UNIVERSIDAD DE DEUSTO

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DECLARATION

I hereby declare that, except where specifically referenced in the text, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification at this or any other university other than Deusto University and the National Technical University "Kharkiv Polytechnic Institute" where I am enrolled in a joint PhD program. This thesis is my own work and contains nothing that is the result of work done in collaboration with others, except as indicated in the text.

Serhii Shapoval

May 2024

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ABSTRACT

This thesis explores the potential of applying and implementing deep learning methods in the field of medical physical and cognitive rehabilitation of users with age or cognitive disabilities. In this context, two case studies have been conducted: one investigating the prospects and possibilities of applying the Serious Games family of integrated deep learning algorithms to the rehabilitation and support of elderly people, and the other focusing on the support and training of categories of people with cognitive disabilities.

The first case study analyzes the physical condition of users who fall into the age category of 60 years or more, as well as progress as a result of prolonged implementation of prescribed rehabilitation measures. In this study, a group of 15 people were asked to perform a standardized set of physical exercises focused on working different muscle clusters and joints. These exercises were performed in two forms: in the standard form, by means of ordinary exercises, and in the form of a special system, in the form of the Serious Game application, in which the same exercises were interpreted in the form of game tasks. The peculiarity of the proposed application was that it integrated a modified algorithm based on a trained Neural Network, which allows to register the user's movements via web-camera. As a result of performing a course of exercises in two interpreters during two days, positive results were achieved in three main research parameters: time and accuracy of exercise performance, as well as the overall activity index. In the course of analyzing the results, it was found that the use of assistant applications has a positive impact on users, and in contrast to conventional exercises, there is an increase in results. Thus, the accuracy of exercise performance when using the assistant system increases from 54.7% to 85.4%, while when performing the same exercises in the standard interpretation, on the contrary, it decreases from 44.3% to 36.2%. More dramatic changes are observed in time indices. When compared to the reference time required to perform a particular exercise (Exercise 4 as an example), the difference in time results when using the application decreases from 45.3% to 14.63%, while when performing standard exercises, on the contrary, it increases from 55.7% to 63.8%. In terms of overall gains, user results improve by 18-40% on average, depending on the user and the exercise in question.

In the second case study the impact of the introduction and use of a course of daily use of software-assistants in the processes of support and training of users with peculiarities of cognitive state is investigated. In this case, testing was conducted on 4 groups of users, totaling 54 people. The groups were gathered according to 2 parameters: presence of cognitive peculiarities, level of cognitive disability. An additional parameter was age, which ranged from 20 to 58 years old. The level of cognitive disability also varies from 5% to 97%. During the testing, the participants were required to use the developed assistant application, which had 2 levels of 5 tasks each. As a result, only one group completed the two levels, at 100% and 92% respectively. The rest of the groups completed only Level 1 tasks. Also, all results were analyzed based on 6 main evaluation parameters: age, gender, level of disability, number of correct answers, time to complete the task, and number of clicks made during the task execution. According to the correlation analysis, the highest values were found in the relationship between the parameters of correct answers and level of disability, correct answers and time, time and age. Further analysis of clustering and evaluation using various methods of statistical analysis, including Pearson correlation coefficient evaluation method, ordinary least squares (OLS), random forest method, support vector machine model showed that all the parameters presented above are interrelated and are in mutual dependence, as evidenced by the index of 0.93 out of 1.00. In addition, the subsequent additional user survey showed that this interpretation of the tasks is more acceptable and interesting.

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ACRONYMS

NN - Neural Network

PC - Personal Computer

AI - Artificial Intelligence

VR - Virtual Reality

AR - Augmented Reality

SR - Serious Games

SDG - Sustainable Development Goals

WHO - World Health Organization

ICIDH - International Classification of Impairments, Disabilities and Handicaps

GBD - Global Burden of Disease

MD - Muscular Dystrophy

CVD - Cerebrovascular diseases

ID - Intellectual Disabilities/Disorders

CD - Cognitive Disabilities/Disorders

AH - Arterial Hypertension

ASI - Artificial Super Intelligence

AGI - Artificial General Intelligence

ANI - Artificial Narrow Intelligence

FFNN - Feed Forward Neural Networks

CNN - Convolutional Neural Network

RNN - Recurrent Neural Network

MCA - Motion Capture Algorithms

MCS - Motion Capture Systems

LSTM - Long Short-Term Memory

GRU - Gated Recurrent Unit

UK - United Kingdom

ACM – Association for Computing Machinery

IEEE – Institute of Electrical and Electronics Engineers

DBLP – Databases and logic programming

CPU - Central Processing Unit

GPU - Graphics Processing Unit

RAM - Random-access Memory

SSD - Solid State Drive

OS - Operational System

SDK - Software Development Kit

AAIDD - American Association on Intellectual and Developmental Disability

DS - Down Syndrome

OLS - Ordinary Least Squares

SVM - Support Vector Machine

ADL - Activities of Daily Living

CFS - Cognitive Function Scale

NHP - Nottingham Health Profile

1

Introduction

1.1 Background

According to the World Health Organization, the total number of people over the age of 65 by the end of 2021 is approximately 9.38% of the world's population. At the same time, this percentage increases every year. So, for example, from 2019 to 2021 this percentage increased by 0.278% [1]. This raises the question: Is this a problem, and if so, how serious is it?

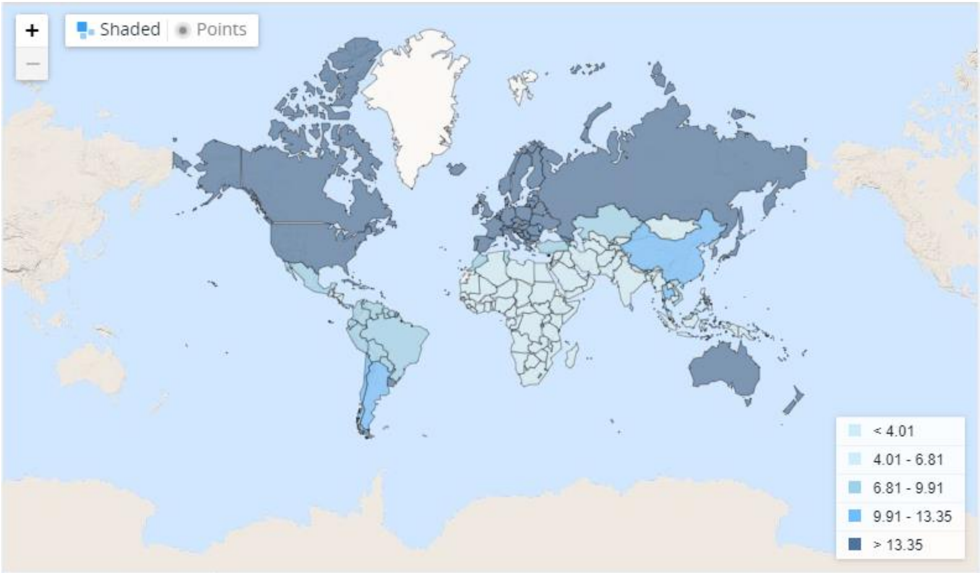


Figure 1.1. Graph of the percentage of the population over the age of 65.

