INTERDISCIPLINARY DOCTORAL SCHOOL

Faculty of Product Design and Environment

Mirela Gabriela APOSTOAIE

THEORETICAL AND EXPERIMENTAL RESEARCH ON BEHAVIORAL COMFORT

SUMMARY

Scientific supervisor

Prof.dr.ing. Mihaela Ioana BARITZ

BRAȘOV, 2025

Acknowledgements

I would like to express my deep and sincere gratitude to all those who contributed, directly or indirectly, to the completion of this doctoral thesis.

First of all, I would like to thank the review committee (whose members I will mention by name at the time of the defense) for the time given to the evaluation of this work, for the constructive observations and for the patience and understanding offered.

I express my gratitude to the Doctoral School of Transilvania University of Brașov for the opportunity to be part of a valuable academic community and for the support offered throughout the entire doctoral period.

I would like to thank the Management of the Faculty of Product and Environmental Design for the opportunity to carry out activities and collaborate throughout my training.

Along with the faculty leadership, I would like to express my special thanks to the director of the Product Design, Mechatronics and Environment department for the institutional support and the conducive framework for my training as a researcher.

I would like to express my special thanks to Prof. Dr. Eng. Mihaela Ioana Baritz, the scientific supervisor of the thesis, for her competent guidance, professionalism, patience and trust in all these years. Under her guidance, I benefited from a clear research orientation, constructive demands and constant support, essential for completing this academic journey.

I would like to express my special thanks to the Academic Guidance and Integrity Committee, consisting of Prof. Dr. Luciana Cristea, Prof. Dr. Sorin Vlase, Prof. Dr. Ileana Constanța Roșca from Transilvania University of Brașov and Prof. Dr. Anca Drăghici from Politehnica University of Timișoara, for their valuable support and encouragement throughout my research.

My thanks go to the teaching staff in the Product Design, Mechatronics and Environment department, who patiently and confidently supported me in my research and teaching activities.

Special thanks are hereby extended to Professor Dr. Eng. Dr. Marketing Angela Repanovici, for her generosity, advice, and openness; to Senior Lecturer Dr. Eng. Barbu Braun, for his clear guidance and constant support; to Professor Dr. Eng. Daniela Barbu, for her valuable contributions and academic support; and last but not least, to Senior Lecturer Dr. Eng. Corneliu Drugă, for the technical support and practical guidance offered at essential moments of the research.

A special thought of gratitude goes to my fellow doctoral students and doctors from the Doctoral School of Transilvania University, with whom I have traveled this complex path in my training as a researcher. Together we have shared not only the formal stages – courses, exams, pre-defendants – but also moments of doubt, motivation, mutual support and sincere encouragement.

Finally – but with the deepest gratitude – I extend my warmest and most sincere thanks to my family and close friends. You have been my anchor in moments of doubt, my motivation during times of fatigue, and my joy in the few moments of respite. Thank you for your boundless understanding, your unconditional support, and for your patience in standing by me even when I was too absorbed in my work to say “thank you.” Without your encouragement, without your faith in me, without your empathy and emotional support, this journey would not have been possible. This work belongs to you as well, in equal measure.

Chapter 1 - Introduction

1.1. Presentation of the field of the doctoral thesis

This thesis falls into the multidisciplinary field combining mechanics with biomechanical evaluation of walking in conditions of visual impairment, aiming to improve the mobility of people with low vision through visual assistance technological solutions. The research combines kinematic and kinetic gait analysis with the use of proximity sensors and auditory feedback systems, focusing on adapting locomotor behavior in the absence of visual information.

Starting from the difficulties related to spatial perception and obstacle anticipation, the thesis proposes the development and testing of a wearable electronic device, capable of providing the user with real-time feedback on the environment. The practical component includes the simulation of two types of visual impairments (glaucoma and cataracts) and the comparative testing of four assistance systems: three existing and one original – a Sonar device worn on the chest, with dynamic frontal detection and differentiated sound signal.

The tests were carried out under controlled laboratory conditions, using the RS Scan Footscan Gait system, on a sample of healthy subjects. The results contribute to the optimization of wearable technologies designed to improve comfort and safety in walking for people with visual impairments.

1.2. Objectives of the doctoral thesis

O1. Development and framing of the research theme in the field of interdisciplinary engineering

O1.1. Identifying the importance of biomechanics in the development and implementation of research to increase the quality of life

O1.2. Analysis of interdisciplinary aspects in the field of theoretical and experimental research on the implementation of integrated components

O1.3. Critical analysis of research on issues related to the usefulness and necessity of developing assistive technologies

O2. Analysis of the implications of visual dysfunctions on the level of biomechanical behavior

O2.1. Development of methodologies for identifying the components of visual dysfunctions that affect quality of life

O2.2. Theoretical evaluation of the biomechanical parameters of the walking cycle

O2.3. Determination and identification of deviations in the parameters of walking cycles under the influence of visual dysfunctions of low vision

O3. Ranking visual aid devices to improve behavioral biomechanics and achieve comfort levels

O3.1. Critical analysis of visual aids for mobility

O4. Modeling and simulation of mobility in relation to visual dysfunctions

O4.1 Modeling the Walking Cycle in the LabView Programming Environment

O4.2. Analysis of simulations of the effect of visual dysfunctions on the gait cycle in the LabView programming environment

O5. Conception, design, construction and use of the Sonar device

O5.1. Conception, design of the Sonar device
O5.2. Technological realization and verification of the device
O5.3. Comparative study of the Sonar device in relation to other visual aid devices
O5.4 Evaluation of experimental results to establish the degree of behavioral comfort
O6. Integrated simulation/experiment assessment to highlight the mode of manifestation and the effects of visual dysfunctions on behavioral comfort

1.3. Content of the doctoral thesis

Chapter 1 - Introduction - substantiates the multidisciplinary field of research by formulating the general and specific objectives of the thesis in relation to the need to develop visual assistance technological solutions for optimizing mobility and behavioral comfort.

Chapter 2 - Some considerations regarding the state of low vision in the modern era - analyzes the conceptual, terminological and etiological evolution of low vision, highlighting its transition to a major concern in the field of public health and highlighting technological advances.

Chapter 3 - Analysis of hardware and software means for the integration of patients with low vision - critically analyzes the existing technological solutions, such as hardware and software, intended to support people with low vision, highlighting their impact on accessibility, autonomy and social integration in the current digital context.

Chapter 4 – Theoretical Foundation – provides a conceptual foundation on the principles and models that support the functioning of visual assistance technologies, focusing on sensory compensation mechanisms, adaptive feedback and human-technology interaction in visual impairment.

Chapter 5 – Experimental System Design – presents the process of designing, developing and testing an experimental Sonar system for the visually impaired, focusing on the development of a wearable, accessible and ergonomic solution that provides effective obstacle detection through adaptive auditory feedback, with the aim of improving behavioral comfort and driving safety.

Chapter 6 – Comparison and integration of the Sonar system with visual aid structures – performs a comparative analysis between the Sonar system developed during the research and three other existing visual assistance devices, evaluating their performance based on objective and subjective criteria, in order to functional and behavioral integration of mobility solutions for visually impaired people.

Chapter 7 – Test protocol and experimental procedure – compares the Sonar system proposed in this research in relation to three other existing visual assistance devices, highlighting the strengths and limitations of each system based on technical and perceptual criteria, in order to identify the optimal solution to support mobility and behavioral comfort of visually impaired people.

Chapter 8 - Final conclusions. Personal contributions. Future research directions

Chapter 2 - Some Considerations on Low Vision in the Modern Age

2.1. Introduction

2.1.1. Historical aspects

The first record of the existence of aspects related to visual aid is from the year 1270 when Marco Polo was in China and discovered that elderly people used different lenses to read or see small objects more clearly. The first visual aid device for the visually impaired is attributed to René Descartes, in 1637. Even though numerous studies and discoveries have been carried out in the years that followed, they have been focused on understanding the process of total blindness or correcting vision with glasses. In the same context, the first school to support the visually impaired was founded only in 1908 in London. [1]

The development of assistive systems for people with low vision or blindness has a rich history, marked by significant innovations that have increased their accessibility and independence.

In 1808 the Italian Pellegrino Turri invented the first typewriter, which he built to help his blind friend write. This invention allowed her to communicate more effectively, thus representing an early example of assistive technology designed to help the visually impaired. [2]

In 1824, the invention of the Braille alphabet revolutionized the world of the blind.

In the 1980s, voice screen readers and text enlargement software applications were developed, allowing blind and visually impaired users to access computer interfaces.

The early 2000s brought significant advances in digital assistive technologies, including the development of on-screen information enlargement software such as ZoomText and screen readers such as JAWS (Job Access With Speech). [8]

Since 2010, the information society has witnessed the emergence of smart glasses and AI-based tools, all designed to help visually impaired people.

2.1.2. Terminology

Since the emergence of the terms related to blindness and low vision, the criteria used to define them have varied from area to area, from country to country, from study to study.

For example, in the United States, the standard definition of legal blindness is set by a visual acuity of 20/200 or worse for the best eye or one that has a field of vision of 20o or less. [11]

The European Council of Optometry and Optics (ECOO) provides the following definition: 'Low vision describes a visual impairment that restricts the ability to perform visual tasks in everyday life. This disability cannot be corrected by regular glasses, contact lenses or medical intervention. Obvious types of visual impairments are loss of visual acuity and loss of visual field. Other examples include loss of contrast sensitivity, abnormalities in color vision and night vision, as well as increased sensitivity to light." The term "visual impairment" has been used to describe a broader spectrum of vision loss. In recent years, some specialists have proposed the use of more general descriptive terms that refer to "vision loss" and "problems associated with vision", respectively. [12] [13]

In 2002, the International Council of Ophthalmology (ICO) adopted a resolution recommending the following terminology:

Blindness – a term to be used only for total vision loss and for conditions in which people have to rely primarily on vision substitution abilities through the use of other sensory physiological systems.

Low vision – term to be used at lower degrees of diminished visual function, in which case individuals can be significantly helped by vision enhancement systems and devices.

Visual impairment – term to be used when the state of vision loss is characterized by a loss of visual function characteristics (such as visual acuity and visual field) at the organ level.

2.1.3. International orientation

The World Health Organization periodically organizes *the International Consensus Conference on Standards for Vision Rehabilitation* where both development standards and objectives for the rehabilitation of visual function and social inclusion are established. Rehabilitation goals include: a) preventing loss of vision function; b) slowing down the rate of loss of visual function; c) improving or restoring visual function; d) compensation for loss of vision function; (e) maintaining the current function at the level of the visual system. [15]

2.2. Etiopathogenesis of low/poor vision

All definitions of low vision take into account a main characteristic of the visual system called Visual Acuity (AV).

According to Aj Jackson and his collaborators, "visual acuity" is almost synonymous with assessing the central visual state, but using optotypes is still more specific and refers to the ability of the visual system to resolve spatial details. Visual acuity is a measure of the angular size of detail that can only be solved visually by the observer, and its limitations are imposed by a combination of optical and neural factors. [17]

Pathological causes of low vision

Following a study Gudlavalleti Murthy and his colleagues classified the pathological causes of low vision/blindness according to the preponderance of the appearance, the main pathology being cataracts, followed by macular degeneration, opacity of the posterior capsule, absent/disorganized globe, corneal opacity/scarring, glaucoma, other retinal disorders, other optic atrophy, refractive error (severe myopia, large hyperopia), retinal detachment, diabetic retinopathy, amblyopia, strabismus. [18]

A. Cataracts

Cataracts occur in the lens of the eye manifesting itself as a transparency disorder or even opacity that prevents light from reaching the retina. This leads to blurred vision, decreased visual acuity, contrast and without surgery can lead to blindness. [19]

B. Macular degeneration

Age-related macular degeneration (AMD) is another major cause of blindness in the elderly, being more prevalent in people over the age of 65. Blindness caused by AMD is usually irreversible.

C. Glaucoma

Glaucoma is the second leading cause of irreversible blindness worldwide and is characterized as a group of eye disorders that have as their main consequence the damage of the optic nerve. Most forms (closed-angle glaucoma or open-angle glaucoma) include intraocular pressure that is too high to maintain eye health, which is why atrophy of the optic nerve head and loss of visual field occurs. [37] [38]

D. Retinal detachment

Retinal detachment occurs when vitreous humor infiltrates the layers of the retina and separates the 2 layers (the layer of light receptors (photoreceptors) and the layer of pigment cells called the pigment of the retinal epithelium (RPE)).

E. Retinopathy

Retinopathy is a term used to describe various non-inflammatory retinal disorders that can cause low vision. The most common forms of retinopathy are diabetic, premature and hypertensive. [50] [51]

Myopia

The World Health Organization defined in 2015 myopia that affects the quality of distance vision as: "a condition in which the refractive error has the spherical equivalence of at least −0.50 spherical diopter in each eye", and strong myopia as: "a condition in which the refractive error has a spherical equivalent of more than −5.00 spherical diopter in each eye". [57]

Hypermetropia

The American Optometry Association divides farsightedness into 3 categories:

a) low - which consists of a refractive error of up to +2.00 spherical diopters;
b) moderate with a range from +2.25 to +5.00 spherical diopters;
c) high – refractive error objectively measured above +5.00 spherical diopters. [60]

Astigmatism

Astigmatism is a refractive error (ametropia) that occurs when parallel rays of light entering through different meridians into the unaccommodated eye are not properly focused on the retina. When incident light rays do not converge at a single focal point, astigmatism occurs.[62]

F. Strabismus

Strabismus is a condition in which the visual axes of the two eyes are misaligned. One or both axes of the eyes deviate, either constantly or intermittently, from the optical axis inwards (eso-tropia/foria), outwards (exo-tropia/foria), upwards (hyper-tropia/foria) or downwards (hypotropia/foria). Strabismus is one of the most common eye conditions diagnosed in children. [65]

G. Amblyopia

Amblyopia is a usually unilateral, rarely bilateral condition in which corrected visual acuity is worse than 20/20 (normal vision according to the WHO), in the absence of any structural abnormality.
Amblyopia is the leading cause of monocular vision loss in childhood, with an estimated prevalence of 1% to 6% and is responsible for permanent vision loss in 2.9% of adults [69] . Children are prone to amblyopia from birth to the age of 7. [70]

2.3. Investigation and evaluation systems

2.3.1. Visual function parameters

Visual acuity (AV) refers to the clarity of vision, representing the eye's ability to observe fine details. This quality is usually assessed using standardized charts (scales, optotypes), such as the Snellen chart, where subjects identify letters or symbols at a specified, standardized distance. The term "visual acuity" itself dates back to 1861 when Dr. Franciscus Donders, who defined it as "the ratio of a subject's performance to a standard performance" in distinguishing the details of a test model. [71]

The World Health Organization (WHO/WHO) uses the following classification in relation to visual acuity of visual impairments. When vision in the eye is better, with the best possible correction for glasses is:

- AV of 20/20 is vision considered normal.
- AV from 20/30 to 20/60, this is considered mild vision loss or near-normal vision.
- AV of 20/500 to 20/1000, this is considered profound visual impairment or profound low vision.
- Less AV than 20/1000, this is considered near-total visual impairment or near-total low vision.
- Without light perception, this is considered total visual impairment or total blindness. [14]

Contrast sensitivity measures the ability to distinguish background objects based on differences in luminance.

The field of vision refers to the area visible during stable fixation of the eyes, specified in degrees of visual angle.

Color vision – Color vision assessment measures the ability to perceive and differentiate colors.

Depth perception and stereopsis - Depth perception refers to the ability to perceive the relative distance of objects in three dimensions.

Stereopsis (when the brain perceives depth by interpreting the visual input of both eyes) is determined only by the two eyes working together to develop a three-dimensional image.

Adapting to light and dark – One of the most important tasks that the retina performs is adapting to light and dark.

Motion perception – Motion perception refers to the ability of the visual system to detect and interpret movement in the visual field

Ocular motility and alignment – Ocular motility refers to the eye's ability to move and track objects, while ocular alignment refers to the coordinated positioning of both eyes to ensure that visual targets are projected onto the appropriate retinal areas.

2.3.2. Methods and means of assessment

Direct observation

Direct observation is a very important factor in visual evaluations, providing examiners with invaluable information about the patient's visual function and eye health. This process is usually divided into two critical stages: General Observations Before Formal Testing and Observations During Testing.

