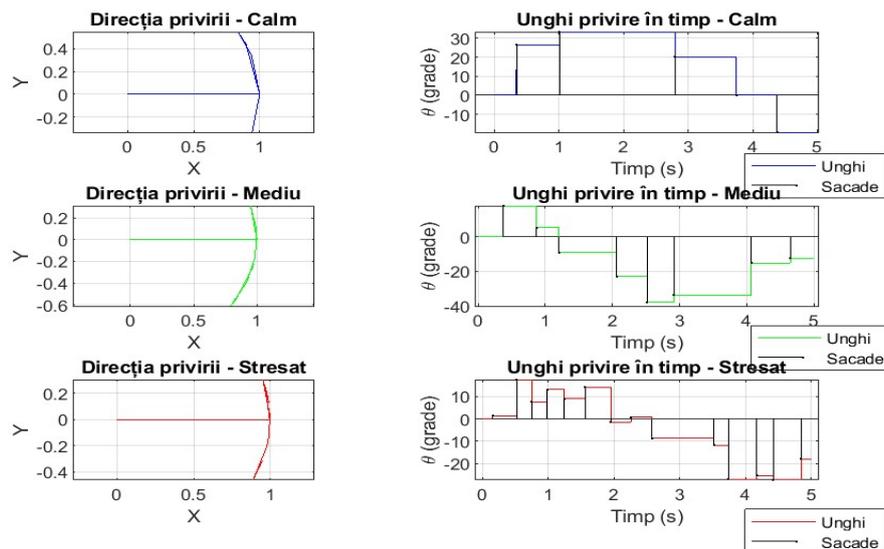


Figure 14 - Saccade variation according to emotional state

The use of the Poisson process is justified by the random distribution of saccades and the lack of regular periodicity. Saccade frequencies differ significantly between emotional states, varying from approximately 2/s in calm to 6/s in stress. This variability allows the model to be used for indirect estimation of emotional state based on ocular behavior.

The proposed model can become a valuable tool for research and clinical applications, offering a non-invasive approach in detecting psychological states or neurological disorders such as ADHD or Parkinson's. The ability to simulate and automatically analyze these phenomena opens directions for developing biofeedback technologies, cognitive evaluation, or adaptive interfaces in virtual reality and applied neurosciences.

7. RESULTS AND DISCUSSIONS

This chapter presents the results obtained following the application of the research methodology and implementation process detailed in previous chapters. Data collected through eye-tracking technology are analyzed and interpreted in relation to established objectives. Results are organized based on specific criteria, such as task types, participant categories, measured oculomotor parameters, providing answers to initially formulated research questions. For each data set, specific and adequate analyses are presented, followed by interpretation of results in the context of proposed objectives.

7.1. Results obtained through the experimental system for calibration and ocular movement tracking

Through the use of the MATLAB system for ocular movement tracking, data were collected from 8 subjects under controlled conditions. The system used visual stimuli consisting of red luminous points displayed in a 3x3 matrix, each for 3 seconds, with 0.5-second pauses. The webcam allowed real-time detection of pupil position, and data were processed to obtain a complete representation of gaze trajectory.

Results are presented graphically and include: estimated pupil positions, target LED coordinates, comparisons between calibration points and measured ones, as well as associated errors. These elements reflect the system's precision in capturing and analyzing ocular behavior, validating the functionality of developed algorithms. Following analysis of all obtained results, good correlation was found between system predictions and real stimulus positions, confirming the efficiency of automatic visual calibration.

7.2. Results of the visual stimulation and video processing stage

In this stage, participants were exposed to mobile stimuli generated in LabVIEW, with three types of trajectories: linear, sawtooth, and sinusoidal. Recorded data were processed using cvMob, Excel, and MATLAB platforms, allowing precise analysis of oculomotor response for each eye.

Although the LabVIEW application also offers the possibility of simulating oculomotor dysfunctions, generating ideal trajectories and characteristic deviations useful in analyzing ocular behavior in pathological contexts, within this thesis only the option corresponding to the emmetropic eye was used.

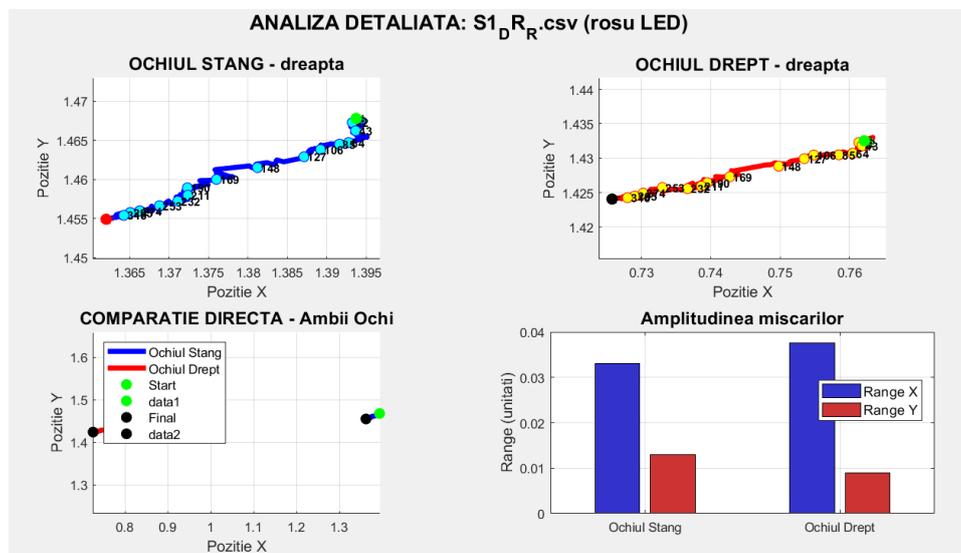
It was observed that the linear trajectory was the easiest to track, while irregular trajectories evidenced greater individual variations.

The obtained data (position, deviation, velocity, acceleration) constitute the basis for comparative analyses and subsequent interpretations regarding oculomotor system performance and coordination.

7.3. Kinematic analysis of ocular movements under chromatic stimulation

This section synthesizes the effects of chromatic stimuli on oculomotor behavior. Participants were exposed to colored backgrounds (green, blue, white, and red), under controlled conditions, using an experimental system with RGB LEDs and dedicated MATLAB-LabVIEW applications for analyzing gaze direction, saccade amplitude and velocity, as well as binocular disparity.