First of all, it should be said that such a situation is caused by certain factors. If we pay attention to Figure 1.1, we can observe that in countries with a relatively high level of economic and social development the percentage of older people in the total population is significantly higher. This situation is not a problem per se. It is a consequence of increased life expectancy in developed countries [2]. Over the past 5 years there has been an increasing amount of discussion about different methods and ways to support such people in different aspects of life. We are talking about physical activity, mental well-being and the social aspects of their lives [3]. Each year there is also an increase in the number of different solutions for thorny and basic needs. But why is this support so important?

Even regardless of the level of medical development and social well-being in any given country, there are biological factors that cannot be influenced. Nevertheless, it is possible to simplify the difficulties associated with age. This support can be accomplished in a variety of ways, such as standard medical therapy, reinforcing exercise, social activities, and others, but these methods are not suitable for everyone [4]. Thanks to advances in technology, there are now many opportunities to create a variety of devices and systems that can supplement or even replace traditional methods that have already become routine. In addition, such support systems can be adapted quite easily to specific user cases, which contributes to increasing the effect of support [5, 6].

In addition to physical support, such systems can also solve no less important problem, which is quite painful for the elderly - the problem of socialization [7]. Often it is the problem of socialization that causes both low physical activity and mental problems. Thanks to such support devices, the problem of socialization among the elderly population becomes less acute. Not only do these people have the opportunity to interact with others through simple communication or joint activities, but they also lose the feeling of aloofness, the feeling that they are superfluous in this world. Plus, such systems allow older people to better adapt to the peculiarities of the digital age, which for most people is a problem [8].

Thus, the development and use of special rehabilitation and support systems solves several problems in the social sphere [9]. This direction is already very promising. The system discussed in this paper is an example of such a solution to support older people in improving their physical and mental well-being.

The eSail project is a system that is being developed with the European research program AAL Programme-Project FrAAgile [96] and is part of a large set of games and solutions for various physical, mental and social supports. The main goal of this project is to design and create a multifunctional support system, which will be both a standalone platform for physical activity support and an additional tool for hospitals and care institutions.

The technical contribution of the research project will be to increase physical activity as well as to provide additional support or rehabilitation for the elderly, in addition to increasing their social activity.

To achieve these goals, the plan is to develop a support system in the form of a computer game, along the lines of "Serious Games," which is designed for mobile platforms and personal computers. The system will be based on a set of exercises for various physical abilities, which have been approved and analyzed by doctors. During the course of this game, the user will perform supportive and strengthening exercises disguised as various game activities. The idea of such an interpretation will help increase the motivation to perform these exercises directly and help with leisure activities.

1.2 Scientific hypotheses and supporting questions

As mentioned earlier, the idea for this project is an interactive system in the form of a computer game designed to support or rehabilitate elderly people with problems of the musculoskeletal system. The goal is to create a simple and at the same time functional platform for users with the ability to perform various physical activities in various virtual settings.

The introduction of modern information technology in the medical field increases the effectiveness of treatment and support.

Rehabilitation methods using complementary software and hardware may be more effective than traditional methods.

The use of additional high-level software systems (Neural Networks) increases the effectiveness and simplifies the process of rehabilitation measures.

Based on the hypotheses presented earlier, it is worth noting that this dissertation is aimed at investigating the capabilities of medical assistive systems, their strengths, as well as options for their application. In the course of the work, auxiliary questions were also asked, which are intended to specify the course of the research, to note the key points and directions, as well as to simplify the course of scientific research in a certain way.

As additional questions, we chose those that most fully reflect the key points that can be encountered in the study of the problem presented. They were divided into the main and clarifying questions, as well as asked in the order in which they can be asked at this or that stage of the research. In this dissertation, the main and fundamental question is:

Q0: How can a computer game be developed and applied in the field of therapy and support for patients with physical problems?

Given that this question is quite complex, it should be divided into several qualifying points. The problem studied in this dissertation is quite comprehensive, so it is necessary to outline the main tasks to be solved in the course of the study. First of all, it is necessary to understand the audience for which the development is being conducted. It is necessary to take into account the emotional and physical state of the intended target content users, for which the main problem is motivation. First of all, it is important to make it so that the potential player would be interested not only during the activity itself, but also would have a desire to return to the system after a while. Therefore, the first clarifying question is as follows:

Q1: What are the most appropriate motivational methods for engaging older people in the support system being developed?

The second task is related to the first. Because of the characteristics of the target audience, it is important not only to motivate the user to participate in this or that activity, but also to make sure that the user completes it before the end. This is also a problem, because when faced with an incomprehensible and strange activity, which for example is one of the levels of the game, there may be "rejection" and the user simply does not want to even look towards the support system, motivating it by various problems, reasons and excuses.

This task is much more difficult than the one described above, because according to the recommendations of doctors, the cycle of activity that the system provides must run continuously and over a relatively long period of time. Therefore, it is important to strike a balance between complexity, duration and user friendliness of the system. Plus, all medical requirements must also be met. This is what the second question, which sounds like:

Q2: How to involve the user in the process of performing the tasks assigned to him, and make him perform all the activities from start to end?

During the research and development should also take into account the characteristics of the target audience, for which the system is developed. It is necessary to clearly understand the full range of nuances that are inherent in older people. This includes interests, special needs, peculiarities of their physical abilities, life situation and so on. It is important to make the system as simple and inclusive as possible. It is also important to consider where and under what conditions the system will be used, for the sake of improving the user experience. So, the third question sounds like:

Q3: What special techniques and rules should be used when developing support systems for the elderly and people with mental disorders?

In addition to physical support, an important aspect is also the social component, which also affects the overall condition of the older generation. At this age, communication with the people around you is extremely important, so when opportunities for social activity are quite limited, these kinds of support systems can be helpful. The socialization assistant can be introduced in different ways and in the context of different situations, therefore, the main question will be:

Q4: In what way should the social integration function be considered in the system?

1.3 Social Impact

This dissertation aims to explore the possibilities of different programmatic and technical solutions in comparison to traditional methods of patient support and rehabilitation. In the course of the work, multiple questions have been asked, which have their reflection in both the medical and social spheres.

From the point of view of the medical field, these solutions fulfill several tasks at once. Firstly, they can act as additional tools for rehabilitation procedures. And there are several advantages to this. In addition to the ease of execution and use (for the end user), such systems allow for a fairly accurate assessment and monitoring of the results and current state of the user, as well as simplify the work of the doctor or preceptor himself due to the accessibility and systematization of the indicators obtained.

Secondly, support systems can often replace some of the tools and devices typical of traditional methods of support and rehabilitation. This advantage not only allows to minimize dependence on the location and availability of medical devices, but also makes it easier and less expensive for the user to fit certain procedures into the daily routine, again taking into account the specifics of each individual case.

And finally, the third is to increase motivation to comply with rehabilitation orders. This consists in the fact that thanks to program methods, practically any exercise or procedure can be interpreted as any task of daily life. In this connection, there is a situation when instead of mindlessly performing, for example, a physical exercise, the user performs a task with a visual or tactile response, which both increases the desire to perform, but also makes it possible to increase the chance that the user will want to perform the action over and over again.