A. General comments before formal testing

Before initiating formal visual evaluations, examiners engage in general observations to collect preliminary information about the patient's visual behavior and eye condition. These observations are essential in shaping the subsequent review process.

B. Observations during testing

During visual assessments, targeted observations are made to assess specific aspects of visual function and eye health. These observations complement objective measurements and are crucial for accurate diagnosis and management.

Medical History

History serves as the starting point for effective visual assessments, providing critical insights that guide the diagnostic and evaluation processes. By systematically collecting detailed information about the subject's ocular and general health, examiners identify risk factors, recognize early signs of pathology, and tailor interventions accordingly.

Assessment of the quality of vision

Visual acuity assessment is a fundamental component of comprehensive eye examinations, assessing the clarity or quality of vision at different distances.

Campimetry – Perimetry

Visual field assessment is a fundamental component of comprehensive eye examinations, assessing the full extent of the patient's peripheral (lateral) vision.

Assessment of eye movements

Eye movement assessment is a fundamental component of visual assessments, as it provides crucial information about ocular motor control, coordination, and neurological function.

Contrast sensitivity assessment

The common way to assess contrast sensitivity is to use a Pelli-Robson contrast sensitivity diagram.

Evaluation of color vision

Different assessment methods have been developed to examine color discrimination abilities, each with specific applications, advantages, and limitations.

2.3.3. Methods and means of examination

Autorefractometer

An auto-refractometer is a tool that helps in the automatic evaluation of refraction. This is an alternative method of finding out refractive error, as opposed to the conventional refraction technique.

The biomicroscope/slit lamp is an essential tool in ophthalmology and optometry, providing a detailed and magnified view of the structures of the eye. It combines a high-intensity light source with a binocular microscope, allowing evaluators to accurately examine both the anterior and posterior segments of the eye.

Retinoscope/skiascope + Lens ruler works on the principle of detecting the movement of a beam of light reflected by the patient's retina. By analyzing the direction and speed of reflected light, the examiner can determine refractive error, such as nearsightedness, farsightedness, or astigmatism.

A tonometer is a device used to measure intraocular pressure. Increased intraocular pressure is a significant risk factor for glaucoma, a group of eye diseases that can lead to vision loss and blindness.

Campimeter is an ophthalmic instrument designed to assess the central field of vision, especially in the central 30 degrees of vision. This tool is essential in detecting and quantifying visual field defects, such as scotomas – areas of partial or complete vision loss surrounded by a normal field of vision. [95]

2.4. Conclusions

In conclusion, this chapter provides a broad picture of low vision, addressing issues such as historical evolution, specific terminology, international perspectives, and pathological causes. The importance of these conditions in contemporary society is highlighted, emphasizing their influence on daily activities, mental health and the process of social integration.

Chapter 3

Analysis of hardware and software means for integration of patients with low vision

Low vision has a significant impact on a person's ability to perform daily tasks, navigate their environment, and maintain independence, turning any human subject examined into a patient. Unlike total blindness, people with low vision retain some degree of vision, but it is often insufficient to read, recognize faces, or engage in activities that require fine visual detail.

3.1. Integrated hardware and software for visual assistance

3.1.1. Electronic and video magnifiers

Optical Magnifiers – These include handheld, stand, and electronic magnifiers that magnify text and images, making it easy to read and work in detail. Electronic magnifiers often come with adjustable magnification levels and contrast settings to suit individual needs.

3.1.2. Screen Magnifier Software

Screen magnification software is a visual assistive technology for people with low vision, improving their ability to interact with digital content by enlarging and enhancing the elements on the screen.

3.1.3. Wearable vision enhancement devices

Telescopic lenses and biooptic glasses are specialized optical devices designed to improve distance vision for people with low vision.

3.2. Everyday assistive technologies for low vision

3.2.1. Digital assistive technologies and artificial intelligence (AI)

Screen readers

Screen readers are essential assistive tools that allow visually impaired people to access digital content through synthesized speech or braille output. These software applications convert on-screen text, menus, and web content into an accessible format that users can navigate using keyboard shortcuts or touch gestures on mobile devices.

Changeable braille displays

A refreshable braille display is a tactile device that allows visually impaired people to read digital content by converting text into embossed Braille characters. These devices work in conjunction with screen readers, allowing users to access text through touch rather than audio.

Optical Character Recognition (OCR) Systems

Optical character recognition (OCR) systems convert printed text into a digital format that can be read aloud by screen readers or displayed on Braille devices. This technology allows visually impaired people to access books, letters, restaurant menus, and other printed materials without assistance.

Voice-activated assistants

Voice-activated assistants such as Amazon Alexa, Google Assistant, and Apple Siri have revolutionized accessibility for the visually impaired. These AI-powered tools allow users to perform hands-free tasks using voice commands, eliminating the need for visual interaction with screens.

Digital Audiobook Players

Digital audiobook players provide access to books, newspapers, and magazines in audio format, allowing visually impaired people to enjoy "reading" independently.

Voice-activated smart glasses

Voice-activated smart glasses integrate artificial intelligence and voice commands to help visually impaired users interact with their environment. These devices can read text, recognize objects, identify faces, and provide real-time descriptions of surroundings, increasing independence.

3.2.2. Touch and audio assistive technologies

Braille Notepads

Braille notepads are portable devices designed to assist people who read and write in Braille. Unlike standard electronic devices, these note-taking devices feature Braille keyboards and refreshable Braille displays, allowing users to write, browse the internet, and access digital documents.

Watches with voice and touch function

Knowing the passage of time is an essential part of everyday life, and for people with visual impairments, talking clocks provide auditory announcements to help them stick to the schedule without having to see a display. These devices come in different formats, including wristwatches, bedside clocks, and apps integrated into smartphones, ensuring flexibility in different settings.

Touch and Talking Thermostats

Touch and talking thermostats improve accessibility for the visually impaired by providing audio feedback and tactile controls for adjusting indoor temperatures.

3.3. Navigation and mobility technologies

3.3.1. Electronic devices for mobility

Electronic mobility aids use sensors, cameras, and GPS technology to help blind people navigate safely in their environment. These devices are often designed as portable instruments or wearable accessories that provide audio or haptic feedback.

Modern electronic mobility aids incorporate artificial intelligence and machine learning to improve obstacle recognition and route optimization, reducing users' cognitive load.

3.3.2. GPS-based navigation systems

GPS-based navigation systems designed specifically for visually impaired users provide turn-by-turn directions with audio feedback. Unlike traditional GPS apps, these solutions incorporate detailed pedestrian guidance, helping users navigate streets, intersections, and public transportation systems safely.

3.3.3. Smart cane with obstacle detection

The smart cane integrate ultrasonic sensors, GPS navigation, and AI-powered feedback mechanisms to improve user mobility. These innovations provide users with real-time guidance and obstacle detection, making independent mobility safer and more efficient.[139] [140]

3.3.4. Wearable haptic feedback devices

Wearable assistive technology integrates haptic feedback, AI, and spatial awareness tools into apparel and accessories to support visually impaired people in mobility. These devices function as smart guides, alerting users to obstacles and providing directional assistance.

3.4. Community-enabled assistive technologies

Governments around the world play a crucial role in ensuring accessibility for visually impaired people by implementing policies and infrastructure projects aimed at increasing mobility, independence, and safety. From pedestrian infrastructure changes to smart city innovations, these efforts aim to create inclusive environments where visually impaired people can easily navigate public spaces.

3.4.1. Accessible pedestrian infrastructure

One of the most critical aspects of government-led accessibility initiatives is the development of pedestrian-friendly infrastructure. Tactile paving, also known as detectable warning surfaces, is widely deployed to provide physical cues that help visually impaired pedestrians navigate sidewalks, crosswalks, and transit platforms. These textured ground indicators allow people using a cane to feeling vibrations through their canes to detect safe walking paths, upcoming intersections, and hazards such as platform edges.

3.4.2. Braille signage in buildings

Braille signage is a fundamental accessibility feature that governments impose in public buildings to ensure that visually impaired people can independently navigate indoor environments. These signs include Braille tactile characters and embossed letters to help users identify room numbers, exits, restrooms, elevators, and emergency instructions.

3.4.3. Smart City initiatives and urban accessibility technologies

Smart city initiatives use emerging technologies such as AI, IoT, and digital mapping to improve accessibility for the visually impaired. Governments have integrated digital navigation tools and real-time information systems into urban infrastructure to improve mobility and independence.

3.5. Scientometric analysis of the literature

In order to identify the main research directions in the field of devices intended for the behavioral comfort of visually impaired people, a scientometric analysis was carried out using the Web of Science database. The search terms were selected in English, in accordance with international customs and the specialized literature of Romania. The results obtained are presented in the table below:

The progressive reduction of the number of articles, from 6,421 to just 233, by adding the terms visual aid and behavior, highlights a relatively unexplored research niche. This finding supports the relevance of the theme proposed in this paper and underlines the need to deepen research in the area of the behavior of visually impaired users in relation to visual assistance technologies. For the scientometric analysis and visualization of the relationships between key concepts in the literature, the VOSviewer software, developed by Leiden University in the Netherlands and available free of charge at https://www.vosviewer.com, was used. The image in Figure 1 illustrates the frequency and co-occurrence of terms extracted from the articles resulting from the search with the expressions low vision, behavior, and visual aid.

For a more relevant representation of the dominant themes, only those terms that appear at least four times in the analyzed corpus were selected. Thus, 59 significant terms were identified, grouped into six interconnected thematic clusters. These reflect areas such as: vision, behavior, low vision, children, people,

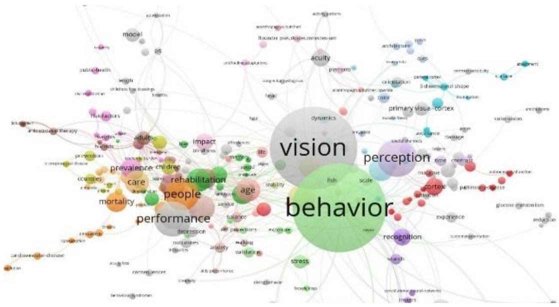

Fig. 1. Visualization of the network of terms associated with low vision, behavior and visual aid (performed with VOSviewer)."

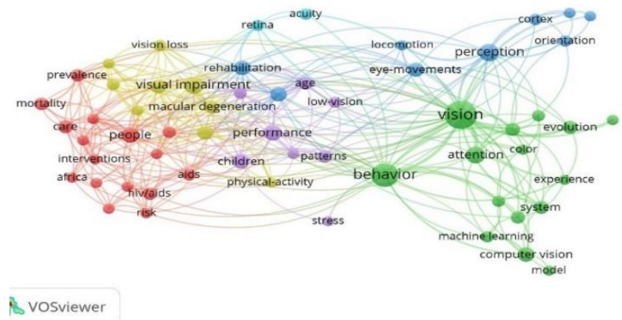

Fig. 2 Terms mentioned at least 4 times in the articles concerned

and rehabilitation. The results highlight the importance of assistive systems in supporting functional behaviour and independent living for visually impaired people.

Figure 2 shows a network of terms extracted from the literature, generated with the help of the VOSviewer software. Only terms that appear at least four times in the analyzed articles were included, in order to highlight the dominant concepts and the semantic relationships between them.

These results validate the choice of the research topic and highlight the need to develop innovative solutions in the field of visual assistance systems.

Conclusions

The scientometric analysis carried out highlights a significant increase, in recent years, in the use of the terms low vision, behavior and visual aid in scientific literature. This trend reflects a growing interest in the intersection of visual impairments, user behavior, and assistive technologies.

The high frequency of the co-occurrence of the terms low vision and visual aid suggests that the development and evaluation of visual assistance techniques and technologies is a priority direction in current research. In addition, the involvement of a growing number of authors from various countries underlines the global nature of concerns about the inclusion of visually impaired people and improving their quality of life through innovative technological solutions.

3.6. Conclusions

In a world designed primarily for those with full vision, people with low vision often face daily challenges that many take for granted – reading a menu at a restaurant, navigating a busy street, or recognizing a familiar face. However, thanks to rapid advances in technology, the barriers once imposed by vision impairment are gradually being dismantled.

The integration of hardware and software solutions has transformed the way people with low vision interact with their environment. Traditional magnifiers have been transformed into sophisticated electronic devices with adjustable magnification and contrast settings, allowing users to read and interact with the world around them more easily.

Beyond improving vision, digital assistive tools have revolutionized accessibility in everyday life. Screen readers and braille displays open doors to digital information, making it possible for people to study, work, and communicate as effectively as their sighted peers. AI-powered voice assistants bring convenience to everyday tasks by allowing users to control their environment, manage schedules, and access information with simple voice commands.

Chapter 4

Theoretical foundation

People with low vision show complex changes in movement coordination, balance, and posture, as the visual, vestibular, and proprioceptive systems work together to maintain stability and spatial orientation. Visual impairment causes disturbances in:

Reflexes and balance: The vestibulo-ocular reflex (VOR), which stabilizes the image on the retina during head movement, is indirectly affected, which compromises spatial orientation and stability. People with low vision rely more on proprioception and tactile information to compensate for the lack of visual information.

Postural changes: The positions of the head, neck, arms and back adjust to compensate for visual impairment. This often involves tilting the head forward, reduced arm movements, and changes in torso alignment, designed to optimize stability and minimize the risk of falling.

Biomechanics of the sole and stability: The sole of the foot, the main point of contact with the ground, plays a critical role in detecting surface variations and maintaining stability. In conditions of low vision, people tend to adopt a cautious gait with an extended support polygon and a lower cadence, which affects the reaction forces of the soil and the distribution of planting pressure.

4.1. Study of the biomechanics of the lower limb in locomotion

The term biomechanics combines the prefix "bio", which means "life", with the field of mechanics, which is the study of the actions of forces. [162]

According to Roșca in the book Fundamentals of Biomechanics "biomechanics is the science born through the mutual influence between: biology, internal medicine, surgery, prosthetics, robotics, traumatology and the study of industrial problems related to human health." Statics and dynamics have two major subbranches of mechanics.[163]

Statics is the study of systems that are in a state of constant motion, that is, either at rest (without motion) or in motion at a constant velocity.

Dynamics is the study of systems in which acceleration is present.[162]

4.1.1. Basis of support

The support base refers to the area underneath an object or person that includes each point of contact that the object or person makes with the support surface. These points of contact can be parts of the body, for example: feet or hands, or they can include things like crutches or the chair in which a person sits.

4.1.2. The support polygon represents the surface delimited by the plantar forces of the feet (of the feet) and the space between them. It is well known that the stability of the body is closely related to the size of the supporting polygon and the angle of stability.

4.1.3. Pushing force:
The force exerted by the foot during the stance phase to propel the body forward. This is especially significant during the terminal phase of the support or in the detachment phase of the leg, when it goes from supporting the weight of the body to pushing it forward.

4.1.4. Plantar pressure:
assessed to understand how body weight is distributed over the surface of the sole while walking. It is a reliable parameter for analyzing foot functions and provides additional information in studies on the etiology of lower limb diseases. [170]

4.1.5. Trajectory

Walking trajectory refers to the path a person takes while walking, influenced by factors such as leg positioning, limb movement, and balance control. It includes both spatial aspects (the trajectory of the foot and body) and the temporal aspects (the synchronization of the movements of the legs).

4.1.6. Speed and linear speed

Two quantities that are parallel to distance and linear displacement are velocity and linear velocity. These terms are often used interchangeably in everyday conversations, but in mechanics they have precise and distinct meanings. [162]

4.1.7. Acceleration

Acceleration (a) is defined as the rate of change in speed or change in speed that occurs in a given time interval (t).

4.1.8. Conclusions

In conclusion, people with low vision experience significant changes in gait, which affect postural stability, coordination of movements, reflexes and balance. These changes lead to compensatory adjustments in posture and gait dynamics, involving the upper segments of the body (head, neck, arms, back).

Biomechanics provides a theoretical basis for the study of gait, by analyzing the forces and movements involved in locomotion. It focuses on the dynamics and statics of the body, as well as the interactions between the foot, ground and other anatomical segments.

4.2. Study models of the walking cycle

4.2.1. Direct pendulum model

The forward and backward movement of the legs has been compared to that of a pendulum, and evidence indicates that pendulum dynamics could explain much of the balancing phase of walking.