Results highlight significant differences between eyes and between chromatic conditions. In the case of green background, subjects presented stable tracking, but with slightly more pronounced oscillations than on neutral background. Red background generated the largest variations and saccadic amplitudes. Temporal analysis (of subject 1) shows progressive degradation of ocular movement control under red color influence, with frequent fluctuations and increased binocular disparity.



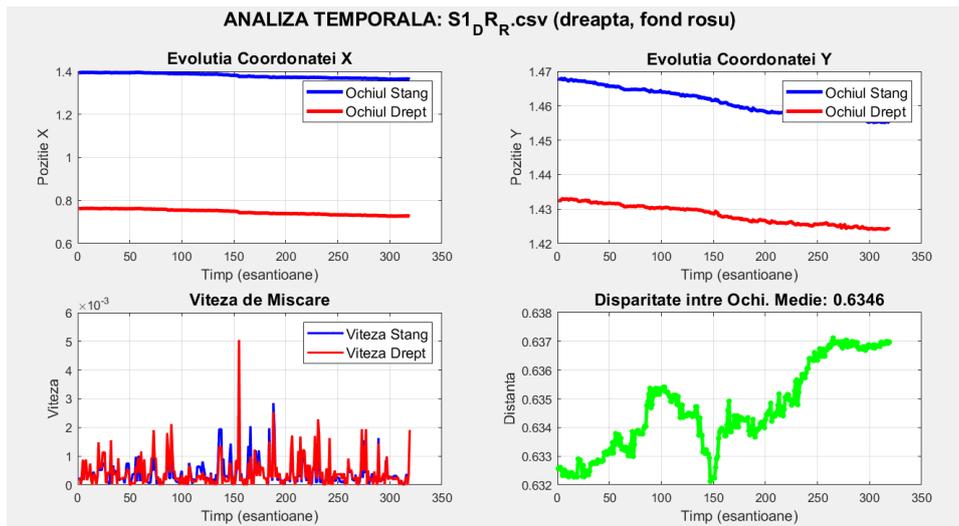


Figure15 – Chromatic stimulation results: S1_DR_R (subject 1, linear trajectory, red background color)

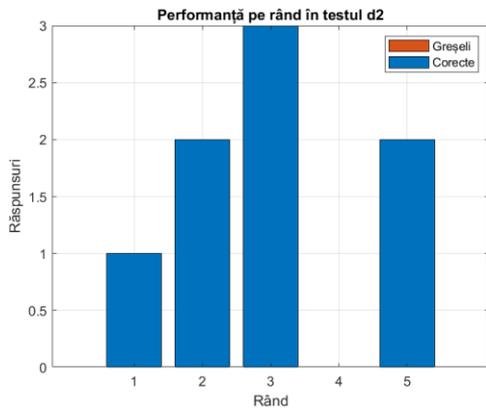
Chromatic stimulation thus significantly influences oculomotor parameters, and the results support the hypothesis that red background most disturbs visual stability and coordination, compared to other tested colors.

The detailed analysis reports, corresponding to each subject and each trajectory (linear, sinusoidal, and zigzag), on each of the colored backgrounds used (white, blue, green, and red), can be found in the thesis - annexes 7-14.

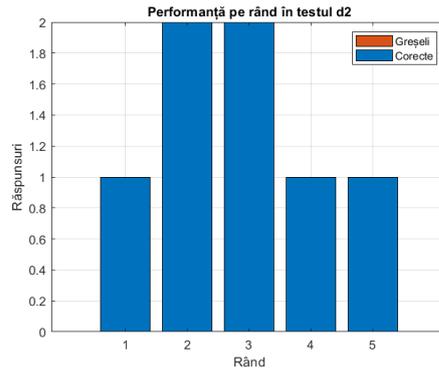
7.4. Results of the attention evaluation stage through standardized cognitive tests

The evaluation of cognitive performances was conducted under controlled conditions, using D2, T.O.V.A., and Stroop tests, implemented with MATLAB scripts. During testing, EEG activity was monitored in real time, offering an integrated perspective on sustained attention and cognitive control. The obtained data allowed identification of interindividual differences regarding concentration capacity, reaction speed, and cognitive inhibition.

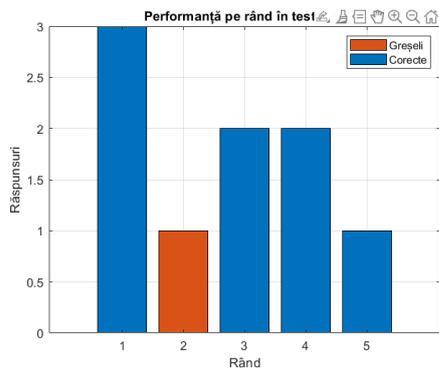
Analysis of the **D2 test** highlighted significant differences between participants regarding selective attention and response consistency. **Subjects 1, 4, and 6** stood out through **high performances and efficient adaptation**, while **subjects 2, 3, and 5** had **moderate results, with variations in error control**. **Subjects 7 and 8** obtained the lowest scores, presenting **difficulties in maintaining cognitive vigilance** throughout the test duration.