Also, an important aspect is the fact that such rehabilitation systems can theoretically improve the "social well-being" of the user, which is especially important for, for example, elderly people or those who suffer from serious physical problems and is in line with one of the Sustainable Development Goals (SDGs), namely Goal #3 - GOOD HEALTH AND WELL-BEING. Thanks to the technology, each user can not only perform tasks, but also share the results with other users, which in theory should further increase the motivation and satisfaction of using such assistants. In addition, different interpretations of software solutions can create situations of healthy sports rivalry between users.

Thus, the use of such systems can have an extremely positive effect on different target segments of society. Therefore, even in this understanding, there is already a positive prospect for research in this direction.

1.4 Research methodology

In the course of this thesis, the main research paradigm will be to research, develop, and test a platform of support for the elderly. Therefore, the main part of the research will be the system development aspect. It will consist of initial requirements, basic specification, direct software development as well as a number of tests of the system. In the course of development, several series of tests are planned at different stages, based on the results of which changes and adjustments will be made to certain parameters, mechanics or the platform concept. First of all, before the start of the direct development the following will be analyzed.

To better plan the chain of steps and actions that will be performed in the course of this dissertation, a flowchart demonstrating the stages of research work was created. This flowchart includes all the main stages, as well as demonstrates their sequence.

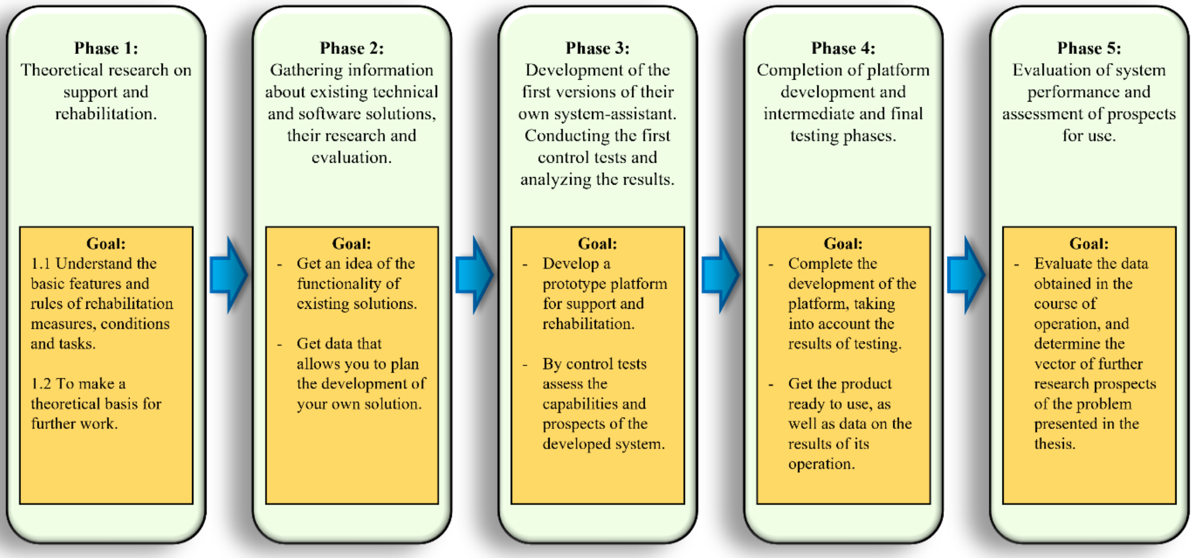


Figure 1.2. Research approach overview.

Figure 1.2 essentially describes the brief purpose of the key sections of this thesis. Phase 1 and Phase 2 represent the aims and objectives of Sections 2 and 3: State of the Art and Methodology, which describe the basic information regarding the topic under investigation, as well as the options for approaching the study of certain aspects of the topic. Phase 3 is the content of the technical hypotheses as well as the description of tools, algorithms and their application and is presented in Section 4: Implementation. Phase 4 describes directly the structural part and operation of the system, which is presented in the body of the thesis, with all program and technical features included in Section 5: Design. The final part Test Results and Discussion introduces Phase 5, which aims to analyze the results of the research and development work done.

Also, some of the stages that were carried out during the study should be described in more detail, for a better understanding of the work process.:

- Review of relevant and high impact publications:

All publications that were chosen as references were taken from databases of journals and sources with high impact factors, to provide a suitable theoretical basis, as well as to search for similar solutions that correspond to the problem studied in this dissertation.

- Research on the evaluation of found rehabilitation systems. Comparing them, highlighting features and functional parameters.

This process is a key one, and serves as a basis for gathering information about the specifics of developing systems for support and rehabilitation. Also, at this stage an initial impression of the perspectives and features of such systems in general was formed.

- Regular consultations with specialists in rehabilitation, elderly care and therapist doctors about the features and basic needs of therapy procedures.

One of the most important principles of development. Given the focus and purpose of the system being developed, it is important to know the fundamental points for which each exercise included in the exercises is intended.

- Communication with the direct target audience to find out the wishes, problems and other features.

Several meetings were held with older people who live in different social conditions and circumstances to better understand their situation and interests.

- Conducting several phases of verification and testing with both control groups and the target audience.

At the final stage of testing and development was also carried out as a usability test of the created application. As a result, the control and target content of testers and users expressed their opinion about the system in the context of questionnaires and general verbal evaluation.

All additional literature that was chosen as a basis for research and development is highlighted in the form of a systematic literature review. It is worth saying that a large number of aspects of system development were based on the information obtained from the studied literature sources. Also, discussions with medical and nursing staff helped to better understand the principles of rehabilitation and supportive interventions, which was reflected in the quality of the system's objectives. All comments during testing were taken into account and relevant aspects of the platform were improved.

1.5 Organization

This section demonstrates the structure of the dissertation, and briefly describes the purpose and content of the main sections. This section covers the organization of the rest of the thesis.

Chapter 1: Introduction

This dissertation begins by explaining the need for this study, positioning the thesis within the appropriate theoretical background, and elaborating on the research gaps, objectives, and research questions.

Chapter 2: State of the art

This chapter demonstrates an overview on the main problems that are tested in this study. Among them is the very notion of rehabilitation measures, their order, features, and rules. It also reviews the basic criteria of the research, the concept of medical support systems, and those social categories that most strongly require these medical studies.

Chapter 3: Methods

This section describes the methods of selecting the main sources of information used in this study, as well as the main points and procedures for their selection. In addition, it describes the main points of testing each unit.

Chapter 4: Study 1: Physical Rehabilitation Block.

The chapter shows the basic methods and means by which the helper system presented in this dissertation was developed. It also describes the main points about the Physical Module data that were used in the development and the main perspectives. The chapter also demonstrates directly the structure of the system itself. Its parameters, features, methods of operation, and so on. It describes the basic features of the interface, tasks, monitored parameters, the structure of the resulting data, the format of the results, and the features of the simulations.

Chapter 5: Study 2: Cognitive Rehabilitation Block.