4.2.2. Gard's inverted pendulum model

It is shown in Figure 4, Gard's inverted pendulum model, in which a virtual leg with LV length is inserted and the leg is modeled as a pendulum with radius r. [174]

4.2.3. The Denavit Hartenberg model

While pendulum models focus on raw motions and energetic principles, they lack the precision needed to describe common interactions, forces, and deviations.

The Denavit-Hartenberg model compensates for this gap by providing a kinematic representation of the lower limb in 3D space.

4.3. Kinematic and dynamic analysis of locomotion

4.3.1. Introduction

During walking, each lower limb in the support phase has four essential biomechanical functions:

(1) it generates the propulsive force necessary for movement;

(2) maintains the vertical stability of the body despite continuous changes in position;

(3) attenuates the shock produced on contact with the ground;

(4) contributes to the conservation of energy by reducing muscle effort, thanks to an efficient organization of these functions.

4.3.2. Mechanics of Foot Movements

The mechanics of human motion encompasses the study of the forces, kinematics, and dynamics that govern locomotion. This chapter explores the principles of foot movement mechanics, with a focus on gait dynamics, pressure distribution, and movement deviations. The perspectives presented are based on key research studies and methodologies that illuminate the complicated relationship between anatomy, biomechanics and locomotion efficiency.

4.3.3. Kinematics of Foot Movements

Kinematics is the branch of biomechanics that studies motion without considering the forces that cause it. This chapter delves into the principles of foot kinematics, with a focus on clinical applications, multi-segment foot patterns, and implications for both normal and pathological movement patterns.

4.4. Deviations from the walking cycle

For normal walking, all of the following functions and systems must be intact: locomotor function (for initiating and sustaining rhythmic walking), balance, postural reflexes, sensory function and motor integration, motor control, musculoskeletal apparatus, and cardiopulmonary functions. The afferent nerves in the visual, vestibular and proprioceptive systems provide essential information about the position of the body and its parts. Disturbances in one of these systems, e.g. proprioception, may be partially compensated for by other sensory systems, such as vision. [189]

4.5. Walking comfort

Movement is essential for human interaction with the environment. Comfort in movement refers to the ease and efficiency with which individuals can perform physical tasks without excessive effort. For visually impaired people, walking comfort presents unique challenges, influenced by the complex interaction between biomechanical, environmental and sensory factors. Recent studies are trying to elucidate the mechanisms by which visually impaired people manage these challenges and the ways in which their mobility can be improved.

4.5.1. Biomechanics of gait

Biomechanics forms the foundation for understanding the mechanics of human motion. The body's musculoskeletal system, made up of bones, muscles, tendons, and ligaments, work together to produce movement. In visually impaired people, gait adaptations are often necessary to compensate for the lack of visual information.

4.5.2. Environmental and ergonomic factors

Environmental design significantly influences the comfort and safety of visually impaired people. Well-structured environments – such as flat surfaces, wider sidewalks, and audible signals at traffic intersections – are essential for improving walking comfort for people with visual impairments.

4.5.3. Sensory perception

Sensory feedback plays a crucial role in regulating the comfort of movement, especially for people with visual impairments. The somatosensory system, which includes proprioception, kinesthesia, and the sense of touch, provides essential information about body position and interaction with the environment. For visually impaired people, auditory and tactile cues serve as compensatory mechanisms. Research highlights the importance of auditory signals in improving spatial awareness, safety, and comfort during mobility

4.6. Measurement methods and simulations of the walking cycle

The study of gait cycles is fundamental to understanding human locomotion. Gait analysis and simulation methods provide essential tools for the evaluation, diagnosis and design of interventions for people with movement disorders or for optimizing performance in sports and rehabilitation. This chapter explores measurement and simulation methods for gait cycles, organized into two main sections: measurement methods and simulation techniques. Each section presents an overview of current practices, highlighting advances in technology and methodology.

4.6.1. Measurement and evaluation methods

Gait measurement involves quantifying various parameters, such as stride length, cadence, speed, joint angles, and forces exerted while walking. These data provide insights into the functional integrity of the musculoskeletal and nervous systems. Traditional and advanced methods are used to collect these measurements, from observational assessments to sophisticated motion capture systems.

4.6.1.1. Tinetti Scale

The assessment of gait quality is an indispensable tool in the functional analysis of mobility, especially in the elderly or with various locomotor and sensory impairments. The Tinetti Scale (Performance-Oriented Mobility Assessment – POMA), developed by Mary Tinetti, is one of the most widely used methods for the clinical assessment of gait and balance. It provides a validated overall score that can be used to estimate the risk of falling and track patients' progress over time or following therapeutic or technological interventions [202] [203] .

The scale is structured in two components: the balance scale (maximum 16 points) and the walking scale (maximum 12 points). In the context of gait analysis studies, such as those involving the use of visual aids or the simulation of visual conditions, the gait scale is particularly relevant and can be applied [204] independently.

4.6.1.2. Purtabilla sensors

Gait analysis used different types of sensors and motion systems, such as accelerometers, gyroscope, magnetoresistive sensors, flexible goniometer, electromagnetic tracking system (ETS), sensing fabric, force sensor, and electromyography (EMG) sensors. Based on these sensors, a single type or a system of sensors combined with several types of sensors can be used for various gait analysis applications. [205]

4.6.1.3. Optical motion capture systems

The typical image processing system consists of several digital or analog cameras with lenses that can be used to collect gait-related information. Techniques such as threshold filtering that converts images to black and white, number of pixels to calculate the number of light or dark pixels, or background segmentation, which simply removes the background from the image, are just a few of the possible ways to collect data for measurement. gait variables

Viewing / depth cameras

Optical biomechanical motion tracking systems

Inertial sensors

Other sensors

4.6.1.4. Floor systems

In systems based on this technique, sensors are placed along the floor on so-called "force platforms" or instrumented walkways where gait is measured by pressure or force sensors and momentum transducers when the subject walks on them. There are two types of floor sensors: force platforms and pressure measurement systems

4.6.1.5. Video-based analysis

Video-based gait analysis uses camera feeds and software algorithms to estimate joint angles and motion trajectories without physical markers.

Types of video cameras

Various cameras were used in the video-based gait analysis, each with distinct characteristics suitable for specific applications. The following camera types and configurations are commonly used:

Standard video cameras.

High-speed cameras.

Cameras without a marker.

Types of software

A variety of software programs are used to analyze the video data collected during gait analysis. These include commercial, open-source, and custom developed solutions:

- Dartfish: Frequently used software for kinematic and spatio-temporal analysis.
- Kinovea: Open source software often used in sports and clinical applications.

4.6.2. Simulation method

Simulation methods provide a controlled environment to study gait dynamics, predict the results of interventions, and train algorithms for gait recognition. These methods model the complexity of human movement and allow experimentation without physical testing.

4.6.2.1. Dynamic simulation techniques

Dynamic simulation techniques focus on modeling the mechanics of human motion, incorporating forces, torques, and motion dynamics. These techniques typically rely on rigid body dynamics and musculoskeletal modeling to simulate human gait. Dynamic simulations are used to study joint loads, patterns of muscle activation, and the effects of assistive devices on gait. They provide information about how external factors, such as uneven terrain or obstacles, affect walking.

4.6.2.2. Virtual reality (VR) walking simulations

Virtual reality (VR) walking simulations create immersive environments for gait analysis and training. These simulations allow researchers to study walking in controlled, repeatable scenarios.

VR is widely used in gait rehabilitation, balance training, and for studying the impact of environmental factors on gait.

4.6.2.3. Computational biomechanics models

Computational biomechanics models are mathematical frameworks used to simulate the forces, joint movements, and energy consumption associated with walking. These models often incorporate finite element analysis (FEA) and inverse dynamics. Commonly used in research and clinical settings, these models look at joint stress, muscle strength, and energy efficiency while walking.

4.7. Contributions to the modelling and simulation of the gait cycle in relation to visual function

Gait is a biomechanical process that requires coordination between the musculoskeletal system, the visual system and the vestibulocular system, respectively. Vision plays a critical role in spatial awareness, balance, and gait, allowing individuals to anticipate obstacles, adjust their stride length, and maintain a stable trajectory. People with visual impairments often experience difficulty walking, which can lead to increased lateral deviations, instability, and altered plantar pressure distributions.

In order to better understand how different visual impairments affect the characteristics of the gait cycle, a simulation was developed using the LabVIEW programming environment. This app models walking on an ideal eye emetropic (normal vision) trajectory and compares it to 5 different visual conditions: strabismus, macular degeneration (AMD), cataracts, glaucoma, and blindness. The simulation follows deviations from the ideal trajectory and analyzes the distribution of plantar pressure based on body weight and the phases of contact of the foot with the ground under different visual conditions mentioned above.

4.7.1. Labview Programming Environment

LabView is the software chosen to do this simulation because it meets several conditions, such as:

- Graphical interface - LabVIEW provides an intuitive module-based programming approach, making it easy to develop and modify simulations without extensive coding.
- Data processing capabilities – the platform is suitable for managing complex mathematical operations and workflows based on interoperable logic.
- Flexibility in simulation modeling - Unlike other programming languages that require extensive manual coding, LabVIEW allows for rapid virtual prototyping and data visualization.

4.7.2. Definition of parameters

For an accurate analysis of the driving cycle, the selection of the initial parameters is important in ensuring a realistic simulation. Several essential parameters were chosen based on biomechanical relevance, practical applicability, and adaptability to different individuals. Primary parameters used in this simulation include gait cycle trajectory, body weight, sole size, sole contact areas, and plantar pressure distribution.

A) Travel trajectory

The displacement trajectory represents the line of displacement of the projection on the ground of the general body center of mass, on a predetermined route and constitutes an indicator in the analysis of the directional stability of locomotion. In the simulation, the walking cycle route has a length of 5 m, being traveled, on average, in about 8 consecutive steps, each with an estimated average length of 60 cm. The simulation renders this trajectory using two reference lines:[211]

B) Body weight

Body weight is an anthropometric factor, significantly influencing the distribution of plantar pressure and the load of osteo-articular structures. To ensure the applicability of the simulation to a wide variety of anthropometric profiles, body weight is introduced as an adjustable parameter, ranging from 30 kg to 160 kg. This flexibility allows the investigation of how different body masses affect the trajectory of the gait cycle, plantar contact pressure and postural stability.[212]

Under real-world conditions, increased body weight causes local increases in plantar pressure in the region of the cockpit, tarsians, and metatarsals, which can contribute to instability.

C) Size of the planting area – Represented by coding the dimensional number of the shoe

The size of the plantar surface is an important parameter in gait analysis, influencing both the distribution of plantar pressure and stability during support. Within the developed simulation application, this variable is modeled by an adjustable range corresponding to the numbers in the European standard (EU 30–48), which allows the plantar surface to be adapted to a wide range of users, from children to adults.

D) Ametropic eyes (strabismus, AMD, cataracts, glaucoma, blindness)

To simulate walking deviations in the real environment, six different eye conditions with ametropia were modeled:

- Normal vision
- Strabism
- Age-related macular degeneration (AMD/AMD)
- Cataracts
- Glaucoma
- Blind

E) Plantar contact areas in gait simulation

In the gait cycle simulation, the plantar surface is segmented into four functional regions, according to the literature to faithfully reflect the actual sequence of contact and force transfer during walking. This division is essential for the analysis of pressure distribution and dynamic stability under normal visual conditions and in the presence of visual impairments, respectively. [214]

- Heel area
- Middle Area
- Metatarsal area
- Tarsal area (toes)

Each of these areas faces different degrees of pressure, influenced by weight distribution, walking speed and visual conditions.

F) Planting pressure distribution

Plantar pressure is an important biomechanical indicator in gait cycle analysis, reflecting how forces are applied to the sole during walking. The simulation models the pressure distribution on the plantar surface based on body weight. A reference plantar area of 12455 mm² was chosen, representing an average adult leg (Table no. 6)

In this simulation, the pressure is classified into five levels for visualization (in relation to body weight and plantar surface):

- Green – Normal pressure – Reference value
- Yellow – 1.5x Normal Pressure – Reference Value
- Orange – 2.5 x Normal Pressure – Reference Value
- Red – 2.75 x Normal Pressure – Reference Value
- Gray – No pressure detected in that area

A virtual LED entity based on Boolean logic is used, which is a software element that simulates the behavior of a physical LED, and its state (on/off) is determined by the evaluation of a logical expression (Boolean).

Fig. 3 Simulation of the plantar footprint of the left leg divided into the 4 zones with all 5 types of virtual LED entities

4.7.3. Analysis of deviations from the trajectory and planting pressure

In order to understand the effects of visual impairments on the gait eyelash mechanism, the simulator developed in LabVIEW provides both visual results (graph) and numerical values regarding the gait trajectory and plantar pressure distribution.

A) Calculation of deviations

In the simulation, the deviations of the walking cycle are calculated based on two main quantities:

Stride length deviation (Ox): The difference in stride length compared to its size in the ideal trajectory.

Lateral deviation (Oy): The size of the lateral deviation of the simulated trajectory in visual impairments from the ideal trajectory.

Overall, this profile of plantar pressure deviations highlights the complex biomechanical changes that occur in the gait of visually impaired people, emphasizing the need to understand and correct these patterns in rehabilitation programs.

B) Reference plantar pressure vs. simulated plantar pressure

The simulation performed in LabView evaluates the plantar pressure by comparing the 2 categories of calculated plantar pressures:

- Reference pressure distribution: The expected pressure applied to each of the four contact zones of the sole under normal walking conditions.

- Simulated pressure distribution: Altered pressure values recorded during the simulation for various visual impairments.

By comparing reference data and simulated data, it is possible to observe how trajectory deviations influence the pressure distribution in different regions of the sole of the foot.

The following relevant aspects are noted:

- Metatarsal area: the simulated pressure is approximately 7% higher than baseline (12.61 N/cm² vs. 11.81 N/cm²), indicating a previous overload trend in simulated gait.
- Median area: the simulated pressure is approximately 12% lower than the reference (0.52 N/cm² versus 0.59 N/cm²), suggesting reduced support on this area, possibly due to postural adaptations.
- Phalangeal area: the simulated pressure is close to the reference point higher by about 4% (9.83 N/cm² versus 9.45 N/cm²), indicating a relatively normal involvement of the anterior area in propulsion, despite visual impairments.
- Heel area: the difference is significant, reaching values increased by up to 80% (simulated pressure of 15.1 N/cm² compared to 8.37 N/cm²). This reflects a strong compensatory strategy, in which the simulated subject tends to maintain a prolonged and accentuated support on the heel for stabilization.

These results highlight how visual impairments affect not only gait trajectory but also plantar support dynamics, leading to biomechanical adaptations that can have important implications on gait balance and efficiency.

C. Graphical evaluation of simulated plantar pressure deviations

Differences between reference and simulated plantar pressure occur due to visual impairments.

The simulation of cataract walking reveals an average deviation of 22.53 mm on the OX and 12.84 mm on the OY. Although the deviations are lower than in DMLV, the trajectory retains an oscillatory trend, associated with a reduction in overall visual clarity. Walking is characterized by shorter steps and frequent trajectory adjustments.

In glaucoma, the longitudinal deviation reaches 69.5 mm, and the lateral deviation reaches 89.85 mm. Loss of peripheral vision affects the ability to maintain the direction of travel, resulting in a fluctuating route, with late corrections and frequent deviations from the ideal trajectory.

Total blindness generates the largest deviations: 102.02 mm on the OX and 119.39 mm on the OY. The complete lack of visual input determines an irregular trajectory, strongly dependent on compensatory mechanisms (proprioception, hearing). The trajectory is unstable, with unpredictable direction and frequent deviations from the optimal travel vector.

Visual analysis of these trajectories confirms that the simulator realistically reflects the effects of various visual impairments on gait stability. The severity and type of impairment clearly influence both the amplitude and frequency of lateral deviations, providing visual support for understanding the compensation mechanisms used by people with impaired vision.

In conclusion, the visual analysis of plantar pressure distribution demonstrates the impact of visual impairments on the mechanics of the gait cycle. As the severity of the visual deficit increases, the support pattern becomes increasingly asymmetrical, with tendencies of overloading certain plantar areas and a decrease in propulsion efficiency. These observations support the validity of the developed simulator and provide useful insights for understanding the compensatory strategies adopted by people with impaired vision.