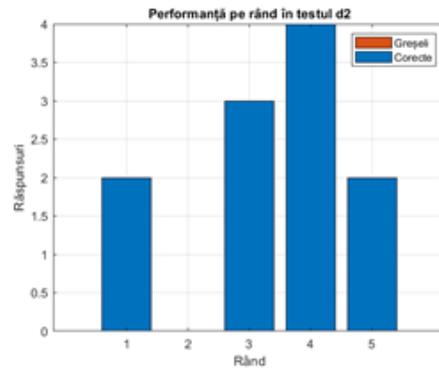
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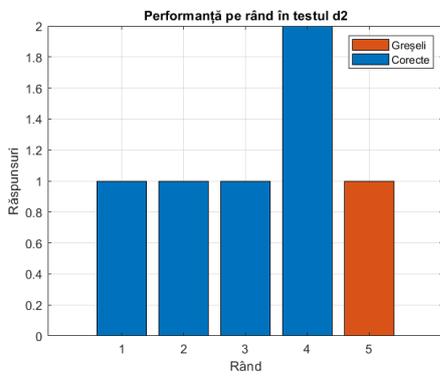
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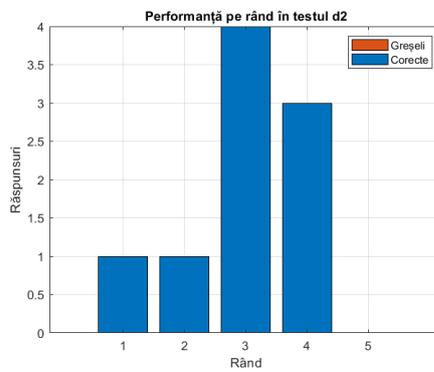
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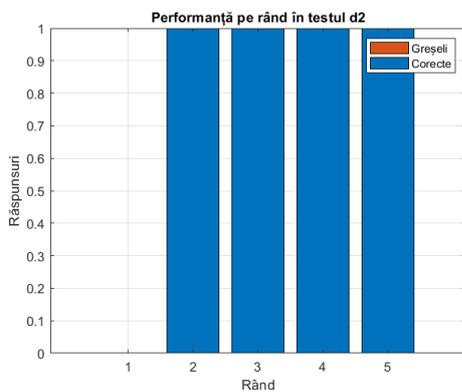
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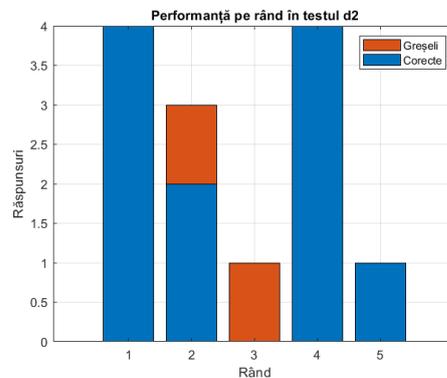
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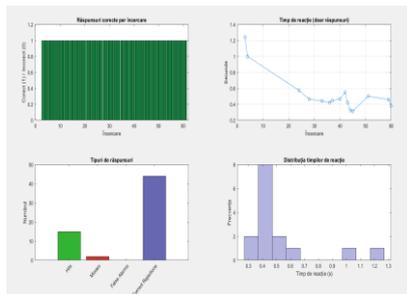
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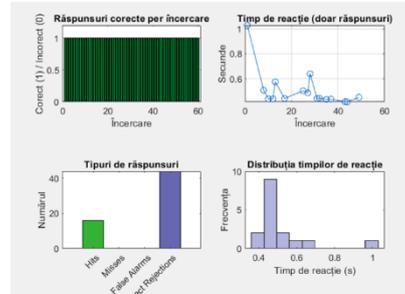
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Figure 16 – Outcomes of the D2 Test of Attention

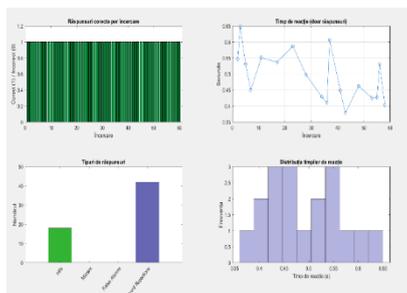
Results of the T.O.V.A. test confirmed previously identified cognitive profiles, emphasizing **sustained attention capacity** and inhibitory control. Most participants maintained high accuracy, but there were clear differences in reaction time dynamics. **Subjects 1, 2, and 8** demonstrated **progressive adaptation and cognitive efficiency**, while subjects **3, 4, and 5** presented **oscillations and errors**, indicating instability in rapid visual information processing.



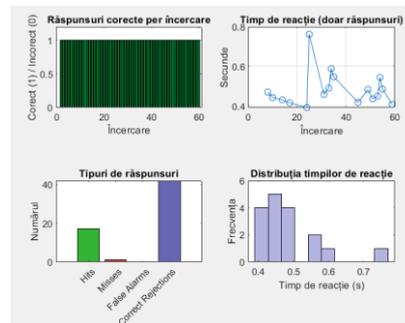
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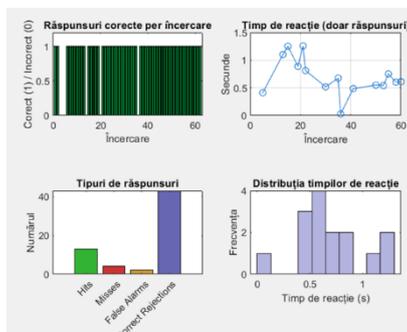
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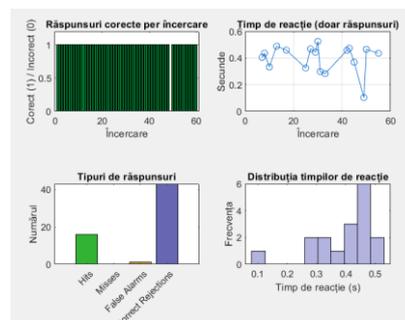
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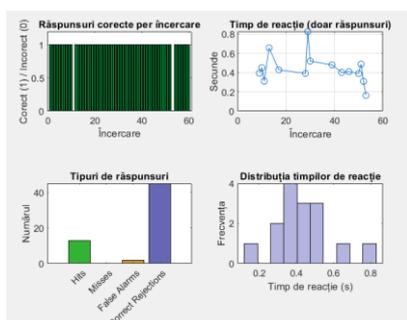
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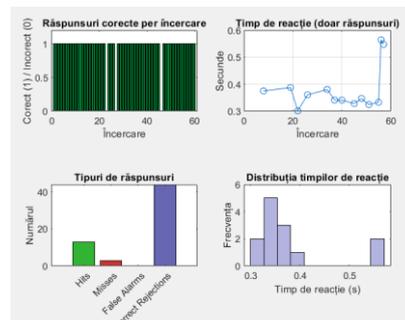
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Figure 17 – Outcomes of the T.O.V.A.

The Stroop test revealed the level of cognitive control in the face of mental conflicts. Most participants obtained excellent scores, managing to inhibit automatic reactions and correctly handle the task. The only notable exception was **subject 5**, who failed to maintain precision under cognitive conflict pressure, suggesting **difficulties in managing attention under stressful conditions**.