The chapter shows the basic methods and means by which the helper system presented in this dissertation was developed. It also describes the main points about the Cognitive Module data that were used in the development and the main perspectives. The chapter also demonstrates directly the structure of the system itself. Its parameters, features, methods of operation, and so on. It describes the basic features of the interface, tasks, monitored parameters, the structure of the resulting data, the format of the results, and the features of the simulations.

Chapter 6: Conclusion

This section describes comparative reflections on the functional and technical capabilities of the resulting system in comparison with other technical and software solutions taken for analysis from open sources. In addition, this section demonstrates the advances that have resulted from the development of the platform.

2

State of the art

"All states must have appropriate structures and mechanisms to ensure continuous improvement in the quality of health care and to improve the appropriate development and use of health care technologies."

(From the European Program. "Health for All by 2020")

The problem of incomplete citizens is a topical and contemporary issue for any problem of incompletely functioning citizens is a topical problem in any country of the world, since any person at some point in his or her life may experience limitations in his or her functioning. In a number of cases modern medicine helps to overcome this or that disease, and the citizen returns to work in his or her specialty and fully functioning in the society. However, unfortunately, there are chronic illnesses [10] that tend to increase in a particular person, which leads to limitations on his or her life activities, reduced quality of life, and disability [11].

On the other hand, there are a number of acute diseases and traumas, the results of which result in acutely manifested disabling consequences for this or that individual [12, 13]. In order to prevent disability, and to reduce or completely eliminate the disabling consequences of an illness or injury, rehabilitation must be carried out. rehabilitation should be carried out, including not only medical, but also professional and social activities [14].

Rehabilitation is a complex, multifaceted process that includes various aspects that are extremely difficult to summarize in one formulation. One of the best formulations was adopted One of the best formulations was adopted at the 1967 Conference of the Ministers of Health of Socialist Countries in Prague [15], which reads, rehabilitation of the sick and disabled is a system of state, socio-economic, medical, professional, pedagogical, psychological and other measures aimed at the prevention of the development of pathological processes that lead to temporary and permanent loss of ability to work, and the effective and early return of the sick and disabled, children and adults to society and socially useful work.

Another formulation states that rehabilitation is a dynamic system of interrelated medical, psychological and social components (in the form of various influences and activities) aimed not only at restoring and maintaining health, but also at restoring (maintaining) as fully as possible personality and social status of a sick or invalid.

However, whichever formulation is considered, it should be noted that the strategic goal of rehabilitation should be the social integration of the so-called rehabilitant and providing him with an acceptable quality of life.

2.1 State of the art methodology

The theoretical basis of both rehabilitation in general and medical and social expertise in past years was the three-dimensional concept of the consequences of illness [16], developed by WHO experts and presented as a supplement to the International Statistical Classification of Diseases [17] in the form of the International Classification of Impairments, Disabilities and Handicaps (ICIDH), which was approved by WHO in 1980 as a tool for analyzing and solving life support problems related to the condition of people with disabilities. According to the three-dimensional concept of the consequences of disease, its impact on the human body is considered at three levels:

I level - consequences of the disease at the organ level - morpho functional changes in individual organs or systems ("defect" functional impairment), in the classification are reflected as "disorders";

Level II - consequences at the organismal level (in the classification - "limitation of vital functions") - disruption of integrative functions of the integral organism or its ability to move, self-care, orientation, communication, control of his behavior, learning, work, allowing the individual adapt to the environment and not depend on of the help of another person;

Level III - consequences at the social (in the classification - "social insufficiency") - social disadaptation (inability to perform a social role, determined by age, upbringing, education, profession and specific environmental conditions).

With one-stage formation of disabling consequences, the goal of rehabilitation is - is to overcome the already arisen consequences of the disease. In this case, functional-rehabilitation measures are carried out to elimination of the consequences of the first level, and prophylactic measures to prevent an unfavorable course of the illness are taken (the prevention of complications and further treatment of the condition). in the future (prevention of complications, recurrences and chronicity of the pathology) through the use of activating methods, mobilizing cyanogenetic mechanisms of the body. At full restoration or compensation of the disturbed functions, the effect is manifested at once on three levels, so the organismal and social consequences are liquidated without additional influences [18]. If full overcoming of consequences on the first level is not achieved, rehabilitation measures acquire adaptive character and are directed to overcoming and compensation of consequences of higher - II and III levels. The goal of rehabilitation becomes social adaptation to everyday life [19, 20], and adaptation to work and vocational training for the patient (invalid) with a functional defect, and in children's age - ensuring the possibility of raising and educating a child. The solution to these issues is provided with the help of social (domestic) and professional, and in children - pedagogical - rehabilitation.

In cases of the gradual development of disabling consequences, the goal of medical rehabilitation is the prevention of disability [21] (the prevention of the appearance and progression of the consequences of illness at all levels). Thus, based on the concept of the consequences of illness, as a result of the resulting "disorders" as a consequence of illness (or trauma) in a person, both the state of his or her body as a whole and his or her ability to perform life activities that determine his or her development as an individual may change. The individual becomes limited in the spheres of activity, tied to certain means of life support. As a result, there is a disorder at the level of the individual, there are the so-called "limitations life activities".

However, the International Classification (Nomenclature) of Impairments, Disabilities and Social Deficiencies did not allow for a sufficiently full disclosure of the role of the social and physical components of the environment in both forming the consequences of illnesses and in overcoming them. A specialist needs a "tool" that, On the one hand, to help assess the consequences of an illness or injury from a medical point of view, on the other hand, the ability to function patient with existing health problems in the external environment, while still assessing personality traits of the individual. In this regard, there is a need for new, modern and, most importantly, multifunctional rehabilitation aids.

2.2 Basic knowledge about physical and cognitive disability

Before we begin research, it is important to ask the following question: "Why exactly was the topic of rehabilitation chosen as a study?" To begin, let's look at the statistics. By the end of 2022, according to various estimates, approximately 1.82 billion people in the world suffer from musculoskeletal disorders and diseases. Musculoskeletal disorders and diseases are the leading cause of disability worldwide, and lumbago remains the leading cause of disability among these diseases in 160 countries. Musculoskeletal disorders and diseases significantly limit mobility and motor skills, leading to premature termination of employment, decreased well-being and reduced opportunities to participate in society [22, 23]. Because of a growing and aging population, the number of people with musculoskeletal disorders and diseases is rapidly increasing.

Musculoskeletal disorders and diseases are more than 150 health conditions affecting the musculoskeletal system. They range from acute and transient phenomena - fractures, sprains and dislocations - to lifelong impairments accompanied by permanent loss of function and disability. Disorders and diseases of musculoskeletal system are usually characterized by pain (often of permanent nature), decreased mobility, deterioration of motor skills and functional capabilities in general, which limits a person's ability to work.

In addition, musculoskeletal disorders and diseases are the most important factor in the global need for rehabilitation services. They are among the main reasons driving the demand for such services for children, and about two-thirds of adults in need of rehabilitation services are people with musculoskeletal disorders and diseases.

Data from the recent Global Burden of Disease (GBD) study indicate that approximately 1.82 billion people worldwide suffer from musculoskeletal disorders and diseases. Although the prevalence of musculoskeletal diseases varies by age and diagnosis, they affect people of all ages throughout the world. People in high-income countries are most affected (447 million), followed by those in the Western Pacific Region (429 million) and the Southeast Asia Region (372 million).