4.8. Conclusions

The results obtained by simulating the walking cycle in conditions of visual impairment of the subject show that these deficiencies have a significant impact on the biomechanics of gait. Both trajectory deviations and changes in plantar pressure distribution obtained from the simulation reflect complex compensatory mechanisms that can be adopted to maintain balance and orientation during movement.

Increases in lateral and longitudinal deviations of the walking cycle trajectory are observed, accompanied by accentuated instability in the direction of travel, as the severity of visual impairment increases. At the same time, there is an increasingly pronounced asymmetry of gait, observable both in the trajectory and in the differences between the length of the stride for the left leg and for the right leg.

Regarding the distribution of plantar pressure, the analysis reveals in the case of the analyzed visual impairments a tendency of overload of the compensatory plantar surface in the heel area, associated with a reduction in support on the median area and an increased variability in the load on the contact surface of the metatarsals and phalanges. These changes suggest the approach of motor adaptation strategies aimed at compensating for directional instability and uncertainty in postural control.

In conclusion, the simulation confirms that visual impairments cause complex biomechanical changes in the gait cycle, with important implications for balance and travel safety. The developed simulation tool allows a detailed analysis of these phenomena and can constitute a useful basis for the design of personalized interventions in gait rehabilitation in visually impaired people.

Chapter 5

Design of the experimental system

The device developed addresses these two main challenges: accessibility and behavioral comfort. By creating an efficient, cost-effective prototype capable of assisting users in detecting obstacles in real time, the goal was to promote safer and more comfortable walking experiences for the visually impaired. Particular attention has been paid to the behavioral aspect of walking, focusing not only on avoiding obstacles, but also on how confident and natural the user feels during movement.

5.1. Design of the experimental system

The device was intentionally designed to be mounted on the trunk for several key reasons:

- Natural orientation towards obstacles - The chest is oriented forward, in accordance with the direction of travel of the user
- Stability of sensor readings - Compared to handheld or head-mounted systems, the chest provides a relatively stable platform while walking
- Hands-free operation – People with visual impairments frequently rely on cane or guide dogs. A chest-mounted system avoids hand occupation or interference with mobility aids, while maintaining independence and comfort.
- Body-centered awareness - Mounting the torso system provides intuitive feedback. Obstacle warnings correspond spatially to the user's body, enhancing perception and reaction

- Avoiding obstruction or fatigue – Head- Head- or hand-mounted devices can cause discomfort or fatigue over time.

To simulate the central visual perception of a person, the servo motor was programmed to perform an oscillatory motion at an angle of 60 degrees, corresponding to the binocular central field of vision. This angle covers approximately ±30° from the visual axis, representing the area where obstacle detection is most relevant for directional orientation and driving decisions.

5.2. Construction of the experimental system

The device integrates a number of carefully selected electrical and electronic components that balance cost-effectiveness with functional reliability: Infrared distance sensor (Sharp GP2Y0A02YK0F), Arduino Uno board, Buzzer Module, SG90 Micro Servo Motor (90° rotation), Electrolytic capacitor, USB cable (30 cm).

The device uses four main proximity zones, each associated with a certain sound intensity:

- 20–50 cm: Very loud audible sound (1000Kz) – immediate obstacle, critical alert.
- 51–70 cm: Loud sound (800Hz) – obstacle detected at a moderate distance; caution is advised.
- 71–100 cm: Medium sound (600Hz) – obstacle detected at a safe distance.
- 101–149 cm: Low sound (400Hz) – early warning.
- ≥150 cm: No sound – no obstacles detected in the range.

This system provides intuitive and progressive feedback, allowing users to make timely decisions and adjust their ride accordingly.

Programming the operating algorithm

The Arduino Code implements an integrated obstacle detection system using a SHARP GP2Y0A02YK0F distance sensor, piezoelectric buzzer, and servo motor. The goal is to assess the distance to an object in real time and generate an auditory and mechanical response depending on its positioning.

The SHARP sensor produces an inverse analog signal proportional to the detected distance.

5.3. Design of the procedure for use

The procedure for using the Sonar device for obstacle detection is aimed at visually impaired people who move in outdoor environments. The device, worn on the chest with the help of a harness or vest, has the role of warning the user about the presence of obstacles in front of him, within the range of the sensor, respecting ergonomic principles to ensure comfort.

5.4. Storage and maintenance method

To ensure optimal and long-lasting operation of the Sonar device, it is essential that it is properly maintained and stored in proper conditions. After each use, the device should be turned off, then cleaned carefully, using a dry or slightly damp cloth, without applying liquids directly to the electronic components. In particular, the sensor surface must be kept clean, as the accumulation of dust or dirt can affect the accuracy of measurements and, consequently, the effectiveness of audible warnings.

5.5. Conclusions

The development of the sonar device dedicated to visually impaired people aimed to integrate a set of technical and ergonomic solutions that meet the real needs of mobility, safety and behavioral comfort. The

analysis of the project allows the formulation of the following conclusions, grouped into three essential dimensions:
Design: The device, worn on the chest and supported by an ergonomic harness, provides stability, comfort and effective protection of the components.
Functionality: The system detects obstacles between 20–150 cm and provides differentiated auditory feedback, adapted to distance and direction.
Usability: The intuitive hearing interface and minimal maintenance make the device suitable for daily use and quick testing.

Chapter 6.

Comparison and integration of the Sonar system with visual aid structures

In order to analyze the effectiveness of the Sonar system, created within this research, it was tested and compared with 3 other visual aid devices existing in the laboratory. These systems are:

1. Baton type system with distance sensors and warning
2. Cuff type system with ultrasonic sensors and warning
3. Bimodular three-way type system and audible warning

6.1. Stick system

The cane in the laboratory is a visual aid device intended for people with blindness or poor vision, which aims to improve the ability to move and the psychological comfort associated with visual limitation. [212]

6.2. Cuff system

A portable cuff device equipped with an ultrasonic sensor and auditory warning, developed and made available by the Laboratory of Applied Optometry of the Transylvania University of Brașov, was also compared. This system aims to detect obstacles in front of the user at the level of the trunk and transmits an audible signal of varying intensity depending on the distance. The device was used in its standard form in order to compare its effectiveness with other tested solutions, including the original device proposed in this paper. [213]

6.3. Three-way system

It was conceived in 2018 for the author's dissertation thesis within the study program "Mechatronic Systems for Industry and Medicine" at the Transilvania University of Brașov. [215]
The system has been designed to be as easy to use and carry as possible because it will be attached to the subject at two essential points: at the waist by a strap and on the subject's leg, above the knee by a hook and loop fastening system.

6.4. Comparison

In order to carry out a rigorous comparative analysis of the four visual assistance devices – cane with sensors, portable cuff, three-directional system and the sonar device created within this work – it was necessary to define a set of evaluation criteria, structured according to their nature: objective or subjective, quantitative or qualitative, general or personalized.
The portable cuff, although simple in structure, offers a highly practical solution for quick detection of frontal obstacles. High portability and low cost are its essential advantages, but the occupation of one hand

and the small detection area make it more suitable for limited uses or for complementing other visual aid methods.

The three-way device provides the most complete spatial awareness, by detecting obstacles at multiple levels of the body. Differentiated audible feedback helps the user identify the exact position of the obstacle, but the complexity of mounting and increased visibility of the components can reduce the degree of acceptance in daily use.

The Sonar device created within this work brings a successful balance between functionality, comfort and accessibility. The chest mount provides intuitive feedback, hands remain free, and the dynamic sensing system, achieved by rotating the sensor, effectively covers the front riding area. Its main limitation is the lack of detection of obstacles below the torso, but this can be compensated for by the combined use of a white cane.

6.5. Conclusions

In conclusion, the comparative analysis of the four visual assistance devices highlighted multiple technical and functional particularities, revealing that there is no universally optimal solution, but rather complementary approaches, adaptable to various user profiles and travel scenarios.

Chapter 7.

Test protocol and experimental procedure

The tests for the evaluation of the sonar device worn on the chest were carried out in a specialized laboratory of the Research and Development Institute of the Transylvania University of Brașov, in a controlled interior space, intended for experimental and biomechanical analysis activities. The choice of this space was intended to ensure a safe environment, with constant ambient variables and the possibility of monitoring the user's behavior while driving.

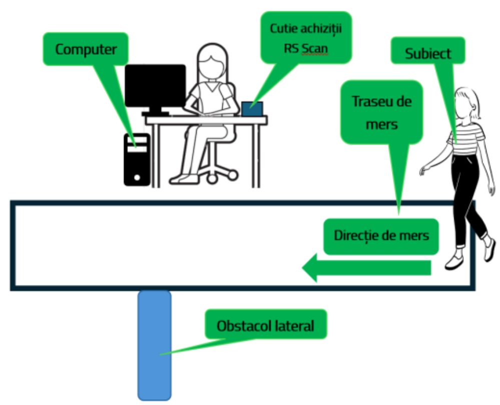

Fig. 4 Diagram of the space used for the experiment

The space allowed direct visual monitoring of the participants by the researcher, and the route was traveled individually, without guided assistance.

7.1 Preliminary testing: individual assessment of visual impairments

Before conducting the main group study, an initial self-assessment phase was carried out to better understand the impact of various simulated visual impairments on gait and plantar pressure.

7.1.1 Simulated Visual Impairments and Test Setup

Preliminary testing included five gait conditions: normal vision and four simulated visual impairments — glaucoma, cataracts, macular degeneration, and blindness. Each condition was tested using simulation glasses that reproduced the visual characteristics specific to each pathology. The simulation glasses limited visual acuity in different ways: [139]

- Glaucoma: constriction of the peripheral field (tunnel vision)
- Cataracts: blurred and low-contrast vision

- Macular degeneration: loss of central vision with preserved periphery
- Blindness: total occlusion of vision

The topic involved in the preliminary testing phase has been coded as Topic 1 in this phase. The participant is a 30-year-old woman with professional experience in optometry.

Anthropometric measurements included body weight of 50 kilograms, height of 160 cm, and shoe size 36. These dimensions placed the subject in the 25th percentile for adult women's height and weight, indicating below-average body height, which was taken into account when analyzing gait patterns and plantar pressure distribution. The subject participated in all walking attempts for the preliminary test phase, both with and without shoes and in each of the four simulated conditions of visual impairment.

7.1.2 Data collection and interpretation

In this phase, only RSScan pressure data and running parameters were collected. These included pitch length, cadence, pressure distribution, and symmetry. No personal observations or subjective impressions were recorded. The intention was to use objective data to assess which visually impaired simulations had the strongest measurable effect on gait patterns.

7.1.3. Preliminary results

For all graphics in normal walking without slippers (MNFP) the color code is:

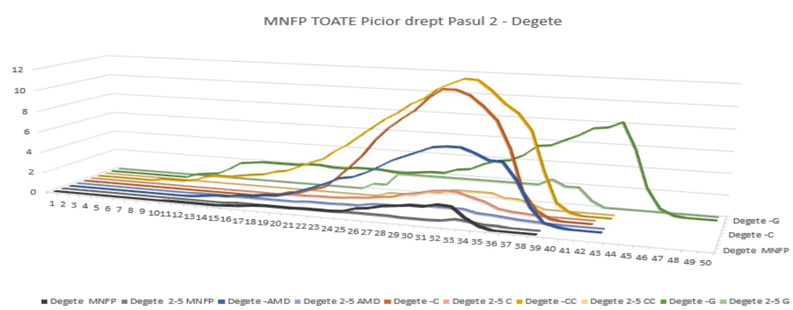

Fig. 5 Measurements taken at the level of the toes in normal walking without shoes, right foot, gray gradient for normal walking, blue gradient for macular degeneration simulation, orange gradient for cataract simulation, yellow gradient for blindness simulation and green gradient for glaucoma simulation

- For normal walking is a gradient of Gray
- For normal walking with Macular Degeneration (AMD) simulation a gradient of Blue
- For normal walking with Cataract simulation (C) a gradient of Orange
- For normal walking with simulation of Blindness (CC) a gradient of Yellow
- For normal walking with Glaucoma simulation (G) a gradient of Green

In the graph in fig.5 on the Y axis we have the pressure applied on the thumb (under the name of Fingers) and on the other 4 toes (under the name of Fingers 2-5), and on the X axis the duration of the step.

It can be seen how the duration of the step and the pressures are lower on the gray color that belongs to a measurement without any obstruction of vision, from which we deduce that the most comfortable measurement is the one with good vision. The graph outlines the idea that when a person has any kind of visual impairment, the pressure applied to the toes will be much greater than for a person with normal vision.

The data presented in the graph in Fig. 6 show us that the greatest pressures occur when the person being measured simulates either an advanced cataract (Orange) or blindness (Yellow), and the duration of the step is the longest is when the person simulates Glaucoma (Green). The graphical representation in Fig.6 highlights the discomfort created by any of the 4 simulated visual problems in relation to free walking without impairments. The information presented in the graph highlights that the person makes contact with the plate in the finger area for a longer period of time when they are not sure of the step they are taking.

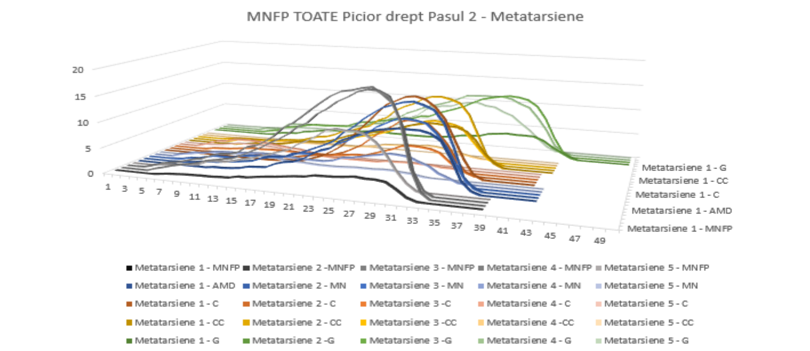

Fig. 6 Measurements taken at the level of the metatarsals in normal walking without shoes, right foot, gray gradient for normal walking, blue gradient for macular degeneration simulation, orange gradient for cataract simulation, yellow gradient for blindness simulation and green gradient for glaucoma simulation

In the graph in fig. 6 on the Y axis we have the pressure applied on the metatarsals numbered from 1 to 5 for each measurement, and on the X axis the duration of the step. The graph in Fig.6 highlights that although the forces are greater on the metatarsals, the gait is shorter, which means a heavy and short step in normal walking, while walking with different simulated pathologies is in many cases just as pressed, but longer, proving insecurity.

7.1.4. Conclusions from the preliminary test

The preliminary testing carried out on a single subject provided important, objective/subjective information on the influence of visual impairment simulations on the biomechanical parameters of gait. The results obtained showed significant changes in both the plantar pressure distribution and the duration of the step, depending on the type of simulated deficiency.

The analysis of the pressure applied to the fingers and metatarsals showed a clear trend of increasing plantar pressure values under conditions of simulation of visual impairments, based on cognitive understanding, and making comparisons with walking under normal conditions (without visual impairments). A prolongation of the duration of contact with the ground was also observed in the case of the simulation with blindness and glaucoma, indicating a cautious adaptation of the subject in the absence of relevant visual information.

7.2. Experimental testing: assessment of biomechanical behavior during the gait cycle using visual aids per sample of subjects

7.2.1. Experimental methodology

The examination of the locomotor behavior of people with simulated visual impairment was carried out under controlled laboratory conditions, following a complex, phased procedure, designed to ensure the consistency, reproducibility and relevance of the data obtained. The study was carried out in a specially designed space within the Research Institute of Transylvania University in Brașov, which provided the necessary infrastructure to safely conduct the experiment and to obtain accurate biomechanical measurements.

A. Evaluation of the experimental space

The tests were carried out in a research laboratory, in a secure environment, with constant lighting and a uniform floor. The walking route was built straight, with a length of 3 meters, being visibly delimited at ground level.

In order to ensure the repeatability and accuracy of the measurements, compliance with the initial environmental conditions was verified at the beginning of each experimental session, in accordance with the parameters set out in the methodology.