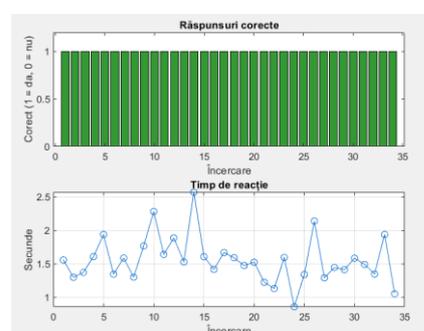
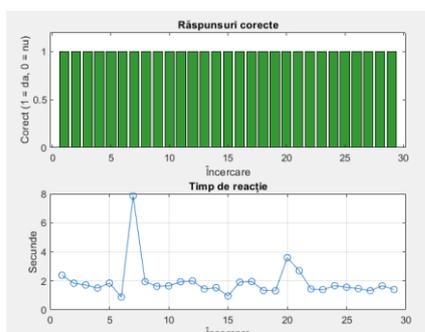
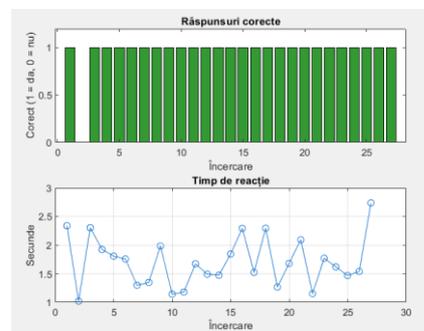
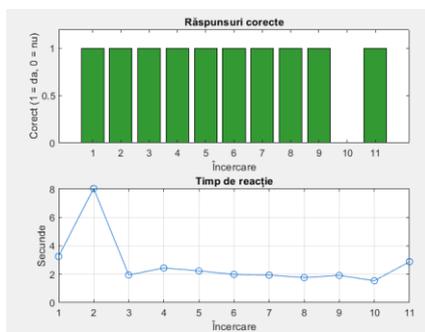
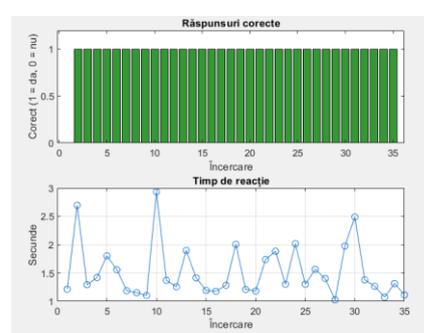
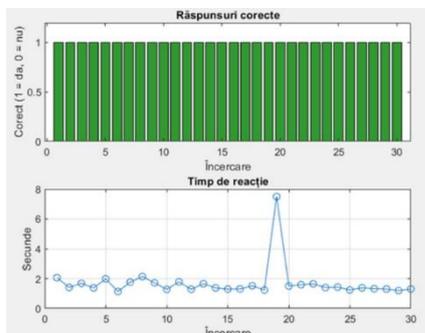
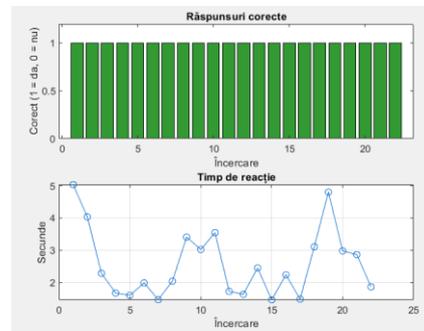
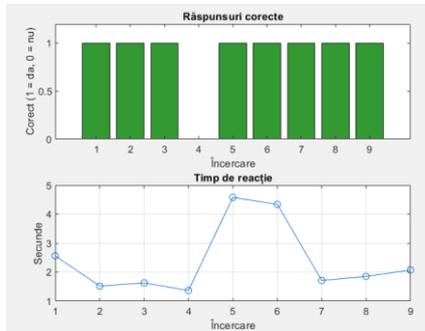


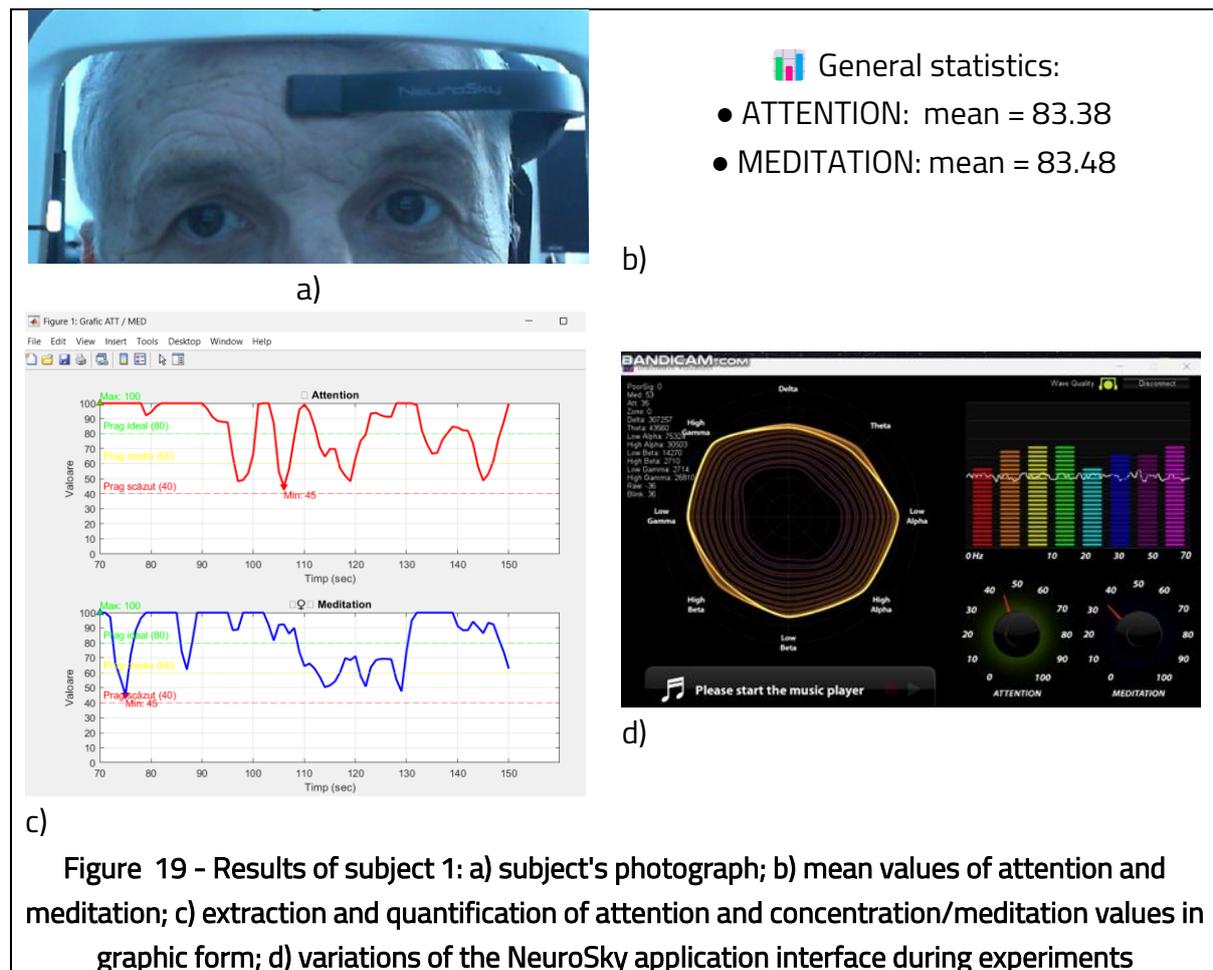
Figure 18 – Stroop Test Results

The correlation between the three tests confirmed that participants with high performances on D2 (subjects 1, 4, 6) had similar results on T.O.V.A. and Stroop, outlining stable cognitive profiles. Subject 7 maintained a coherent approach but had performance oscillations, while subject 5 recorded difficulties on all tests, indicating possible deficits in sustained attention and inhibitory control.