Lumbago accounts for most of the total burden of musculoskeletal disorders and diseases. Other contributors to this burden include fractures (436 million people worldwide), osteoarthritis (343 million), other injuries (305 million), cervicalgia (222 million), amputations (175 million) and rheumatoid arthritis (14 million).

Although the prevalence of musculoskeletal disorders and diseases increases with age [24], they also affect younger people, often in the years of greatest economic activity. Lumbago, for example, is a major cause of premature termination of employment. The adverse effects on society are truly enormous, not only in terms of direct health care costs, but also in terms of indirect costs (which translate into missed workdays, reduced productivity). In addition, musculoskeletal disorders and diseases are closely associated with significant deterioration in mental health and reduced functional capacity [25]. The number of people suffering from lumbago is projected to increase in the future, most rapidly in low- and middle-income countries.

2.2.1 Types of Elderly Disability

Age-related changes [26] in the musculoskeletal tissue are the main cause of musculoskeletal disorders inherent to the elderly. They are characterized by gradual atrophy of muscles and their replacement by fat cells. At the same time the balance between the replenishment of calcium in the bones and its washout due to the lack of vitamin D is disturbed [27]. This important element is responsible for absorption of calcium from the intestines, and over time, even if the number of dairy products consumed remains the same, a deficiency of calcium is formed, which means that the bones become more fragile.

The three most common musculoskeletal disorders in the elderly have a similar name from the Greek "osteon" - bone. Unfortunately, bone tissue undergoes irreversible changes with age, and often they develop into diseases associated with a lack of calcium in the body [28].

Musculoskeletal system is represented by bone and muscle systems, which undergo several physiological changes with age. Thus, the process of forming new muscle fibers is disrupted, and after 60 years they are reduced in size. If in the period from 20 to 50 years muscle mass decreases by 10% on average, then after 50 years it is lost by 10% of the remaining mass for each decade. The synovial membrane of the joints thins, hyalinization occurs, and the volume of synovial fluid decreases. Dystrophic changes in articular cartilage, subchondral sclerosis develop, subchondral cysts are formed, the spatial relationship of bones changes, the degree of congruence of articular surfaces decreases. Of great importance are chronic microtraumatization of joints, degeneration and destruction of articular cartilage, accompanied by inflammation with the formation of synovitis with focal hypoxia and ischemia of bone, which leads to the development and progression of osteoarthritis.

Bone changes are caused by osteopenia. Bone mass decreases, bone resorption prevails over bone formation, calcium homeostasis changes (its absorption in the intestine is reduced and conversion of vitamin D into an active metabolite is slowed), parathyroid gland activity increases, estrogen deficiency increases with active calcium washout from bones. High activity of osteoclasts causes perforation of trabeculae in the place of resorption, which leads to violations of bone microarchitectonics, reduction of bone density, and consequently - to the development of osteoporotic changes. As a consequence, not only the strength of bone tissue is reduced, which is manifested by a decrease in its tolerance to external influences, but also the functioning of the musculoskeletal system is impaired (development and increase of hypomobility syndrome).

2.2.2 Methodology of rehabilitation example

The main purpose of prevention of osteoparosis in elderly and senile persons is to preserve the mass and density of bone tissue (this helps to prevent fractures), prevention of osteoarthritis - to slow its progression, reduce the risk of exacerbations and involvement in the pathological process of previously intact joints, prevention of sarcopenia - to preserve muscle tissue mass and slow down the involutionary sanogenic way. People of older age group with osteoarthritis, osteoporosis and sarcopenia are recommended a diet with restriction of salt, sugar, coffee, tea, pickles, smoked foods, spicy dishes. Refined carbohydrates on the background of increased intake of dietary salt due to the mechanisms of regulation of water-salt balance is an additional risk factor for decompensation of arthrosis. Rational diet improves the sensitivity of the vascular receptors, normalizes the vascular blood flow, and improves chondrocyte metabolism. Against the background of reducing the caloric intake of food in order to reduce body weight to reduce the load on the joints of the spine and lower limbs requires a sufficient intake of water (at least 8 glasses per day). Elderly people need a fish diet; dairy, cereal products and especially vegetables containing calcium, enterosorbents (peptides, hemicellulose), vitamins (A, B, D, E), increased consumption of protein in the absence of contraindications from the kidneys are recommended.

The main medical and social rehabilitation components:

Medical - change of motor stereotypes; exercises with dosed load on the joint (dosed walking, climbing, biking, swimming) are recommended; walking is most useful (up to 7 km per day); dosed walking means limiting the time of continuous (without rest) stay "on feet" - no more than 30-40 minutes, but not limiting the distance covered during the day; it is necessary to limit a long immobile stay in a standing position, climbing stairs; positions with resting on the knees, squatting should be avoided; for unloading the affected joints it is also recommended to use a walking stick, and for severe deformity and instability of the joint - orthoses, elastic bandage or adhesive bandage; in the absence of contraindications it is advised to perform strength exercises of certain types according to an individual training program [29].

Medical and social - medical and social assistance to elderly and senile people with high risk of falls is reduced directly to preventive measures:

- creation of a safe and barrier-free living environment, in particular in medical and medical and social institutions (ensuring sufficient lighting, avoiding slippery and uneven surfaces, if necessary - equipping toilets, bathrooms, corridors with special handrails);
- Use of special walkers when moving around the house or on the street;

- equipping interiors with special alarms that will notify relatives or staff if there is a fall or deterioration that could lead to a fall;

Application of physical rehabilitation methods to train adaptive mechanisms for maintaining balance and walking correctly. Training the muscles of the lower extremities to ensure the correct "pattern" of walking, which can counteract falls.

Changes in the musculoskeletal system with age are a single aging problem within the framework of senile asthenia. Creation and use of integrated medical and social rehabilitation and preventive programs, as well as their introduction into clinical practice will not only help to eliminate risk factors, modify the lifestyle of older people, increase physical activity, reduce the risk of falls and fractures, but will also promote the initiation of treatment and increase adherence to it, as well as become a major predictor of the effectiveness of diagnostic search. In this connection re-training and advanced training of personnel working in the social sphere, aimed at increasing the level of medical knowledge on the problems of osteoarthritis, osteoporosis and sarcopenia in elderly people, are topical. Combining the efforts of social workers and medical personnel is promising in solving the above tasks [30].

Taking all these processes as an example, the most urgent and pressing problem for the elderly is the growing problem of Muscular Dystrophy (MD). Rehabilitation of patients with MD is a daily, multi-year endeavor.

This type of care requires the involvement of a physical and rehabilitation medicine physician, medical rehabilitation physician, or other physician who serves as a medical rehabilitation specialist (physical therapy physician, physical therapist, reflexology physician, orthopedic trauma physician, neurology physician, etc.). The doctor of physical and rehabilitation medicine, medical rehabilitation physician or a physician performing his/her function monitors and applies rehabilitation programs, adapting/adjusting to the individual needs of the patient according to the International Classification of Functioning, depending on the stage of the disease, level of mobility and presence/absence of comorbidities. If necessary, a physician-neurosurgeon, a physician-surgeon-otorhinolaryngologist, as well as a speech therapist, defectologist and other specialists are involved in counseling and rehabilitation assistance, if necessary.