The following variables have been monitored and kept within controlled limits:

- Average ambient temperature 21o-/+ 1o C
- Relative humidity between 40–60%
- Atmospheric pressure around 760 mmHg
- Lack of external noises or vibrations that could influence participants' gait or concentration
- Natural lighting in the work area 200-300 lx.

B. Choice of tools

The choice of instruments was made according to the objectives of the study, with the aim of ensuring accurate and comparable measurements between different driving conditions.

RSScan Platform

Software-ul Footscan 7 Gait

Glaucoma and cataract simulation glasses

The four visual assistive devices:

- Cane with sensors -
- Portable cuff -
- Three-way system
- Sonar experimental -

Chestionarul Tinetti Gait

Subjective perception questionnaire

Question 1: How much does visual dysfunction affect you?

Question 2: How much does visual function affect you in mobility?

Question 3: Which part of the body was most requested during the recordings?

Question 4: Which device was the easiest to mount?

Question 5: What was the heaviest device (physically)?

Question 6: Give each device a rating for comfort, safety, and stability in use.

Question 7: What was the device that had the fastest response in encountering an obstacle?

Question 8: Make a classification from all points of view, taking into account all the parameters.

C. Structure of the experimental procedure

The test protocol consisted of five major stages, carried out in a fixed order, identical for all participants, to ensure comparability of the results. Each stage included a set number of routes along the route, in the following sequence:

- Walking with normal vision (control measurement) – 3 journeys of the route without visual aids.
- Glaucoma simulation without visual aids – 3 runs with glasses simulating glaucoma-like dysfunction.
- Glaucoma simulation with visual aid devices (4 devices tested) -3 runs for each device (12 runs).
- Cataract simulation without devices – 3 trips with glasses that simulate cataract-type dysfunction.
- Cataract simulation with devices – 4 devices tested, 3 runs for each device (12 runs).

This experiment aims to determine the behavior of subjects with visual dysfunction during a gait cycle. In total, each participant completed **33 times** of the route, distributed on all experimental conditions.

7.2.2. Sample selection and training of participants

The sample of this study included 25 participants, aged 18 to 69 years, body weights between 50 and 110 kg, heights between 148 and 190 cm, and shoe numbers between 36 and 44, to cover a wide range of demographic and anthropometric characteristics. This diversity ensures a better representativeness of the results and allows the influence of individual variations on gait to be analysed. The sample size is consistent with the literature, where similar studies have used comparable numbers of participants: Négyesi et al. (2025) tested 24 participants, Marigold and Patla (2008) included 20 participants, and Jansen et al. (2011) worked with 12 participants. [227] [224] [225]

Experimental anamnesis assessment of participants

Prior to the initiation of any experimental activity, an anamnesis assessment of the participants included in the study was performed. This stage had the role of ensuring a control of the individual variables and eliminating potential methodological confusions.

Adults with no history of locomotor or neurological disorders or ophthalmological surgeries were selected. Participants did not exhibit balance disorders, postural instability, or cognitive impairments that could have influenced the ability to understand instructions or cooperate during testing.

Participant training

After the preliminary preparation (verification of environmental conditions and calibration of devices) of the space and test instruments, the participants went through the training stage, in which they became familiar with the procedures for creating a safe test framework. This phase aimed to ensure an effective and affective understanding of how to use the visual impairment simulation glasses (glaucoma and cataracts) and sensory assistive devices used in the study.

Sample of subjects

Participation in the study was voluntary, and each participant previously signed an informed consent and personal data protection agreement (GDPR), according to the regulations in force.

The participants come from various occupational backgrounds (optometrist, design engineer, PC operator, counselor, IT-ist, etc.), which provided a diversity of functional profiles useful in the practical validation of the results. Anthropometric parameters such as average height 1.72 and average body weight 80.3kg were recorded for each subject, the data being subsequently correlated with biomechanical results for further analysis. All participants showed good functional vision under normal conditions, some cases requiring optical corrections (eyeglasses), which was treated as a controlled factor in the analysis.

In order to characterize the context in which the study was conducted as fully as possible, the individual profiles of the nine participants are presented below. This includes demographic, anthropometric information and observations related to participation in testing, with the aim of highlighting the diversity of behaviors according to personal variables.

The sample of participants included 25 subjects aged 18 to 69 years, with a mean age of 41.2 years. The heterogeneous age distribution, illustrated in the figure above, allowed the analysis of locomotor behavior over a wide age spectrum, including both young adults and middle-aged or elderly people.

The experimental sample consisted of 25 participants, of which 13 were male and 12 were female. The relatively balanced gender distribution provides a balanced framework for analyzing potential biomechanical differences between male and female gait.

The majority of participants (56%) had refractive errors, all corrected with glasses, so they did not influence the measurements. The remaining 44% did not need optical correction, having a functional visual acuity of 1/1. This distribution ensures a balance of visual function for the subjects and allows an objective analysis of locomotor behavior.

The weight of the participants ranged from 50 kg to 110 kg, with an average of 78.6 kg. This wide range contributes to the diversity of biomechanical profiles, influencing the distribution of plantar pressures, balance and effort during walking. Body weight is an important biomechanical factor, directly affecting the load on the joints and determining possible adaptations in the locomotor model.

The height of the participants was included as a basic parameter in the analysis of the anthropometric profile, the recorded values varying between 148 cm and 190 cm, with an average of 171.2 cm. This variable significantly influences gait biomechanics, affecting stride length, center of gravity projection position, range of motion, and overall balance. As mentioned in the literature, the diversity of the heights of the subjects in the sample contributes to the practical extension of the study, allowing the identification of possible correlations between height and locomotor response in different visual conditions or with assistive devices. [228]

The size of the participants' shoes ranged from 36 to 44 (according to the EU standard), including intermediate values such as 39 1/3 or 41 1/3. This anthropometric variable is relevant in the context of gait analysis, as the size of the sole can influence the mode of contact with the ground, the distribution of weight force and stability during movement.

The percentile was calculated based on the weight-to-height ratio, providing a relevant reference to the general population. In the analyzed sample, percentile values vary between 25 and 97.5, reflecting significant morphological diversity.

7.2.3. Measurements

7.2.3.1. Verification of environmental conditions and calibration of equipment

To ensure the repeatability and accuracy of the measurements, at the beginning of each experimental session, the environmental conditions were rigorously checked, in accordance with the parameters established in the methodology.

The following variables were monitored and kept within controlled limits: Average ambient temperature, relative humidity between 40–60%, atmospheric pressure around 760 mmHg, lack of external noise or vibrations that could influence the participants' gait or concentration

7.2.3.2. Initial evaluation of participants

Before initiating any experimental activity, a careful evaluation of the participants included in the study was carried out. This stage was intended to ensure a rigorous control of individual variables and to eliminate potential methodological confusions.

7.2.3.3. Training of participants

After establishing the baseline and verifying the test environment, the participants entered the training phase, which played a key role in familiarizing them with the procedures and creating a safe testing framework.

The simulation of visual impairments was carried out by means of specially adapted glasses, which reproduced narrowed visual fields (for glaucoma) or blurred and diffuse vision (for cataracts). Participants had the opportunity to experience walking with these glasses on a separate route, without measurements, to accommodate the sensory challenges associated with each type of simulation.

7.2.3.4. Conduct of measurements

The central stage of the study was represented by the actual performance of the measurements, which took place in a controlled environment, with constant parameters. The measurements were carried out in a single session per participant, with breaks allowed as needed, to prevent fatigue or loss of concentration.

The tests were carried out in two major methodological positions:

Position 1 – Assessment with normal vision: Participants walked the route without any type of visual simulation or assistive device. This was the control stage.

Position 2 – Simulated Visual Impairment Assessment: Participants walked the route wearing the glaucoma and cataract simulation glasses, both without devices and with each of the four devices.

Each participant was tested under the following conditions:

- Glaucoma simulation (X) – walking without a device (3 repetitions)
- Glaucoma simulation (X) – walking with each of the four devices (A,B,C,D) (4 conditions × 3 repetitions = 12 measurements)
- Cataract simulation (Y) – walking without device (3 repetitions)
- Cataract simulation (Y) – walking with each of the four devices (A,B,C,D) (4 conditions × 3 repetitions = 12 measurements)

In total, each participant achieved:

3 (control) + 3 (glaucoma without device) + 12 (glaucoma with devices) + 3 (cataract without device) + 12 (cataract with devices) = 33 measurements.

7.2.4. Results and discussions

7.2.4.1. Results of biomechanical measurements

A. Step symmetry

Between the steps performed with the left and right foot, symmetry is an essential indicator in the evaluation of balance and stability in walking. This biomechanical component provides relevant information about how visual impairments or technological interventions can influence motor coordination.

In the first stage of the study, participants were evaluated under normal gait (NM) conditions, without visual interference or the use of assistive technologies. Step asymmetry was 0% for all subjects, indicating an equal number of steps performed with each foot. This result highlights effective postural control under conditions of full functional vision and provides a solid baseline for further comparisons.

The simulated cataract increased the average gait asymmetry to 13.07%, indicating a clear impairment of balance.

The simulated glaucoma generated an average asymmetry of 12.00%, also significantly affecting walking compared to normal.

The sensor stick reduced asymmetry to 8.34% in cataracts, but recorded 15.12% in glaucoma.

The cuff had a moderate efficiency in cataracts (9.60%), but low in glaucoma (16.57%).

The three-way device increased asymmetry in cataracts to 14.67% and kept it high in glaucoma (13.60%).

Sonar was the most effective, with asymmetries of only 7.20% in cataracts and 5.60% in glaucoma.

B. Contact time of the plantar surface on the RSScan plate

The impact of four visual aid devices (cane, cuff, three-directional device and sonar) on the crossing time of a short route, recorded with the help of the RSScan board, under cataract simulation conditions, was evaluated. Time, expressed in seconds, reflects the behavioral efficiency of walking in the presence of the deficiency and the associated device.

The results showed a superior performance of the Cat + Sonar combination, which was associated with the shortest travel time for 10 of the 25 subjects. The high frequency suggests good compatibility between the acoustic feedback provided by the sonar and the needs for orientation in blurred vision conditions.

- The S20 subject recorded a +20.5% deviation with sonar, and the S7 achieved a 0% deviation, even indicating a similar efficiency to normal walking.
- Subjects S3, S4, S5, S6, S8, S13, S15 and S25 also preferred sonar, with deviations between 0% and +27%.
- Cat + Tridirectional was the device of choice for 7 participants, including the S2, with a minimal deviation of only +3.8%.
- The Cat + Cuff was optimal for 4 participants, including S9, which had a reduced deviation of +5%.
- Cat + Cane was preferred by 4 other participants, but with greater deviations.

In the glaucoma simulation, the effectiveness of the devices was also evaluated by relating the crossing time to normal walking. The distribution of the results was more balanced than in the case of cataracts:

- Gl + Sonar was the optimal choice for 8 participants, including S1, S3, S4, S7, S10, S14, S22 and S24, with deviations between 0% and +50%.
- The Gl + cuff gave the best results for 7 subjects, including S2 (+8%) and S8 (0%), indicating a very good response to tactile signals.

- GI + Tridirectional was also the device of choice for 7 subjects, such as S5, S6, S9, S13, S16, S17 and S23, with deviations between 0% and +27%.
- GI + Cane was preferred by only 3 participants (e.g. S12, S19 and S21), with modest results compared to the other options.

C. Average strength developed at the plantar level

The analysis of the force applied to the left leg in cataract walking shows an average decrease of 1.36% compared to normal walking, with large variations between participants. Some saw significant decreases in strength, while others compensated with increases.

The simulated cataract reduced plantar strength in most participants, with 14 out of 25 walking more easily than in normal walking.

Glaucoma affected walking confidence more strongly, with 17 participants significantly reducing the force of contact with the ground.

The cane maintained an average strength close to normal (decrease of only 0.47%), but with large variations between participants.

The cuff produced an average 4.04% decrease in strength, but provided a more balanced and predictable effect.

The three-way device reduced the force by 2.10%, but had large fluctuations depending on the user.

The sonar increased the average strength by 3.74%, being effective in cataracts, but less effective in glaucoma, where the lack of peripheral vision made it difficult to orient oneself.

D. Projection of center of pressure trajectory

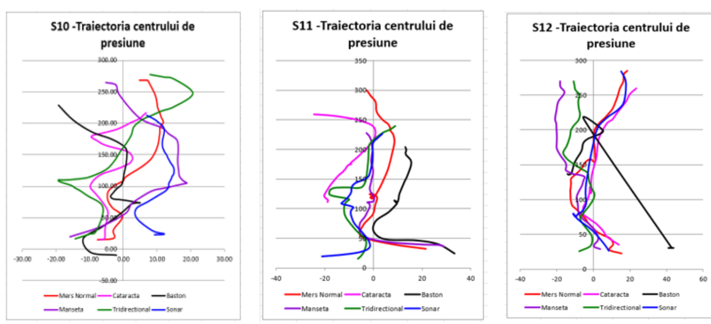

Fig. 7 The trajectories of the pressure centers in normal walking, in cataract simulation and in the use of the 4 visual aid devices with cataract simulation.

The analysis of the trajectories of the center of pressure revealed significant differences between walking under normal conditions and that performed under the influence of the simulation of a cataract-type visual condition. Based on visual observations and direct comparison of the routes, the participants were classified into three categories, depending on the degree of deviation of the trajectory from the normal gait: large, medium and small deviations.

Participant S10 had a clear, vertical and coherent normal gait trajectory (red line) with a slight deviation to the right at the top. The cataract simulation (pink) caused a visible deviation to the left, with a wider trajectory, a sign of an uncertain visual adaptation. With the stick (black), the gait became unstable, and the trajectory curved significantly to the left, indicating a change in strategy on the move. The cuff (purple) contributed to a shorter but more centered trajectory, suggesting a more cautious movement. The route with the three-way (green) was relatively balanced in the middle area, but with some lateral deviations. In contrast, with sonar (blue line), the trajectory was more controlled and well aligned in the direction of travel, suggesting a more efficient orientation.

Participant S11 showed a relatively stable and well-defined normal (red) trajectory with a slightly oblique gait to the left. Under the effect of the cataract (pink), the trajectory was significantly distorted, with ample oscillations and lateral displacement. With the (black) cane, the route became very winding, with loops and turns, which reflects an obvious difficulty in maintaining the direction. The use of the cuff (purple) brought more stability, the trajectory being more compact and closer to the vertical line. The three-way (green) allowed for a balanced trajectory, while the sonar (blue) produced a clear and parallel path to the normal one, suggesting a good adaptation in orientation and balance.

Participant S12 followed a coherent vertical route under normal conditions (red line), with slight oscillations at the top. Under cataract (pink), the trajectory became chaotic, with many changes in direction and instability. The stick (black) generated a completely different trajectory, with a sharp deviation and an almost straight-line path to the side, indicating a lack of directional control. With the cuff (purple), the trajectory was better controlled, even if slightly wavy. The three-way (green) produced a more centered trajectory, but with oscillations in the lower area, and the sonar (blue) allowed a trajectory close to normal, suggesting better compensation for visual impairment.

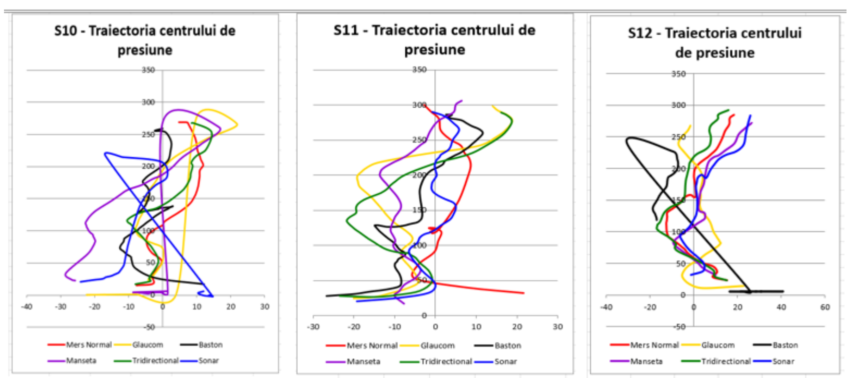

Fig. 8 Trajectories of pressure centers in normal walking, in glaucoma simulation and in the use of the 4 visual aid devices with glaucoma simulation

For the S10 subject, the trajectory of the center of pressure in normal (red) gait is well centered, with a balanced and symmetrical line. With the onset of glaucoma (yellow), the route becomes marked by pronounced lateral deviations and a lack of coherence in direction, which indicates poor visual control of steps. The stick (black) does not bring an effective correction, but even accentuates the oscillations, especially in the middle part of the trajectory. In contrast, the cuff (purple) and three-way (green) contribute to a clear stabilization of the gait, and the sonar (blue) provides a coherent and close trajectory to the initial one, restoring the direction and balance of the gait.