7.5. Results of EEG measurements based on attention and meditation indicators

Analysis of EEG recordings performed with NeuroSky provided a valuable perspective on cognitive activation during testing. Mean values of attention and meditation indicators, analyzed in parallel with performances on D2, T.O.V.A., and Stroop tests, highlighted distinct visual-motor system profiles for each participant.

Subject 1 presented a balanced activation between attention and meditation, with stable values around 83, suggesting efficient coordination between active concentration and cognitive relaxation. Performances on the three tests were consistent and precise, with a mean reaction time of 2.40 seconds.



Subject 2 recorded the highest values for both indicators (nearly 99), with exceptional stability, which was reflected in perfect behavioral results, including on T.O.V.A. and Stroop, where accuracy was 100%.

Subject 3 presented predominantly cognitive activation, with lower meditation, but maintaining an efficient balance between concentration and adaptability. Tests confirm a very good visual-motor profile, with a mean reaction time of 1.70 seconds on Stroop.

Subject 4 had dominant meditation over attention, suggesting a state of alert calm. Although there were oscillations, the system demonstrated resilience and stability. Cognitive performances were high, especially in Stroop and T.O.V.A.

Subject 5 maintained a balance between attention and meditation, with a slight predominance of cognitive activation. His performances were good, with increased precision and mean reaction time of 2.72 seconds in Stroop.

Subject 6 had one of the highest cognitive activations (attention nearly 100), indicating intensive use of mental resources. Meditation varied more, but visual processing remained optimal throughout the testing duration.

Subject 7 recorded sustained cognitive activation and progressive adaptation, with stable meditation. EEG data and excellent performances on cognitive tests confirm the efficiency of visual-motor coordination and mental flexibility.

Subject 8 presented an active and well-balanced profile, with high attention and increasing meditation toward the end of the test. Performances were excellent in all three tests, with maximum accuracy in Stroop and increased reaction speed.

Overall, EEG analysis faithfully correlates cognitive activation with observed behavioral performances, demonstrating the relevance of attention and meditation indicators in interpreting visual-motor system functioning under varied cognitive conditions.

7.6. Results of the post-experimental evaluation stage

At the completion of the experimental session, all participants completed the standardized subjective evaluation questionnaire titled *"Impact of Colors on Emotional States"*, implemented through the Google Forms platform. This final stage allowed obtaining direct feedback from subjects regarding their perceptions and experiences during the experimental protocol.

7.7. Automatic analysis of binocular saccades

Implementation of the MATLAB tool for automatic analysis of binocular saccades allows systematic processing of experimental data obtained from 8 subjects, on 3 types of trajectories (linear, sinusoidal, zigzag) and 4 background color variants (white, blue, green, red), resulting in a total of 96 individual analyses. The algorithm validates the capacity to coherently process the entire data set and to provide, for each experimental combination,

essential parameters of saccadic behavior — frequency, amplitude, and mean duration — alongside binocular asymmetry indicators.

Results obtained through automatic analysis of binocular saccades reflect the complexity of individual responses, highlighting both common traits of oculomotor behavior and significant variations between subjects. Comparative analysis suggests the existence of distinct tendencies at individual level, with differences in saccade organization and their distribution during visual task duration.

Automatic processing confirms complete functionality of the developed instrument and supports its applicability in experimental evaluation of binocular oculomotor function, providing support for quantitative interpretations to be presented subsequently.

Analyzing results for sinusoidal trajectory on red background, remarkable behavioral diversity is observed between subjects, which reflects individual adaptation to the complexity of this type of visual tracking. Sinusoidal trajectory constantly solicits the oculomotor system through continuous direction changes, generating distinct response patterns for each participant.

Subjects S3 and S6 present temporally concentrated velocity events, with intense peaks that significantly exceed the detection threshold, suggesting a tracking strategy through rapid jumps between key points of the trajectory. These subjects seem to adopt a predictive approach, anticipating direction changes and executing large saccadic movements for rapid gaze repositioning.

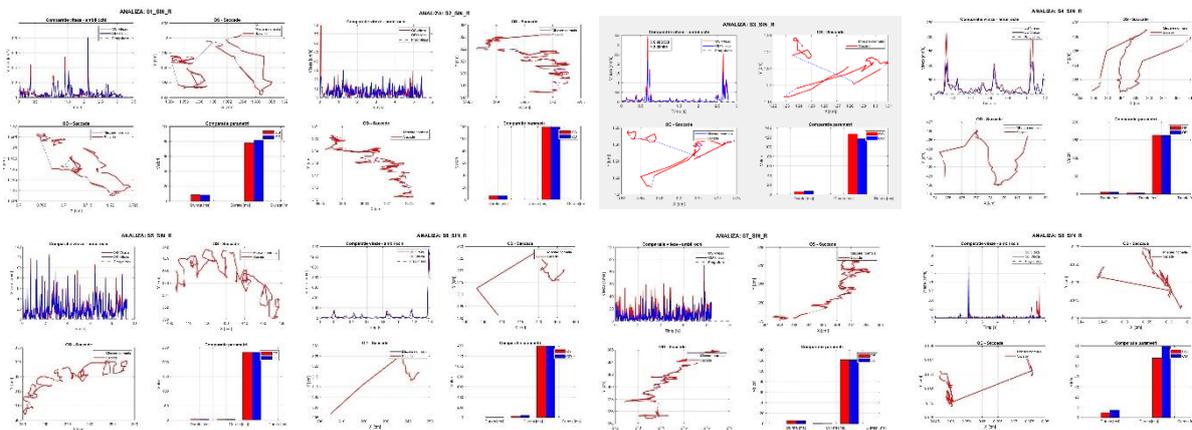


Figure 20 – Results of automatic binocular saccade analysis for sinusoidal trajectory, on red background - results of all participants

In contrast, **subjects S1, S2, S4, S5, and S7** demonstrate continuous exploratory behavior, with multiple saccadic events uniformly distributed throughout the visual task duration. These subjects' trajectories present complex patterns with search zones and fine

adjustments, indicating more detailed tracking of the sinusoidal shape through continuous monitoring of directional variations.