Patients with MD need support of the maximum level of functions of the musculoskeletal apparatus to prevent and minimize secondary complications (development of contractures, muscle atrophy, compensatory skeletal deformation, osteopenia, osteoporosis). Regular moderate physical activity is indicated. When carrying out rehabilitation measures, avoid excessive (maximum) loads, eccentric exercises with high resistance.

Methods of rehabilitation of MD are divided into non-technical (these include physical therapy: physical therapy, walking, swimming, cycling, etc.) and technical (orthotization of limbs), as well as mechanical and robotic methods (mechanotherapy, verticalization, use of rehabilitation simulators). When carrying out rehabilitation measures, it is necessary to:

- try to integrate physical therapy and regular physical activity into the child's daily activity, to form a way of life on their basis;
- take into account that the dominant symptom in children is fatigue, and therefore distribute physical activity throughout the day - "little but often";
- be proactive - set rehabilitation goals for the next few months, taking into account the patient's current musculoskeletal status and predicted deterioration.

Depending on the leading clinical symptoms, different rehabilitation programs may be prescribed for patients with MD [31].

1) Methods of physical rehabilitation:

- Active and passive stretching (independent and assisted) 5 - 6 times a week for at least 60 seconds per muscle group;
- prolonged traction using positioning, splinting;
- orthotics and taping;
- devices for verticalization (verticalizer, bed-verticalizer, parapodium-verticalizer), walking and orthopedic shoes;
- kinesiotherapy, including hydrokinesotherapy (swimming at a water temperature of 30 - 33 °C (optimal temperature limits for the best muscle metabolism).) (Therapeutic exercise in the pool, Hydrokinesotherapy for heart and pericardial diseases, Hydrokinesotherapy using underwater simulators for heart and pericardial diseases);
- mechanotherapy, non-loading motor methods (mechanotherapy, robotic mechanotherapy, apparatus statokinetic loads, therapeutic physical training with the use of simulators, therapeutic mechanotherapy in water), training with biofeedback on movement coordination (stability platform) to maintain functional muscle capabilities and improve movement coordination (biofeedback training on support response, therapeutic physical therapy exercises using suspension systems, simulated walking with stabilization, balance therapy);

2) Physical activity: to prevent atrophy and secondary complications, patients with preserved mobility and those in the early stages of mobility loss should engage in regular submaximal (light) muscle strengthening activities under the supervision of instructors, medical staff or trained parents;

3) Therapeutic physical training (therapeutic physical training for heart and pericardial diseases, individual therapeutic physical training for heart and pericardial diseases, group therapeutic physical training for heart and pericardial diseases, therapeutic physical training with biofeedback for heart and pericardial diseases, therapeutic exercise with the use of simulators in heart and pericardial diseases, biofeedback training on spirographic indicators in heart and pericardial diseases, biofeedback training on hemodynamic indicators (blood pressure) in heart and pericardial diseases, therapeutic exercise in bronchopulmonary diseases, individual physical therapy for bronchopulmonary system diseases, group physical therapy for bronchopulmonary system diseases, mechanotherapy for bronchopulmonary system diseases, mechanotherapy on simple mechanotherapeutic devices for bronchopulmonary system diseases, mechanotherapy on block mechanotherapeutic devices in bronchopulmonary system diseases, therapeutic physical training with biofeedback in bronchopulmonary system diseases, training with biofeedback on dynamographic indices (strength) in bronchopulmonary system diseases, training with biofeedback on support reaction in bronchopulmonary system diseases, biofeedback training on subgraphic indicators in bronchopulmonary diseases, biofeedback training on kinesiologic image in bronchopulmonary diseases, biofeedback training on spirographic indicators in bronchopulmonary diseases, biofeedback training on hemodynamic indicators (blood pressure) in bronchopulmonary diseases, therapeutic physical training with the use of devices and simulators.;

4) Speech therapy for speech, swallowing, chewing and salivation disorders;

5) Surdological support for hearing impairment;

6) Defectology classes for cognitive disorders;

7) Physiotherapeutic methods of rehabilitation:

- local thermal procedures (applications of ozokerite, paraffin, balneo-procedures, thermal baths), e.g. paraffin-ozokerite application, paraffin exposure on hands or feet (paraffin bath), mineral therapeutic baths)
- acupuncture

8) Surgical intervention in the presence of skeletal deformities (according to the relevant clinical recommendations);

9) Assistive devices for functional compensation and adaptation:

- patient-operated wheelchairs, patient-operated wheelchairs, patient/companion-operated wheelchairs (manual wheelchairs);
- motorized wheelchairs controlled by the patient/caregiver (motorized wheelchairs);
- electrically operated adaptation beds, manually operated adaptation beds, mechanically operated hospital beds, hydraulically operated hospital beds, electrically operated standard hospital beds (automatically adjustable beds).

And that's just about one aspect of rehabilitation for the elderly. This is why it is important to pay as much attention as possible to assisting and developing tools to facilitate and empower rehabilitation medicine [32, 33].

2.2.3 Cognitive aspect

More than 20% of adults age 60 and older have cognitive or neurological disorders (excluding headache-related disorders), and 6.6% of all disabilities among people over 60 are caused by neurological and psychiatric disorders. These disorders among the elderly population account for 17.4% of the years of life lived with a disability. The most common neuropsychiatric disorders in this age group are dementia and depression, affecting about 5.5% and 8% of the global elderly population, respectively. Anxiety disorders affect 3.9% of older adults, substance use problems affect nearly 1.2%, and about 26% of deaths from self-harm occur at age 60 or older. Substance use problems among the elderly often go unnoticed or are misdiagnosed [34].

At any point in a person's life, a wide variety of risk factors can threaten their mental health. In addition to the normal stressors that arise in all people's lives, older adults may also be affected by factors more characteristic of old age, such as significant and steady deterioration of abilities and decreased functional capacity. For example, older adults may face limited mobility, chronic pain, decrepitude, or other health issues that require some form of long-term care. In addition, events such as the loss of loved ones or a decline in socioeconomic status after retirement may occur significantly more frequently in the lives of older adults. All of these factors can lead to isolation, loneliness, or psychological distress, which may result in their need for long-term care.

Dementia [35, 36] and depression [37, 38] are the most common illnesses in this category of people. Dementia is a syndrome, usually of a chronic or progressive nature, in which there is a degradation of memory, thinking, behavior, and ability to perform daily functions. There are an estimated 50 million people worldwide living with dementia, with 60% of those with dementia living in low- and middle-income countries. The total number of people with dementia is projected to increase to 83 million in 2030 and 155 million in 2050. Depression can cause great suffering and leads to limited functioning in the context of everyday life. Unipolar depression affects 8% of all seniors and accounts for 5.9% of total disability among people over age 60. Depression is underdiagnosed in primary care settings and not all patients receive treatment.

Cognitive impairment in the elderly, symptoms represent a group of conditions arising from various neurological, somatic and psychiatric diseases. The main causes are various neurodegenerative (Alzheimer's disease), cerebrovascular diseases (strokes) and dysmetabolic disorders (hypoxic, hepatic, renal).