In the case of subject S11, normal gait (red) has an orderly and symmetrical trajectory. Glaucoma (yellow) significantly disrupts the route, creating a contorted and extended lateral line, a sign of loss of confidence in orientation in space. The baton (black) makes the situation worse, generating a fragmented and unpredictable trajectory. On the contrary, the cuff (purple) ensures a centralized and progressive route, the three-way (green) maintains good continuity, and the sonar (blue) offers one of the closest trajectories to normal walking, proving high functional efficiency.

For subject S12, the trajectory in normal walking (red) is long, continuous and relatively well centered. In the presence of glaucoma (yellow), the trajectory becomes chaotic, with interruptions and sudden changes of direction, suggesting a significant impairment of spatial control. The cane (black) produces a strongly deviated and steep trajectory with an unclear direction. The cuff (purple) provides a curved but controlled trajectory, the three-way (green) maintains a relatively stable direction, and the sonar (blue) tends to reconstruct an orderly line, close to the red one, demonstrating practical utility in orientation.

E. Tinetti Score

Maximum score:12. The Tinetti scores obtained by the 25 participants indicate significant variations depending on visual condition and the use of visual aids.

The cataract simulation led to the obvious decrease in the Tinetti scores, with values between 3 and 8. These scores fall predominantly into the red and orange categories, which indicates a significant impairment of walking stability and safety. Participants S1, S2, S5, S6, S10, and S11 recorded the lowest scores (3–5), signaling a severe impact of blurred vision on walking.

In glaucoma, the Tinetti scores were in a slightly higher range (4–8), with predominant presence in the orange zone, indicating moderate but slightly better managed difficulties compared to the cataract simulation.

Of the four devices tested, sonar was associated with the highest Tinetti scores (between 10 and 12) in 17 participants, suggesting superior efficiency in compensating for instability caused by cataracts. The three-way device was associated with good results (over 10) in 7 cases, the cuff in 3 cases, and the cane only in 3 cases. These results indicate a significant variation in performance depending on the device, but also on the individual peculiarities of the gait.

In the case of glaucoma, sonar led to the best scores for a number of 21 participants, indicating consistently good performance. The cuff and the three-way device were each associated with maximum scores in 5 cases and 2 cases respectively, while the cane recorded no score above 10. This distribution model again highlights the efficiency of sonar, but also the fact that the devices do not work uniformly for all users.

F. Deviations from normal walking.

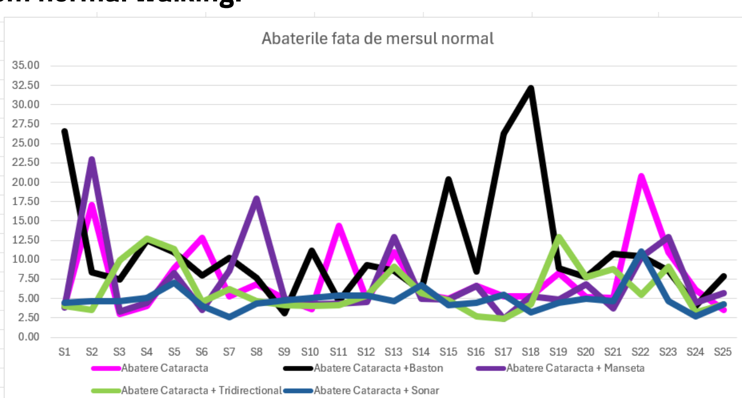

Fig. 9 Average deviations from normal walking under simulated cataract conditions, with and without assistive devices

The cane increased the average deviation to 8.43%, 41.4% more than without the device, worsening the stability of the gait. The cuff generated a deviation of 6.64%, 11.4% higher than in unassisted walking, indicating low efficiency. The three-way device reduced the deviation to 6.14%, 3.8% below the level without the device, providing a slight improvement. Sonar recorded the smallest deviation, of 4.38%, 26.5% lower than in unassisted driving.

Only sonar was able to significantly stabilize cataract gait, reducing lateral oscillations.

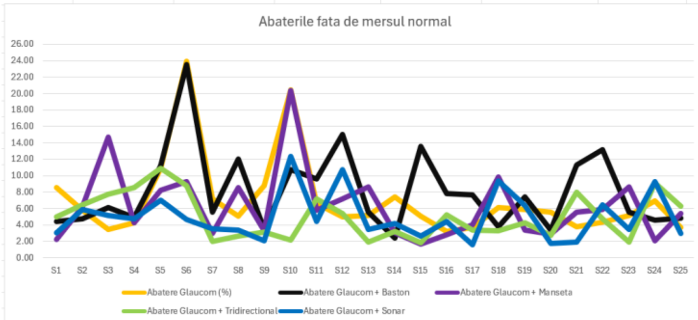

Fig. 10 Average deviations from normal walking under simulated glaucoma conditions, with and without assistive devices

The cane had an average deviation of 8.43%, almost identical to walking without a device (8.66%), without a correction effect. The cuff reduced the deviation to 6.64%, providing a 23.4% improvement over unassisted walking.

The three-way device decreased the lateral deviation to 6.14%, 29.1% less than without the device.

The sonar reduced the deviation to 4.38%, with a significant improvement of 49.4% compared to walking without support.

Of all the devices, only sonar brought a constant and substantial change in gait stability.

7.2.4.2. Results of the questionnaire

Question No. 1: How much does visual dysfunction affect you?

The average score for cataract was 8.88, while the mean for glaucoma was 6.52, suggesting that participants experienced cataracts as a significantly more visually restrictive condition than glaucoma.

Question No. 2: How much does your visual function affect you in mobility?

The average scores for cataracts were 9.12 and for glaucoma was 6.84, indicating that participants perceived cataracts as having a significantly more severe impact on orientation and movement in space.

Question No. 3: Which part of the body was more requested during the recordings?

. In the case of cataract simulation, the most frequently reported areas of solicitation were the head (48%) and torso (24%), followed by the legs (24%), and only one participant (4%) indicated the hands.

In contrast, in the case of the glaucoma simulation, the responses focused even more strongly on the head, which was indicated by 68% of the participants (17 out of 25). Only 16% (4 people) indicated the legs, another 16% (4 people) — the trunk, and the hands were not mentioned at all.

Question No. 4: Which was the EASIEST to mount?

Participants' responses regarding the ease of mounting assistive devices clearly indicate a majority preference for the Sonar device, followed by the cuff, while the three-way device was perceived as the most difficult to install.

The sonar was placed in 1st place (easiest to mount) by 14 participants out of 25 (56%) and in 2nd place by 7 other participants (28%). None of the participants rated it as the most difficult to install

The cuff was also well appreciated, earning 11 mentions for 1st place (44%) and another 11 for 2nd place.

Question 5: What was the heaviest device (physically)? (Higher weight in wear)

Sonar has been perceived as the lightest device constantly. It was ranked 1st (easiest) by 16 participants (64%) and 2nd by 7 other participants. Only one person placed it in 3rd place, and one in 4th place, which indicates an almost unanimous perception of excellent portability.

The cuff took a second place in the positive perception of weight. It was ranked by 8 participants (32%) in first place and by 16 (64%) in 2nd place.

Question No. 6: Rate each device from 1 to 10 for comfort, safety, and stability in use.

The sonar was again the best-rated device, with an average of 8.68 and low standard deviation (~±0.64), indicating a stable and consistently positive perception. Most participants gave it grades between 8 and 10, which highlights a high level of confidence in this device from the perspective of comfort in wearing and perceived safety in use.

The three-way device took the second position in the ranking, with an average of 7.04, but with a moderate standard deviation (~±0.93).

Question 7: What was the device that had the fastest response in encountering an obstacle?

The sonar was, again, the best-rated device, with an average of 9.12 and low standard deviation (~±0.80). Most participants gave it scores between 8 and 10, which indicates a clearly positive overall perception of the speed of the reaction.

The three-way device occupied the second position, with an average of 7.52 and moderate standard deviation (~±0.95).

Question No. 8: Make a classification from all points of view, taking into account all parameters.

Sonar clearly stands out as the most appreciated device in general use. It was placed 1st (best) by 72% of participants (18 out of 25) and 2nd place by the other 28% (7 out of 25).

The cuff occupies the second place in the general classification. It was considered the best device by 6 participants (24%) and ranked 2nd in 6 other cases (24%), but the distribution of ratings was more dispersed compared to Sonar.

7.2.4.3. 7.2.4.3. RELATIONSHIP OF COMFORT IN WALKING - Subjective

Design and implementation of the relationship for determining the state of comfort during the walking cycle

Taking into account the parameters obtained above, their levels of variation, their weight in determining the behavior during the walking cycle, the following relationship was established:

$$SCM_S = 100 * [\alpha * \left(1 - \left|\frac{T_i - T_{ref}}{T_{ref}}\right|\right) + \beta * \left(1 - \left|\frac{F_i - F_{ref}}{F_{ref}}\right|\right) + \delta * \left(\frac{S_i}{100}\right) + \varepsilon * \left(\frac{ST_i}{12}\right) + \theta * (1 - \frac{SSC-1}{3})] \quad (36)$$

SCMS – Walking Comfort Score - Subjective

Ti – contact time with the RSScan board in the analyzed condition (ms).
Tref– the reference contact time in normal walking for the same subject (ms).
Fi – the maximum force developed at the plantar level in the analyzed condition (N).
Fref – the maximum force at the plantar level in normal gait (N).
And – the symmetry of the steps with respect to the normal gait (in %, where 0% perfect symmetry, 100% asymmetry).
STi – Tinetti score for walking, between 0 and 12 points.
SSC – subjective comfort score (1 = easiest, 4 = most difficult).
Ponderi: α- 0.3, β- 0.25, δ- 0.2, ε- 0.15, θ- 0.10.
To define the subjective Walking Comfort Score (SCMS) indicator, five fundamental factors were selected, validated in the literature. Thus, plantar contact time (Ti) is an essential parameter of stability and pace of walking, being used in footwear studies and correlated with the perception of comfort. The maximum force developed at the plantar level (Fi) reflects the way the plantar surface is loaded and is directly associated with the feeling of comfort in the gait cycle. Step symmetry (Si) has a high functional value, as asymmetry is associated with increased effort and risk of imbalance, and the literature confirms the link between gait symmetry and perceived comfort. The Tinetti Clinical Walking Score (STi) is a validated tool for assessing functional stability, widely used in geriatrics and rehabilitation, having a good correlation with gait quality and fall risk. The subjective comfort score (SSC) reflects the individual perception of the effort and comfort of walking; It is evaluated in multiple studies on footwear and musculoskeletal support, [229] [230] [231] [232] [233] confirming [234] the relevance of self-reported components in the global gait analysis. Thus, the weights chosen (α=0.30; β=0.25; δ=0.20; ε=0.15; θ=0.10) reflect the decreasing importance from objective parameters, to scores used in clinical trials and to subjective perception.
Subject S1 recorded a reference score of 100% in normal driving conditions. In the presence of the cataract simulation, its performance dropped to 44%, which indicates a visible impairment of walking comfort. With the use of assistive devices, the performance varied: with the Cane, the score was 39.6%, with the Cuff 58.9%, with the Tridirectional device 49.7%, and with the Sonar 59.2%. In the case of sham glaucoma, the score was 29.7%. The use of devices improved the results as follows: Stick 41.2%, cuff 46.4%, Three-way 50.3%, and Sonar 62.0%.
Subject S2 recorded a reference score of 100% in normal driving conditions. In the presence of the cataract simulation, its performance dropped to 54.5%, which indicates a visible impairment of walking comfort. With the use of assistive devices, the performance varied: with the Cane, the score was 53.5%, with the Cuff 64.7%, with the Tridirectional device 85.4%, and with the Sonar 87.2%. In the case of simulated glaucoma, the score was 64.9%. The use of devices improved the results as follows: Stick 43.2%, Cuff 89.3%, Three-way 59.3%, and Sonar 82.9%.
Subject S3 recorded a reference score of 100% under normal driving conditions. In the presence of the cataract simulation, its performance dropped to 63.4%, which indicates a noticeable impairment of walking comfort. With the use of assistive devices, the performance varied: with the Cane, the score was 48.8%, with the Cuff 66.8%, with the Tridirectional device 73.8%, and with the Sonar 83.6%. In the case of sham

glaucoma, the score was 80.5%. The use of devices improved the results as follows: Stick 49.9%, cuff 56.1%, Three-way 72.1%, and Sonar 94.5%.

Subject S4 recorded a reference score of 100% in normal driving conditions. In the presence of the cataract simulation, its performance dropped to 82.1%, indicating a lesser but present impairment. With the Cane, the score was 55.1%, with the Cuff 75.5%, with the Tridirectional device 48.6%, and with the Sonar 92.4%. In the case of glaucoma, the score was 70.6%, and the use of the devices resulted in the following values: Stick 64.8%, cuff 74.8%, Three-way 74.2%, and Sonar 92.6%.

The S5 subject scored 100% in normal walking, but the simulated cataract drastically reduced performance to 35.1%. The devices have brought improvements in the following way: Stick 40.6%, cuff 51.8%, Three-way 43.0%, and Sonar 91.1%, which indicates a remarkable efficiency of the latter. In glaucoma, the score without help was 34.3%. With the devices, the values were: Cane 36.7%, Cuff 46.5%, Three-way 72.3%, and Sonar 66.9%.

Subject S6 started with a score of 100% in normal driving conditions. Under the effect of simulated cataracts, the score dropped to 60.7%, signaling moderate discomfort. The assistive devices had the following results: Stick 44.4%, cuff 47.3%, Three-way 55.7%, and Sonar 82.3%, the latter providing considerable support. In glaucoma, the initial score was 59.4%, and the devices improved the results as follows: Stick 43.3%, Cuff 52.8%, Three-way 79.1%, and Sonar 79.8%.

Subject S7 had a 100% performance in normal walking, but under the influence of cataracts the score dropped to 52.4%. With the Cane, the result increased to 62.8%, with the Cuff at 71.1%, with the Tridirectional device at 79.8%, and with the Sonar at an outstanding 96.9%. Under glaucoma conditions, the initial score was 69.3%, and the devices had the following effects: Cane 48.5%, Cuff 68.6%, Three-Way 79.9%, and Sonar 88.6%.

The Topic S8 had a 100% base performance. Cataract reduced the score to 70.9%, and the devices generated the following results: Stick 64.7%, Cuff 65.2%, Three-way 70.5%, and Sonar 88.5%. In glaucoma, the score of walking without devices was 56.1%. With the Stick, the performance increased to 51.0%, with the Cuff it decreased slightly to 46.6%, while with the Three-way it reached 74.7%, and with the Sonar to 89.7%.

Subject S9 had a 100% normal gait. In the presence of cataracts, the performance decreased to 59.9%, and with the Cane it was 58.2%, with the Cuff 70.5%, with the Three-way 67.1%, and with the Sonar 71.4%. In the case of glaucoma, the initial score was 68.7%. With the Stick it increased to 61.8%, with the Cuff to 75.1%, with the Three-way to 74.0%, and with the Sonar to 96.4%.

Subject S10 had a score of 100% in normal walking. The cataract simulation resulted in a drop to 51.1%, and the devices had the following impact: Cane 54.3%, Cuff 69.2%, Tridirectional 68.9%, and Sonar 89.6%. In glaucoma, the score without help was 58.0%. The devices produced the following results: Stick 34.2%, Cuff 57.1%, Three-Way 71.1%, and Sonar 72.8%.

Subject S11 had a score of 100% in normal walking. Cataracts reduced his performance to 40.4%, a strong impact. With the Cane, the score was 33.8%, with the Cuff 72.1%, with the Tridirectional 82.2%, and with the Sonar 87.7%. In glaucoma, the device-free score was 66.3%. With the Stick, the subject reached 46.2%, with the Cuff 85.7%, with the Three-way 66.8%, and with the Sonar 89.3%.