Subject S8 stands out through extremely reduced movement amplitude, with coordinates concentrated in a very limited space, possibly indicating difficulty adapting to trajectory complexity or a predominantly central tracking strategy with minimal ocular movements. Red background appears to influence saccadic performance through its effect on visual contrast and temporal perception of movement. This background color can modify visual system sensitivity to detecting directional changes of the sinusoidal trajectory, contributing to the diversity of tracking strategies observed between subjects.

Binocular asymmetries present significant variations between subjects, with mean duration differences between left and right eye ranging from 10-50 ms, which may reflect differences in visual processing or oculomotor coordination specific to complex trajectories. This variability confirms the importance of individual evaluation of binocular function in the context of dynamic visual tasks and underlines the capacity of the developed instrument to detect and quantify these subtle differences between subjects.

7.8. Simulation of saccade effect on gaze direction in relation to emotional state

Implementation of the script developed in the MATLAB environment allows comparative analyses between distinct emotional states. According to the following example, the comparison is made between constant calm state (with emotional parameter $e = 0.1$) and constant stress state ($e = 0.9$), demonstrating the model's capacity to differentiate specific ocular behaviors.

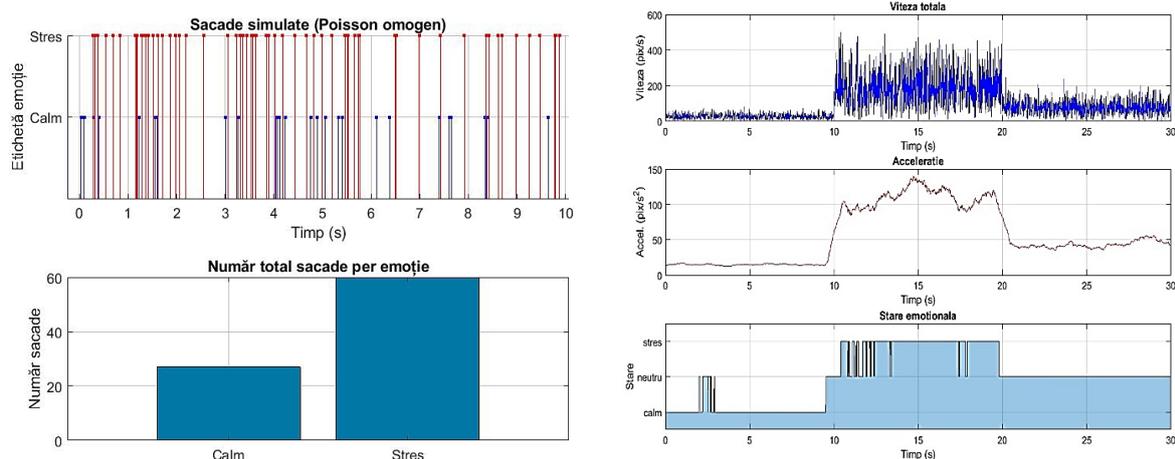


Figura 21 - Graph of saccade variation in relation to emotional state

The implemented simulation uses the homogeneous Poisson process for saccade generation, applying differentiated rates $\lambda = f(e)$ specific to each emotional state. Results

are visualized through temporal graphs and comparative histograms that demonstrate variations in ocular behavior according to emotional state.

The developed application processes real experimental data collected from sample subjects through cvMob software (biomechanical movement analysis software from video sequences that provides bidimensional kinematic analysis). This processing generates complete data sets, including X and Y positions (in pixels or millimeters) of virtual markers applied to the ocular area from video sequences recorded in the experimental procedure, as well as corresponding temporal data (in seconds). Integration of this data allows quantitative evaluation of the effect of emotional states on ocular movement parameters under controlled experimental conditions.

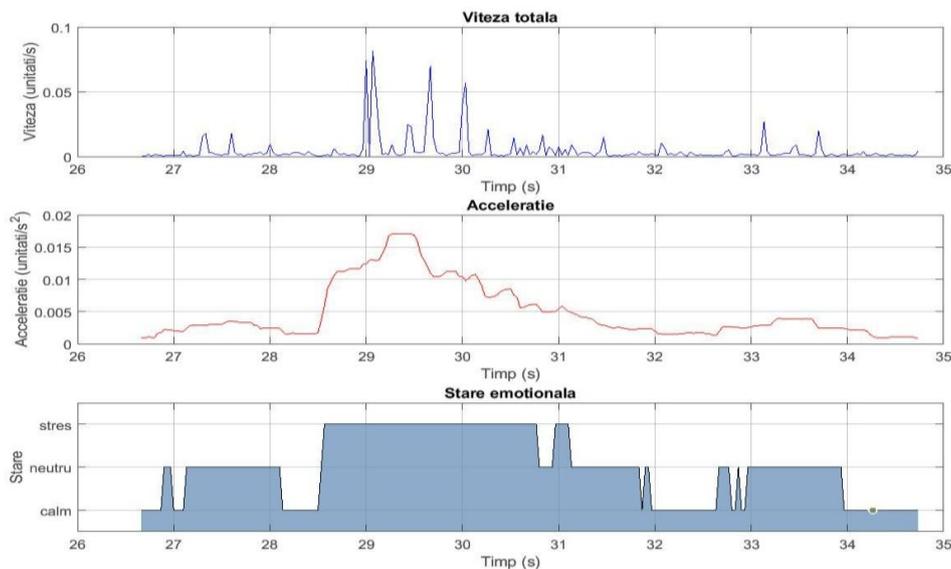


Figure 22 - Analysis of real kinematic parameters of ocular movement (velocity, acceleration) according to emotional state

The AEMO (Emotion Analysis from Ocular Movement) application developed within the research demonstrates efficient processing and analysis capabilities for experimental data. The system processes CSV files exported from cvMob, which contain Time, X, and Y columns, automatically calculating velocity and acceleration of ocular movement and estimating instantaneous emotional state through classification into "calm," "neutral," and "stress" categories based on preconfigured dynamic thresholds.