The major risk factors are those common to all cerebrovascular diseases (CVD), which include arterial hypertension (AH), atherosclerosis, coronary heart disease, heart rhythm disorders, diabetes mellitus, smoking, obesity, high cholesterol, and high homocysteine levels. There are also several main categories of causes of such diseases:

1) Cognitive impairment due to "strategic" brain infarcts or hemorrhagic stroke. In this case, cognitive impairment in the elderly after stroke may develop as a result of a single brain infarct, sometimes even a small volume, which is localized in a strategically important area for cognitive activity. Most often, cognitive disorders develop with lesions of the optic tubercles, striatum, prefrontal frontal cortex, the junction zone of the temporoparietal-occipital lobes of the brain of the left hemisphere. In this case, cognitive and other neuropsychiatric disorders occur acutely and then persist, partially or (rarely) completely regress, as is the case with other focal neurologic disorders in strokes.

2) Cognitive disorders due to multi-infarct brain damage. They develop as a result of repeated episodes of acute cerebral circulatory failure (ACBF) of ischemic type of cortical-subcortical localization. The most frequent causes are thrombosis or embolism of cerebral vessels. Cognitive disorders in elderly people with multi-infarct state develop with involvement of areas important for cognitive activity in the infarct zone, as well as with the cumulative accumulation of sufficiently large volumes of brain damage.

3) "Subcortical variant" is the most common cognitive impairment in aging. It is based on cerebral microangiopathy with a predominant lesion of small-caliber end vessels that primarily supply the subcortical basal ganglia and deep parts of the cerebral white matter. The term "small vessel disease" is also used to describe this form of cognitive disorders. Due to the close functional relationship of the subcortical basal ganglia with the frontal lobes of the brain, their vascular lesion causes secondary dysfunction of the frontal lobes. Frontal lobe dysfunction plays a leading role in the formation of major cognitive, other neuropsychiatric and motor disorders. Unlike post-stroke cognitive disorders, "subcortical" ones are characterized by a gradually progressive course or a stepwise increase in the severity of the defect.

4) Cognitive disorders due to cerebral hypoperfusion. The causes of acute cerebral hypoperfusion can be acute heart failure, decreased circulating blood volume, marked and prolonged decrease in blood pressure, etc. In these cases, multiple brain infarcts are formed at the boundaries between vascular basins in the so-called "watershed zones" (zones of adjacent blood supply, terminal zones). Cognitive disorders of elderly and old age due to cerebral hypoperfusion are characterized by acute development of cognitive disorders, qualitative features and severity of which depend on the localization and degree of brain damage.

5) Combined forms of SVD develop as a result of simultaneous impact of several pathogenetic factors listed above: repeated ischemic and/or hemorrhagic strokes, cerebral hypoperfusion, chronic insufficiency of blood supply to the brain. For example, the combined variant may develop in patients suffering from arterial hypertension with episodes of hypotension against the background of inadequate hypotensive therapy. In this case, in addition to hypertensive cerebral microangiopathy, episodes of blood pressure drop play a pathogenetic role, which due to

altered reactivity of cerebral vessels will lead to episodes of hypoperfusion in the areas of terminal blood supply.

However, the mental health status of older adults can be improved by promoting active and healthy aging. Mental health education for older people is concerned with creating housing and environments that improve well-being and enable people to lead healthy and integrated lives.

2.3. Neural Networks and Artificial Intelligence main aspects

Artificial intelligence (AI) is the science and technology of creating intelligent machines, especially intelligent computer programs. AI is related to the similar task of using computers to understand human intelligence, but is not necessarily limited to biologically plausible methods.

The following classification of AI types is currently used:

Artificial Super Intelligence (ASI) is a hypothetical AI that will not only be able to reproduce the maximum of human abilities, but even surpass them. Believers in ASI believe that it will gain the power to penetrate into the thoughts and feelings of a person in order to subjugate him to its will. Obviously, at this point is the realm of science fiction.

Artificial General Intelligence (AGI) is one step below ASI in the degree of reasonableness, adherents of this type of AI are limited in their beliefs by the possibility of creating machines that can at least perform the same actions as a person.

Artificial Narrow Intelligence (ANI) allows you to see faint hints of intelligence in the behavior of machines (that's why it's called weak). It is designed to perform only a strictly defined narrow range of applications (that's why it's called narrow). In the case of ANI, no human-like autonomous behavior or self-development is possible. ANI-enabled systems can only exist in the form in which they were created by humans and cannot even theoretically escape their control [39].

Neural networks are computational systems or machines designed to simulate the analytical actions performed by the human brain. Neural networks belong to the field of artificial intelligence (AI) and are used to recognize hidden patterns in raw data, grouping and classification, as well as to solve problems in the field of AI, machine learning and deep learning.

Artificial neural networks consist of several layers:

- input;
- hidden;
- output layers.

Each of them has several nodes, which are connected to all nodes in the network by means of different links and have their own "weight" affecting the strength of the transmitted signal. This architecture allows for parallel processing of data and constant comparison with the results of processing at each stage. Neural networks are initially trained on dimensioned data sets with obvious patterns, and then use the acquired skills for self-learning and achieving results. A neural network can make millions of attempts to achieve the same results as the example provided for training. There are dozens of types of neural networks, which differ in architecture, peculiarities of functioning and spheres of application. At the same time, three types of networks are the most common.

Feed forward neural networks, (FFNN). A straight-line type of neural networks, in which neighboring nodes of a layer are not connected, and information is transmitted directly from the input layer to the output layer. FFNNs have low functionality, so they are often used in combination with other types of networks.

Convolutional neural network, (CNN). They consist of layers of five types:

- input;
- convolutional;
- combining;
- connected;
- output.

Each layer performs a specific task: for example, summarizing or connecting data. Recurrent neural networks are used for image classification, object recognition, prediction, natural language processing and other tasks.

Recurrent neural network, (RNN). Utilize directed sequence of communication between nodes. In RNN, the result of computation at each stage is used as input data for the next. Because of this, recurrent neural networks can process a series of events in time or sequence to produce a computational result. RNNs are used for language modeling and text generation, machine translation, speech recognition and other tasks.

There are several basic types of tasks for which neural networks can be used.

Classification. For recognizing faces, emotions, types of objects: e.g., squares, circles, triangles. Also, for pattern recognition, i.e., selecting a particular object from a proposed set: e.g., selecting a square among triangles.

Regression. For determining age from a photograph, making a forecast of stock exchange rates, assessing the value of property and other tasks that require a specific number as a result of processing.

Time series forecasting. For making long-term predictions based on a dynamic time series of values. For example, neural networks are used to predict prices, physical phenomena, consumption volume, and other indicators. In fact, even the operation of Tesla's autopilot can be attributed to the process of time series forecasting.

Clustering. For studying and sorting large amounts of unlabeled data in conditions when the number of classes in the output is unknown, i.e. for combining data by attributes. For example, clustering is used to identify picture classes and customer segmentation.

Generation. For automated content creation or content transformation. Neural network generation is used to create unique texts, audio files, videos, coloring black and white movies, and even changing the environment in a photo [40].