Subject S12 started from a normal score of 100%. Under cataracts, he got 64.6%. With the Cane: 55.2%, with the Cuff 80.3%, with the Three-way 77.2%, and with the Sonar 84.2%. In glaucoma, the score was 73.2%. The device performances were: Stick 47.6%, Cuff 80.4%, Three-way 83.2%, Sonar 89.1%.

Subject S13 had 100% normal walking. The Cataract reduced the score to 53.7% and the Cane kept it at 49.0%. The cuff increased the score to 67.0%, the three-way to 60.4%, and the Sonar reached 91.5%. In glaucoma, the baseline score was 72.9%. With the Cane, the performance was 42.3%, with the Cuff 67.2%, with the Tridirectional 79.6%, and with the Sonar 90.7%.

Subject S14 had an initial score of 100%. With cataracts, the performance was 53.8%. The baton brought the score to 49.6%, the cuff to 60.5%, the three-way to 83.3%, and the sonar to 89.8%. In glaucoma, the score was 70.7%. With the Cane: 69.3%, with the Cuff 60.2%, with the Tridirectional 83.3%, with the Sonar 90.6%.

Subject S15 started with 100% normal running. Cataracts reduced the score to 67.1%. With the Cane, the performance was 53.0%, with the Cuff 38.7%, with the Tridirectional 48.4%, and with the Sonar 86.5%. In glaucoma, the initial score was 44.5%. With the Cane, the result was 45.6%, with the Cuff 52.8%, with the Three-way 72.1%, and with the Sonar 83.9%.

Subject S16 had a score of 100% on normal walking. Under cataracts, he got 63.7%. With the cane: 65.5%, the cuff 81.9%, the three-way 74.6%, and the sonar 81.8%. In glaucoma, the baseline performance was 70.0%. With the Stick he reached 52.8%, with the Cuff 74.6%, with the Three-way 72.4%, and with the Sonar 91.0%.

Subject S17 started at 100% and dropped to 63.1% below cataracts. With the Cane: 79.1%, with the Cuff 68.7%, with the Tridirectional 66.2%, and with the Sonar 89.8%. In glaucoma, the device-free score was 46.2%. With the Stick he obtained 51.2%, with the Cuff 74.1%, with the Three-way 69.0%, and with the Sonar 87.9%.

Subject S18 was 100% normal. Cataracts reduced the score to 62.7%. With the Baton it was 71.8%, with the Cuff 74.5%, with the Tridirectional 68.0%, and with the Sonar 93.4%. In glaucoma, the baseline score was 49.0%. With the Cane: 56.6%, with the Cuff 79.9%, with the Three-Way 68.2%, and with the Sonar 96.3%.

Subject S19 started at 100%, dropped to 55.0% under cataracts. With the Cane: 55.4%, with the Cuff 64.7%, with the Tridirectional 69.5%, with the Sonar 77.5%. In glaucoma, the initial score was 68.8%. With the Stick 45.3%, with the Cuff 58.0%, with the Three-way 64.2%, and with the Sonar 94.2%.

Subject S20 had a score of 100% at the beginning. Under the cataract he obtained 61.3%, with the Stick 38.8%, with the Cuff 43.3%, with the Tridirectional 31.3%, and with the Sonar 86.5%. In glaucoma, the score without help was 69.2%. With the Cane: 79.8%, with the Cuff 66.8%, with the Three-way 79.1%, and with the Sonar 88.3%.

The S21 subject had a 100% performance in normal walking. Cataract reduced the score to 82.6%, and with the Cane it was 50.4%, with the Cuff 49.6%, with the Tridirectional 71.6%, and with the Sonar 93.1%. In glaucoma, the initial score was 78.0%. With the Cane: 67.2%, with the Cuff 78.3%, with the Tridirectional 75.7%, with the Sonar 95.9%.

Subject S22 had a score of 100% under normal conditions. Cataracts led to a decrease to 53.9%. With the Cane: 52.5%, with the Cuff 82.0%, with the Tridirectional 57.1%, and with the Sonar 88.8%. In glaucoma, the performance was 78.3%. With the Stick 44.0%, with the Cuff 74.2%, with the Three-way 68.2%, with the Sonar 86.8%.

Subject S23 had a score of 100% in normal walking. Cataracts reduced his performance to 51.7%. With the Cane: 43.8%, with the Cuff 67.0%, with the Three-way 64.0%, and with the Sonar 95.7%. In glaucoma, the score was 71.2%. With the Cane: 35.8%, with the Cuff 60.5%, with the Tridirectional 83.6%, with the Sonar 92.3%.

Subject S24 had 100% normal walking. Cataracts brought the score to 49.0%. With the Cane: 77.1%, with the Cuff 70.2%, with the Three-Way 84.4%, and with the Sonar 82.8%. In glaucoma, the baseline score was 60.8%. With the Cane: 56.9%, with the Cuff 68.2%, with the Three-way 75.3%, and with the Sonar 80.2%.

Subject S25 had a 100% performance. Under cataracts, the score was 56.6%. With the Cane: 47.4%, with the Cuff 55.3%, with the Tridirectional 68.6%, and with the Sonar 87.1%. In glaucoma, the initial score was 81.7%. With the Stick 29.5%, with the Cuff 65.6%, with the Three-way 80.2%, and with the Sonar 95.5%.

7.2.4.3. **RELATIONSHIP OF WALKING COMFORT – Objective**

In order to eliminate the influence of the subjective questionnaire and obtain a strictly objective indicator of walking comfort, we redistributed the weight corresponding to the subjective comfort score to the other four measured parameters (plantar contact time with the RSSCAN plate, maximum force developed at plantar level, step symmetry and Tinetti score for walking), keeping the sum of the weights equal to 1, so that the formula is based exclusively on quantifiable criteria and validated tools.

$$SCM_O = 100 * [\alpha * \left(1 - \left|\frac{T_i - T_{ref}}{T_{ref}}\right|\right) + \beta * \left(1 - \left|\frac{F_i - F_{ref}}{F_{ref}}\right|\right) + \delta * \left(\frac{S_i}{100}\right) + \varepsilon * \left(\frac{ST_i}{12}\right)] \quad (37)$$

SCMo – Walking Comfort Score - Objective

Ti – contact time with the RSScan board in the analyzed condition (ms).

Tref– the reference contact time in normal walking for the same subject (ms).

Fi – the maximum force developed at the plantar level in the analyzed condition (N).

Fref – the maximum force at the plantar level in normal gait (N).

And – the symmetry of the steps with respect to the normal gait (in %, where 0% perfect symmetry, 100% asymmetry).

STi – Tinetti score for walking, between 0 and 12 points.

Ponderi: α- 0.3, β- 0.3, δ- 0.2, ε- 0.2.

Globally, there are differences between comfort scores calculated with the subjective factor and those based solely on objective data. Subjective factor values are usually higher for some conditions and devices, but the general trend remains in both sets: walking with glaucoma has a more severe impact than walking with cataracts, and the use of devices increases the comfort score, with variations depending on their type. The sonar consistently stands out as the best performing device, having high and stable scores in both data sets, close to the normal walking level and frequently above 90%, regardless of the type of visual impairment. This consistency confirms its role as the most effective solution among the devices tested.

7.2.5. Conclusions

Conclusions of the preliminary test: The preliminary test allowed comparative analysis of the influence of various simulated visual impairments on the biomechanical parameters of gait. All simulation conditions generate visible postural adaptations, but with different amplitudes. Of these, cataracts and glaucoma caused the most significant changes, manifested by the prolongation of the duration of the gait, increased plantar pressure and variations in the distribution of force on the support surface. In the case of cataracts, there was a marked tendency to maintain prolonged contact with the ground, reflecting the uncertainty generated by the impairment of central vision, while glaucoma highlighted additional loads on the lateral areas of the plantar surface, as a result of the restriction of the peripheral visual field.

Based on these objective findings, cataracts and glaucoma were selected as the main simulation conditions for the continuation of experiments in the extended study.

Conclusions resulting from step symmetry: Simulated visual impairments significantly influence step symmetry, generating obvious imbalances in some participants. The introduction of visual aids partially contributes to correcting this imbalance, but the effectiveness varies. Sonar proved to be the most effective device tested, with the lowest average asymmetry values in both types of deficiency. These results support the use of visual assistive technologies in the assisted mobility of visually impaired, with the mention that individual adaptation remains a key factor in the functional success of these solutions.

Conclusions on the time spent on the RSScan board: The analysis of the time spent by the participants on the RSScan board provided valuable information on the efficiency of walking in simulated visual impairment conditions (cataracts and glaucoma), as well as the effectiveness of each assistive device tested. The crossing time, expressed in seconds, was used as an objective indicator of adaptive walking behavior and orientation comfort level.

Under cataract conditions, the analysis of crossing times shows that Sonar led to the best temporal performance in 12 of the 25 participants. In several cases, the Sonar crossing time was closer to or even shorter than under normal walking conditions, suggesting higher cognitive mobilization or a greater degree of concentration generated by the additional sensory feedback.

At the same time, in the case of the S22 and S25 subjects, the Sonar performance was even better than in normal walking, indicating a possible active compensation of the visual deficit with the help of directional acoustic signals. The S22 subject, for example, recorded a time of only 1.95 s with Sonar, compared to 2.40 s with simple cataract and 1.85 s with normal walking, which highlights an efficient adaptation to the auditory signal. Overall, Sonar stood out as the most consistent performer of all the devices tested in the context of cataracts.

In contrast, for glaucoma, the distribution of preferences was found to be more heterogeneous. Although Sonar provided the best temporal results in 11 participants, other devices were more effective for certain subjects. For example, the cuff led to the best performance on the S2, S6, S10 and S17, suggesting that tactile feedback via vibration is effective in conditions of tubular field of vision, characteristic of glaucoma, providing useful proximity information for lateral navigation.

Conclusions on the average strength developed at the plantar level: The analysis of the average force developed at the plantar level in this study highlighted important differences both between the two types of simulated visual impairments and between the assistive devices used.

In simulated cataract conditions, characterized by impaired central vision, plantar force analysis indicated that the Sonar provided the best performance in a significant number of participants. Specifically, 7 of the 25 participants recorded the highest plantar strength values with the help of Sonar, which suggests that directional acoustic feedback was well integrated into gait control, providing confidence and stability while driving.

The cane was most effective for 7 other participants, indicating that additional physical support and direct contact with the ground provided a clear advantage in cataract, especially for subjects who appear to have compensated for visual impairment through proprioceptive mechanisms.

The three-way device proved to be the most effective for 2 participants, which highlights that the integration of signals from multiple planes can contribute to finer gait control, especially in particular cases.

The cuff, on the other hand, was not the optimal solution for any participant in the context of simulated cataracts. However, it provided values relatively close to optimal in most cases, suggesting functional stability, even if not maximum performance.

In the glaucoma simulation, where the loss of the peripheral visual field is the main obstacle, the distribution of preferences has changed significantly. The cuff provided the best performance in 6 participants, demonstrating that tactile feedback applied to the forearm is effective in compensating for the lack of lateral information.

Sonar was best performed in 6 participants, indicating that in some cases, auditory information continues to be relevant even in the absence of peripheral vision, especially for subjects with good auditory orientation ability.

The three-way was optimal for 3 participants, which shows that combining multiple levels of spatial warning helps to improve control in three-dimensional space, a critical aspect in tubular vision conditions.

The cane was the optimal solution for 4 participants, suggesting that in some cases, direct physical support remains essential for maintaining stable plantar strength, even in the absence of lateral visual cues.

Conclusions on the trajectory of the center of pressure

In cataract simulation, a general trend of loss of trajectory coherence was observed, especially in participants with lower sensorimotor ability. Of the four devices tested, sonar proved to be the most effective, managing to generate near-normal trajectories in 12 out of 25 participants, suggesting an effective integration of directional auditory feedback in conditions of blurred central vision. The cuff and the three-way device provided comparable results (each with 9 participants having small deviations), while the cane was effective in a smaller number (8 participants), indicating a variable effectiveness of physical support in the absence of clear visual information.

In the simulation of glaucoma, characterized by loss of peripheral visual field, sonar again had the highest efficiency, with 13 participants maintaining stable and coherent trajectories. The three-way device stood out positively, generating trajectories close to normal walking in 10 participants, suggesting that the distribution of signals from multiple directions can effectively compensate for the lack of peripheral information. The cuff was effective for 9 subjects, especially those with good tactile receptivity. In contrast, the cane provided improvements for only 8 participants, showing limited efficiency in compensating for the loss of lateral field of vision.

Looking at the results as a whole, sonar stands out as the most consistently performing device, with a total of 25 cases (12 in cataracts and 13 in glaucoma) in which the trajectories were close to those of normal walking.

Conclusions regarding the Tinetti score:

Analysis of Tinetti scores showed that simulated visual impairments significantly affect gait stability. In normal walking, all 25 participants obtained the maximum score of 12 points. Cataracts produced the worst scores (3–8 points), and glaucoma had a lower impact (5–8 points). The devices improved performance to varying degrees: the cane brought only partial improvement, the cuff took many participants into the yellow zone of stability, and the three-way device gave consistent scores of 9–10. The sonar was the most effective, with scores between 10 and 12 on most participants, bringing walking closer to normal.

Conclusions on deviations from normal walking:

The analysis of lateral deviations in 25 participants showed that simulated visual impairments significantly affect the gait trajectory. In cataracts, deviations were the largest and the cane proved ineffective, while sonar reduced deviations by 12.3%. In glaucoma, deviations were smaller, but sonar remained the most effective, reducing deviations below 5 mm in some participants. The three-way device provided constant improvements, and the cuff had moderate but uneven effects. The cane was the least effective in both conditions. Sonar has emerged as the best solution for restoring directional gait control.

Satisfaction questionnaire conclusions:

The questionnaire completed by the 25 participants showed that cataracts are perceived as more restrictive than glaucoma, with higher average scores on impaired vision and mobility. The sonar was the most appreciated device, considered the most comfortable, easy to wear and efficient, with 72% of participants placing it in first place. The cuff took second place, but with more varied opinions, and the three-way device was rated moderately, efficient, but difficult to fit. The cane was the lowest rated, being considered heavy, uncomfortable and slow in reaction. Overall, participants preferred modern auditory feedback devices, which were considered more useful than traditional solutions.

Conclusions regarding the relationship of comfort in subjective walking:

The analysis of SCM (Walking Comfort Score) scores for 25 participants highlighted a significant impact of simulated visual impairments on locomotor comfort, but also the different efficiency of the four devices tested. Under simulated cataract conditions, the average comfort dropped to 57.6%, with individual values often below 60%, signaling great difficulties in maintaining directional stability. The cane did not make any improvements, and even reduced the average to 52.4%, indicating a difficult adaptation to tactile feedback in the absence of central vision. The cuff moderately increased comfort (63.4%), but with large variations between participants. The three-way device obtained a better average (66.3%) and provided solid results in cases of poor orientation. The most effective proved to be sonar, which increased comfort to 86.1%, bringing scores closer to those of normal walking in many cases, thanks to auditory feedback that is easy to integrate into motor decisions.

In the glaucoma simulation, where the peripheral visual field was impaired, the mean SCM was 62.3%, with severe decreases in some participants. The baton maintained a low average (49.6%) and the cuff brought a moderate increase (64.4%). The three-way offered an obvious improvement, with the average rising to 72%, especially among partially adapted participants. The sonar confirmed the superior efficiency in this condition as well, obtaining an average of 88.5%, with values of over 90% in several participants.

In conclusion, sonar is confirmed to be able to restore behavioral comfort when walking, regardless of the type of visual impairment, providing the best support through directional, adaptive and effective auditory feedback.

Chapter 8.

Final conclusions. Personal contributions. Future research directions

8.1. Final conclusions

The paper approached in an interdisciplinary and complex manner the mobility issue of visually impaired people, integrating conceptual analysis, biomechanical experimental investigations, simulation modeling, as well as the evaluation of the functionality and behavioral comfort associated with the use of visual aid devices.

The detailed theoretical analysis highlighted the evolution of technological and social approaches dedicated to people with low vision, highlighting the essential role of emerging technologies in improving their independence and quality of life. At the same time, the scientometric study confirmed a current trend of focusing research on the technological components of visual assistance, but the behavioral dimension of user-device interaction is less in-depth.