The application implements a robust detection system, which when configured thresholds do not allow identification of all emotional states (due to overly restrictive values or being outside reference intervals), automatically activates a fallback mechanism based on temporal analysis (the application uses an alternative classification method for emotional states based on the time/duration in which certain behaviors occur, not on amplitudes or instantaneous values). Processing results are visualized through three distinct graphs for

velocity, acceleration, and emotional state, and calculated data are saved in CSV format for subsequent analyses and integration into experimental databases.

For optimizing analytical performance, the application integrates parameters of colored visual stimuli used in the actual research: wavelength, brightness, and exposure duration. The inclusion of these parameters in processing is based on evidence from specialized literature that confirms the determining influence of colored light characteristics on ocular behavior under controlled visual stimulation conditions.

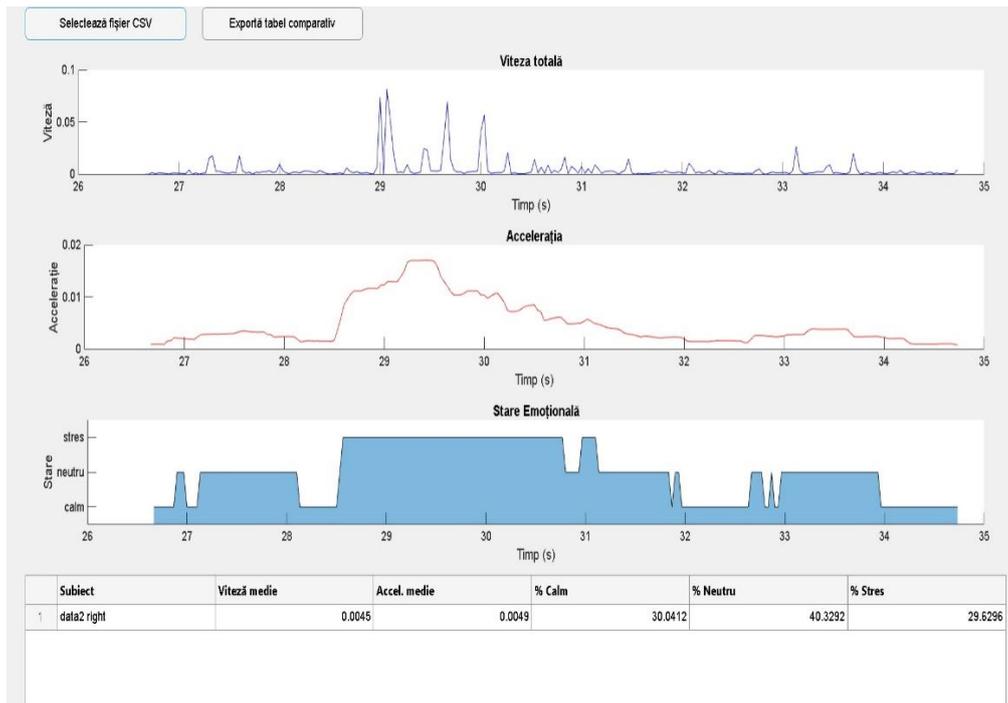


Figure 23 - Interface of the AEMO application developed within the experimental research

Analysis results demonstrate the method's potential for precise identification of emotional states at key temporal moments and for quantifying the impact of colored stimuli on attention, concentration, and anxiety processes. The generated database, containing behavioral parameters recorded from participating subjects, constitutes a valuable tool for occupational optometry specialists in diagnostic, evaluation, and optimization processes of visual and cognitive performance in work environments with specific visual stimulation.

8. CONCLUSIONS, ORIGINAL CONTRIBUTIONS, FUTURE RESEARCH DIRECTIONS

In relation to the proposed objectives and applied methodology, the conducted research offers a series of preliminary findings that support the relevance of investigating visual function and oculomotor behavior under controlled conditions. These results reflect the applicative potential of developed instruments, as well as the feasibility of integrating them into future standardized testing protocols. The conclusions formulated below synthesize the contributions brought by this exploratory stage, highlighting possible directions for expanding and consolidating research within a multidisciplinary framework.

8.1. Conclusions

↳ The research demonstrates that **ocular movement monitoring** constitutes an objective and non-invasive method for evaluating emotional responses induced by colored stimuli, offering important perspectives on the interaction between visual perception and affective processes. Results highlight **the capacity of colors to generate rapid and differentiated modifications of visual attention and emotional state, confirming the relevance of this approach in the field of experimental psychology.**

↳ The study reveals the existence of distinctive patterns in oculomotor responses **associated with different chromatic categories**, demonstrating that warm colors generate behavioral and attentional modifications distinct from cool colors. Identification of these specific response profiles provides an empirical basis for developing emotional recognition algorithms in intelligent biomedical systems.

Clear differentiation between color effects on arousal and relaxation states constitutes a solid foundation for implementation in adaptive biomechanical systems, which can automatically modulate operating parameters based on emotional state detected through ocular monitoring. These discoveries facilitate integration of psychophysical principles in human-machine interface design for applications in rehabilitation engineering and medical assistance.

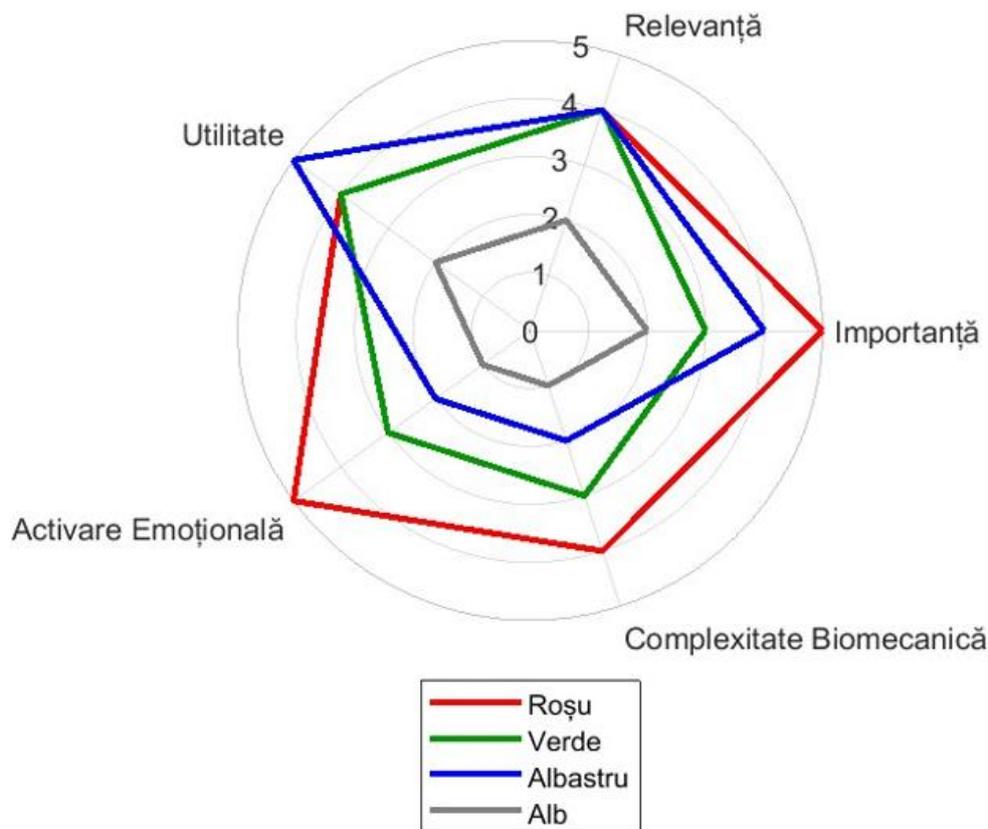


Figure 24 – Influence of colored light on the visual and emotional system

The identified correlation between chromatic properties and ocular fixation duration offers biomedical engineering precise instruments for developing non-invasive diagnostic devices and continuous monitoring systems for psycho-emotional state in clinical and industrial environments.

- ↻ Multiparametric analysis of ocular indicators - fixation duration, saccade frequency, and pupillary dilation - demonstrates the existence of a complex system of physiological responses correlated with the intensity of induced emotional states.
- ↻ Research results demonstrate the translational potential of the developed methodology, offering direct applicability in interdisciplinary domains such as cognitive psychology, neuromarketing, and adaptive interface design.
- ↻ Recognition of methodological aspects that require optimization.
- ↻ Emotional response intensity, evaluated through brain wave measurements, confirms the magnitude of modifications in ocular behavior (fixation time, pupillary dilation, saccade frequency) as a response to visual and auditory stimuli with emotional charge.
- ↻ Performance on standardized cognitive attention tests (D2, Stroop, and T.O.V.A.) correlates significantly with brain activity patterns recorded through the NeuroSky headset.

- ↪ Integration of data obtained from cognitive attention tests with electroencephalographic measurements from the NeuroSky headset allows development of a model that objectively characterizes attention and concentration levels in visual processing.

8.2. Original contributions

This doctoral thesis brings a series of original contributions to the field of human visual system analysis and eye-tracking technologies, derived from the experimental research conducted and the contextual analysis of the biomechanical domain. These contributions address methodological development, technological innovation, and theoretical grounding, offering new perspectives on the integration of multisensory stimuli in the evaluation of visual and cognitive functions.

The identified contributions are as follows:

- ↪ Identification and substantiation of the importance of studying the human visual system through a comparative analysis of European practices in optometry and visual system assessment.
- ↪ Formulation of principles to develop and validate a theoretical and experimental model for the analysis of eye movements.
- ↪ Identification of major research directions through scientometric analysis of the specialized literature.
- ↪ Proposal of an opto-biomechanical theoretical model using dedicated modeling software.
- ↪ Proposal of an experimental model based on flexible and interconnected elements.
- ↪ Emphasis on the role and relevance of analyzing the human visual system.
- ↪ Contributions to the development and extension of theoretical aspects through digital modeling in the opto-mechanical domain.
- ↪ Contributions to the advancement of biomechanical analysis applications for the visual system.
- ↪ Critical and criteria-based analysis of equipment used for monitoring human visual behavior.
- ↪ Development of a flexible, open system for the acquisition, processing, and interpretation of experimental data, ensuring compatibility and data integrity.
- ↪ Design and implementation of robust and validated mechanisms for correlating the effects of visual system stimulation with both objective and subjective responses (through experimental data modeling).
- ↪ Quantification of the level of synergy in human ocular biomechanics.
- ↪ Elaboration and implementation of empirical equations for specific evaluations in the monitoring and analysis of the visual system.

8.3. Future Research Directions

The results of this research provide relevant starting points for the extension and deepening of investigations into visual function. In the context of the continuous advancement of visual monitoring technologies and the growing interest in integrating such data into medical and engineering applications, a favorable framework for interdisciplinary approaches is emerging. In particular, the connections between experimental psychology, neuroscience, mechanical engineering, biomedical engineering, and biomechanical systems open new perspectives for the development of advanced tools for visual behavior analysis. Exploring these directions may contribute to the consolidation of objective methodologies applicable both in research and in clinical or educational practice.

- ↪ A first future research direction, emerging from the results of the exploratory study, involves the use of compatible, open, and integrated data acquisition equipment, with the goal of creating a portable system.
- ↪ A second research direction focuses on the development of an integrated methodology for visual function evaluation, combining data obtained through controlled simulations (including in pathological conditions) with the quantitative analysis of eye movements, for the purpose of continuous and objective oculomotor behavior monitoring.
- ↪ The third future research direction targets the extension of the application to the analysis of visual behavior across different categories of participants, aiming to capture the evolution of visual function in relation to variables such as age, clinical history, the presence of oculomotor disorders, or neuro-motor particularities.

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LIST OF PUBLISHED WORKS ON THE DOCTORAL THESIS TOPIC AND DURING THE DOCTORAL STAGE

During the doctoral program, scientific research activity was materialized through the elaboration and publication of 19 scientific works, of which 11 as first author and 8 as co-author. These publications were structured in two main categories: works directly relevant to the doctoral thesis topic, which address specific aspects of the research domain, and related works elaborated during the doctoral period, which contribute to interdisciplinary formation and research competency development.

The works were published in journals indexed in international databases Web of Science and Scopus, as well as in volumes of prestigious scientific conferences, demonstrating international recognition of research results.

Articles as first author - relevant to the doctoral thesis topic

1. **A. M. Lazar** *et al.*, "Conceptual Model of an Eye Movement Simulation Procedure for Motor Dysfunction Prediction," in *9th International Conference on Advancements of Medicine and Health Care Through Technology*, S. Vlad and N. M. Roman, Eds., Cham: Springer Nature Switzerland, 2025, pp. 13–22. doi: 10.1007/978-3-031-95671-3_2. https://link.springer.com/chapter/10.1007/978-3-031-95671-3_2
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