The simulations carried out in the LabVIEW programming environment allowed to anticipate the biomechanical changes that occur in the gait of visually impaired people. These models highlighted the destabilizing effects of limiting visual information on dynamic balance, which were later confirmed by experimental biomechanical testing.

Experimental investigations carried out on healthy subjects undergoing simulation of two types of visual impairment (cataract and glaucoma) showed that these visual limitations cause obvious postural adaptations, manifested by lateral deviations of the gait trajectory, increase in the duration of bilateral support, changes in plantar pressure and decrease in gait symmetry. At the same time, the objective assessment of plantar strength and center of pressure confirmed the existence of compensatory strategies that vary from one individual to another.

The comparative testing of the four visual assistance devices revealed differentiated performance according to the type of simulated impairment and the particularities of each participant. The device developed in this work — the sonar system with infrared detection and directional auditory feedback — has consistently demonstrated the best results in reducing trajectory deviations, increasing efficiently distributed plantar force, maintaining postural stability and restoring behavioral comfort perceived by users.

The integrative behavioral comfort assessment (MCS), correlating biomechanical parameters and subjective responses, has highlighted the importance of mixed assessment, as the subjective perception of comfort does not always correspond to the level of biomechanical optimization. There are participants who, although they had biomechanical parameters close to normal, still felt uncertainty or adaptive stress in the absence of normal vision, confirming the complexity of the psychological factors involved.

The results of the satisfaction questionnaire reinforced the superiority of the Sonar system from the perspective of the users, as it was perceived as the lightest, fastest, most comfortable and most efficient in use. The three-way devices and the cuff offered intermediate performance, and the classic cane with sensors was the least effective in the context of the simulations carried out.

Overall, the research demonstrated the value of integrating theoretical modeling, controlled experimental testing, and subjective validation into the development of mobility assistance solutions for the visually impaired. The proposed device has real application potential, representing an ergonomic, accessible and efficient solution, with the ability to adapt for both central and peripheral vision impairments. At the same time, the results support the need for future research aimed at customizing devices according to the specifics of the deficiency, the individual walking style and the sensory integration capacity of users.

8.2. Personal contributions

- Analysis and synthesis of the defining elements for the field of poor vision – According to the standards of the European Council of Optics and Optometry (ECOO).
- Identification of the casuistry and etiopathogenesis of poor vision – Analyses by categories of ocular pathologies causative for the appearance of visual dysfunctions.
- Identification of refractive errors and their effect on retinal image quality.
- Correlation of visual function parameters with the standardized level corresponding to poor vision.
- Selection of methods and means useful for examining, testing and measuring the characteristics of low visual function.
- Structuring the means to increase the quality of life of patients with low vision – Prioritizing devices, assistive technologies, social and informational support elements.
- Studies of support configurations and increase of quality of life for the socio-economic integration of patients with low vision – Analysis of the development and implementation of the Smart-City concept for visually impaired people.
- Scientometric analysis of the literature to identify the research area in which specific systems can be developed.
- Synthesis of gait cycle study models to identify the effects of visual dysfunctions on behavioral comfort status.
- Analysis of methods for capturing the biomechanical movement of the locomotor system.
- Contributions to the modeling and simulation of the gait cycle in relation to the visual function in the LabVIEW programming environment.
- Design and structuring of a visual aid device on non-invasive sensory principles.
- Design and construction of the sensory system – SONAR – based on the principles of mechanical engineering.

- Design, implementation, verification and optimization of the operating algorithm of the IR radiation sensor system.
- Application of the principles of occupational ergonomics in the use, handling and maintenance of the entire device.
- Comparative analysis of the visual aid devices used in the present experimental research in order to determine their effectiveness (Stick - Cuff - Tridirectional - Sonar).
- Recording the biomechanical behavior during the gait cycle of the sample of subjects who had simulated visual dysfunction.
- Extraction of essential data for defining behavioral comfort and correlating them from professional equipment (RSScan).
- Processing and evaluation of results through validated scales (Tinetti scale) and through the interpretation of the subjective questionnaire.
- Design, definition and application of the behavioral comfort index determined on biomechanical principles to highlight the importance of mobility performance of patients with poor vision using the Sonar device.
- During my doctoral studies, I disseminated the research results in 11 published articles, of which 7 are indexed in ISI Web of Science databases, 2 in the Scopus database and 2 are indexed in Google Scholar. Of these, in 7 articles I was the first author, and in 4 articles I was co-author.
- I have also participated in a number of 11 national and international scientific conferences, contributing with scientific papers that reflect the stages and conclusions of doctoral research. Of these, 6 conferences had their papers indexed by ISI, 2 conferences were indexed by Scopus, and 2 conferences were recognized in Google Scholar. At the AFCO 2024 conference, organized by Transilvania University of Brașov, the paper presented won the award for the best scientific contribution in the section dedicated to doctoral students.

8.3. Future research directions

- Starting from the concept developed (research within the bachelor's project, dissertation and applied research) over time it is found that the present work fits into a flexible, open line, possibly integrable in complex structures.
- Optimizing device ergonomics and portability - Reducing weight, improving grip and adapting the design for comfortable everyday wear. High quality and performance materials, combining IR sensors with depth sensors (LIDAR or ToF)
- Adapting sound signals for different levels of auditory perception through the use of headphone accessories
- Integration with mobile apps for monitoring and customization
- Integration of studies into interdisciplinary research programs.

📚 Specialized Books (7)
[11] Scheiman, M., et al. (2007). Low Vision Rehabilitation: A Practical Guide for Occupational Therapists. Slack Inc.
[13] Jackson, A. J., & Wolffsohn, J. S. (2007). Low Vision Manual. Butterworth Heinemann/Elsevier.
[27] Manolescu, D. (1958). Ophthalmology. Medical Publishing House, Bucharest.
[117] NV Access. NVDA Screen Reader – Manual & Guide. NV Access Foundation.
[162] Hall, S. J. (2014). Basic Biomechanics (7th ed.). McGraw-Hill Education.
[163] Roșca, I.-C., & Șerban, I. (2015). Fundamentals of Biomechanics. Transylvania University of Brasov Publishing House.
[166] Huston, R. L. (2009). Principles of Biomechanics. Taylor & Francis Group.

📄 Specialized Articles (16)
[1] Goodrich, G., Aries, A., Rubin, G., Keeffe, J., & Legge, G. (2008). The low vision timeline: An interactive history. Vision Impairment Research, 10(2–3), 67–75.
[4] Goldish, L. H., & Taylor, H. E. (1974). The Optacon: A Valuable Device for Blind Persons. Journal of Visual Impairment & Blindness, 68(2), 49–56.
[9] Nguyen, X. T. A., Koopman, J., van Genderen, M. M., Stam, H. L. M., & Boon, C. J. F. (2022). Artificial vision: the effectiveness of the OrCam…. Acta Ophthalmologica, 100(4), e986–e993.
[10] Muqit, M. M. K., et al. (2023). Prosthetic Visual Acuity with the PRIMA System…. medRxiv.
[18] Murthy, G. V. S., Vashist, P., John, N., Pokharel, G., & Ellwein, L. B. (2010). Prevalence and causes of visual impairment…. Ophthalmic Epidemiology, 17(4), 185–195.
[19] Hashemi, H., et al. (2020). Global and regional prevalence of age-related cataract: a systematic review…. Eye.
[26] Flaxman, S. R., et al. (2017). Global causes of blindness and distance vision impairment 1990–2020…. The Lancet Global Health, 5(12), e1221–e1234.
[35] Fleckenstein, M., et al. (2021). Age-related macular degeneration. Nature Reviews Disease Primers, 7(1), 1–25.
[36] Maurya, M., Munshi, R., Thakur, S., & Zambare, S. (2022). Emerging Pharmacological Targets for Dry AMD. Journal of Exploratory Research in Pharmacology, 6(3).
[39] Reis, T. F., Paula, J. S., & Furtado, J. M. (2022). Primary glaucomas in adults: Epidemiology…. Clinical and Experimental Ophthalmology, 50(2), 128–142.
[41] Allison, K., Patel, D., & Alabi, O. (2020). Epidemiology of Glaucoma. Cureus, 12(11), e11686.
[56] Choudhury, M. A., & Rahman, S. N. (2019). Assistive technologies for visually impaired persons: How far have we come? IEEE Access, 7, 113103–113115.
[58] Zhang, H., Li, J., & Wei, Y. (2020). Development of smart wearable devices for blind navigation. Sensors, 20(18), 5001.
[73] Narayana, P., & Chattopadhyay, A. K. (2020). A survey on navigation systems for visually impaired people. Journal of Ambient Intelligence and Humanized Computing, 11, 1–22.

[152] Apostoaie, M. G., Baritz, M. I., Repanovici, A., et al. (2023). Visual Aid Systems from Smart City to Improve the Life of People with Low Vision. Sustainability, 15(8), 6852.
[166] Huston, R. L. (2009). Principles of Biomechanics. Taylor & Francis.

🌐 Websites (7)
[2] Hernandez, J., Mahajan, S., & Victor, S. (2005). History of Accessibility Technology. https://cs.stanford.edu/people/eroberts/courses/soco/projects/2005-06/accessibility/firstwave.html
[12] ECOO. Low Vision (Position Paper). https://ecoo.info/2011/03/position-paper-low-vision/
[14] American Optometric Association. Low Vision and Vision Rehabilitation. https://www.aoa.org/healthy-eyes/caring-for-your-eyes/low-vision-and-vision-rehab
[15] CDC – Centers for Disease Control and Prevention. Vision Loss and Mental Health. https://www.cdc.gov/visionhealth/resources/features/vision-loss-mental-health.html
[30] Southern Vision. Cataract. https://southernvision.co.nz/cataract/
[40] World Health Organization. Blindness and vision impairment. https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment
[43] RNIB – Royal National Institute of Blind People. Technology for Life. https://www.rnib.org.uk/living-with-sight-loss/technology-for-life/

List of publications

The research activity carried out within this thesis resulted in the publication and presentation of a number of 16 scientific papers at prestigious international and national scientific events. Of these, 8 papers are indexed in ISI Web of Science (WoS Core Collection), 2 papers in Scopus, 2 papers in Springer volumes (indexed SpringerLink and Scopus), 2 papers are indexed in recognized international databases (Google Scholar – BDI), and 2 papers were presented at national conferences.

A significant contribution is the publication of the paper "Visual Aid Systems from Smart City to Improve the Life of People with Low Vision" in the journal Sustainability (ISI Web of Science, 2023), which highlights the integration of smart city concepts and modern technologies into urban infrastructure for the visually impaired.

1. **Apostoaie Mirela Gabriela**, Baritz Mihaela Ioana, 3D Printing Procedure Applied in the Design of Portable Devices for Visual Aid, Polcom 2018, Bucuresti, **Scopus** , https://0a109aga9-y-https-www-scopus-com.z.enformation.ro/record/display.uri?eid=2-s2.0-85071051096&origin=resultslist&sort=plf-t&src=s&sid=f7d84e05b03076c72c88b34b0577c0a5&sot=b&sdt=b&s=AUTHOR-NAME%28apostoaie%29&sl=22&sessionSearchId=f7d84e05b03076c72c88b34b0577c0a5

2. Baritz Mihaela Ioana, **Apostoaie Mirela Gabriela**, Lazar Alexandra, Portable campimeter to evaluate visual field modifications of subjects with low vision state, IFMBE 2019, Timisoara, **ISI** , https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000552314200141

3. **Apostoaie Mirela** Gabriela, Baritz Mihaela Ioana , Analysis of the spectacles behavior made by composite structures, Polcom 2019, Bucuresti, **ISI**, https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000534200700040

4. Baritz Mihaela Ioana, **Apostoaie Mirela Gabriela**, Development of equipment for visual aid and motor, EHB 2019, Iasi, **ISI,** https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000558648300016

5. **Apostoaie Mirela Gabriela,** Some aspects regarding the construction of a portable perimeter made of composite materials, Polcom 2019, Bucuresti , ISI, https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000534200700042

6. Baritz Mihaela Ioana, **Apostoaie Mirela Gabriela,** Visual Aids Based on Ultrasonic Sensors to Increase Mobility of Patient with Blindness or Low Vision, AVMS 2019, Timisoara, **Scopus**, https://0a109aga9-y-https-www-scopus-com.z.e-nformation.ro/record/display.uri?eid=2-s2.0-85097198745&origin=resultslist&sort=plf-t&src=s&sid=f7d84e05b03076c72c88b34b0577c0a5&sot=b&sdt=b&s=AUTHOR-NAME%28apostoaie%29&sl=22&sessionSearchId=f7d84e05b03076c72c88b34b0577c0a5

7. **Apostoaie Mirela Gabriela**, Baritz Mihaela, The Concept of comfort applied in the analyzes on the behavior of people with low vision - current stage, COMAT 2020, Brașov, **GOOGLE SCHOLAR** , http://193.254.231.99:8080/jspui/handle/123456789/2507

8. **Apostoaie Mirela Gabriela**, Baritz Mihaela Ioana Assistive systems for subjects with low vision, ICISIL 2021 Brașov, **GOOGLE SCHOLAR** , http://aspeckt.unitbv.ro/jspui/handle/123456789/2620

9. **Apostoaie Mirela Gabriela**, Baritz Mihaela Ioana, Repanovici Angela , New Paradigms Used in the Study of Behavior in Condition of Postural Discomfort / Comfort, EHB 2021, **ISI,** https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000802227900166

10. **Apostoaie Mirela Gabriela**, Baritz Mihaela, Repanovici Angela, Barbu Daniela Mariana, Lazăr Alexandra Maria, Bodi Gyury , Visual Aid Systems from Smart City to Improve the Life of People with Low Vision, Journal – Sustenability 2023 nr.15, **ISI,** https://0a10qagay-y-https-www-webofscience-com.z.e-nformation.ro/wos/woscc/full-record/WOS:000983092100001

11. **Mirela Gabriela Apostoaie**, Mihaela Ioana Baritz, Barbu Braun, Angela Repanovici, Alexandra Lazăr, Gyory Bodi, Simulation of Comfort Behavior During the Gait Cycle of People with Low Vision, International Conference on E-Health and Bioengineering - EHB 2024 Iași, **ISI** , https://ieeexplore.ieee.org/abstract/document/10805621

12. Anca Ioana Tătaru (Ostafe), Mihaela Ioana Baritz, Angela Repanovici, Corneliu Nicolae Druga, Daniela Mariana Barbu, **Mirela Gabriela Apostoaie,** Analysis of the Distribution of Forces and Pressures on the Plantar Surface in Different Walking Types, 6th International Conference on Nanotechnologies and Biomedical Engineering, ICNBME 2023, Chișinău, **Springer, https://link.springer.com/chapter/10.1007/978-3-031-42782-4_13**

13. Anca Ioana Tătaru (Ostafe), Mihaela Ioana Baritz, Angela Repanovici, Corneliu Nicolae Druga, Daniela Mariana Barbu, Mirela Gabriela Apostoaie, Biomechanical Analysis of the Balance of the Human Body, 6th International Conference on Nanotechnologies and Biomedical Engineering, ICNBME 2023, Chișinău, **Springer**, https://link.springer.com/chapter/10.1007/978-3-031-42782-4_10

14. Anca-Ioana Tătaru, Mihaela-Ioana Baritz; Angela Repanovici; Luciana Cristea; **Mirela Gabriela Apostoaie**; Adrian Cătălin Lungu, International Conference on E-Health and Bioengineering - EHB 2024 Iași, **ISI,** https://ieeexplore.ieee.org/abstract/document/10805721

15. **AFCO 2024** - Award - It is also mentioned that in May 2024, the doctoral student participated in the AFCO conference (Graduates in Front of Companies), organized by the Transilvania University of Brașov, where she presented the paper *Experimental analysis of dynamic stability for people with low vision*, which reflects part of the results of the research carried out within the doctoral program. The paper won the prize awarded by the jury of the conference in the section dedicated to doctoral students. https://afco.unitbv.ro/2024/images/Documente/Premii_AFCO_2024.pdf

16**. Doco2024** (Doctoral Conference) Brașov- Visual Aid Systems from Smart City to Improve the Life of People with Low Vision