2.4 Neural Networks and Motion capture

Motion capture algorithms (MCA) represent a wide range of methodologies used to collect and analyze motion data in various domains. They fall into several main types, including marker-based, markerless, and inertial systems. Marker-based systems utilize physical markers attached to key points in the anatomy, which provides accurate tracking but often requires controlled environmental conditions. Markerless systems, on the other hand, rely on computer vision and computer vision algorithms, using cameras and sophisticated techniques to track movement without markers. This provides greater flexibility, but can create challenges in the accuracy and stability of the system. Inertial algorithms use sensors placed on a person's or object's body to capture motion data, providing portability and freedom of movement, but can face issues with drift and sensor calibration [41].

Motion capture systems (MCS) have also largely taken advantage of artificial intelligence algorithms to improve the processing and analysis of the acquired data. In particular, neural networks such as convolutional neural networks (CNNs) [42] and recurrent neural networks (RNNs) [43] have found wide application in motion processing. CNNs are used to extract features from raw motion data, allowing for more accurate motion extraction and classification, while RNNs are able to model temporal dependencies and account for motion sequences, improving the understanding of motion context. The integration of artificial intelligence algorithms with motion capture algorithms opens up new opportunities for more accurate motion analysis, overcoming the challenges of noisy data and improving the accuracy and adaptability of motion capture systems in a wide range of applications, including biomechanics, animation, sports science and rehabilitation therapies.

Currently, there are several types of motion capture algorithms based on different principles of operation and further application [44, 45].

1) Marker-based motion capture algorithms

Marker-based motion capture algorithms are based on the use of physical markers that are attached to key points on the body of a person or object. These markers have known characteristics and stand out vividly from their surroundings. The principle of operation is to use cameras or sensors that can capture the position and orientation of these markers in three-dimensional space. Marker-based MCS work by capturing the position of markers using multiple cameras placed around the object or in space to maximize coverage of the capture area. These cameras acquire images of the markers and transmit the data to a computer, where special algorithms process the images to determine the exact position of each marker in three-dimensional space. Motion is then recreated by analyzing the change in marker position over time. Complex mathematical models and algorithms track the movement of the markers and, based on this data, reconstruct the movement of an object or person in three-dimensional space [46].

This method is highly accurate and provides detailed motion information including position, rotation angles, and movement trajectories. However, it requires precise marker placement on the object and visibility to cameras, which can be a limiting factor in uncontrolled or dynamic environments.

2) Camera-based motion capture algorithms

Camera-based motion capture algorithms work on computer vision and image processing to track the movements of objects or people without the use of physical markers. These systems are based on the use of one or more cameras placed around a motion capture area to acquire video streams from different angles of view [47].

The principle of operation is to identify and track unique characteristics of objects or body parts in video streams using computer algorithms. These characteristics can be certain dots, patterns, or even shapes that stand out against the background or context of surrounding objects. Camera-based systems use computer vision algorithms such as motion tracking, pattern recognition, or deep neural networks to analyze video streams and detect the movement of objects or body parts. By tracking the movement of these features over time, the systems reconstruct object movements in three-dimensional space [48].

This method allows tracking movements in a more natural environment without the need for markers, which gives more freedom and flexibility. However, it can be more prone to noise and requires more sophisticated image processing algorithms to ensure tracking accuracy and stability, especially under changing lighting conditions or in the presence of environmental noise.

3) Sensor-based motion capture algorithms

Sensor-based motion capture algorithms utilize inertial sensors such as accelerometers, gyroscopes, and magnetometers placed on the human body or an object to track and record its movements in space [49].

The principle of operation of such systems is to measure acceleration, angular velocity and magnetic field around an object using embedded sensors. Accelerometers measure linear acceleration, gyroscopes measure angular velocities, and magnetometers measure the magnetic field, making it possible to determine changes in the position and orientation of the object in space. The data received from the sensors is processed by filtering and integration algorithms that integrate measurements from different sensors to determine the position and orientation of an object in three-dimensional space. For example, the Kalman filter method can be used to combine data from different sensors to improve the accuracy and stability of measurements [50].

This method offers portability and freedom of movement, as it does not require special structures or chamber installation in the surrounding space. However, sensor-based systems can encounter problems such as accumulation of measurement errors, data drift, or the need to calibrate sensors to ensure long-term measurement accuracy.

4) Motion capture algorithms based on neural networks

Neural network-based motion capture algorithms are essentially a separate branch of methods using external cameras, but in this case the special feature is the use of neural structures to analyze and process motion data for feature extraction, motion classification, or prediction of next steps.

Converged neural networks (CNNs) are often used to extract features from images or sequences of motion data. They are able to automatically extract features and patterns in the data, such as pose or motion features, by applying convolution and pooling layers to gradually abstract information. Recurrent neural networks (RNNs) or their variations such as Long Short-Term Memory (LSTM) or Gated Recurrent Unit (GRU) can be used to model a sequence of movements. They are able to incorporate context and time dependencies to improve the understanding of movement sequences and their dynamics [51, 52].

The principle is to train neural networks on large amounts of motion data, where the models are trained to recognize, classify or generate motions. Neural networks can be used to recognize specific movements such as walking, running, hand flapping, and others, as well as to predict future steps based on the current state. The use of neural networks in motion capture algorithms allows for deeper and more automated motion analysis, overcoming some of the traditional limitations such as the complexity of pose detection and noise in motion data. However, this approach requires a large amount of labeled data to train neural networks and can require significant computational resources for training and inferring models.

2.4.1. Application of motion capture algorithms in the medical field.

If we talk about the medical aspect of applying such algorithms, there are several directions:

1) Diagnosis and monitoring.
2) Prosthesis monitoring.
3) General research.
4) Serious games.

In disease diagnosis and monitoring, motion capture algorithms play an important role in providing a more accurate and objective assessment of motor function in patients. Here are some examples of their use [53]:

- *Diagnosis of neurological disorders*: Motion capture algorithms help in the diagnosis and evaluation of neurological diseases such as Parkinson's disease or Alzheimer's disease. They allow you to analyze changes in patients' movements, identifying characteristic patterns and symptoms that may be difficult to notice under normal circumstances.
- *Assessing response to treatment*: Motion capture algorithms are used to monitor patients' response to treatment. They allow assessment of how motor skills change under the influence of medication or therapy, which helps in treatment management and optimization.
- *Monitoring rehabilitation progress*: During rehabilitation after stroke, injury or other conditions, motion capture algorithms are used to monitor a patient's progress. They allow recording and analyzing movements, which helps physical therapists and rehabilitation specialists to evaluate the effectiveness of the rehabilitation program and make adjustments accordingly.
- *Health Monitoring*: Motion capture algorithms can be used to monitor overall health. For example, they can help assess balance, coordination, and overall physical activity, which can be useful in diagnosing various diseases or assessing a patient's overall health.

Motion capture algorithms can be used to monitor and diagnose prostheses, providing accurate assessment of patients' motor capabilities and efficient prosthesis management. There are basically only three main options for this use case [54]:

- *Functional Needs Assessment*: Motion capture algorithms enable detailed assessment of the functional needs of patients who require prostheses or orthoses. They help in identifying specific motor tasks or areas where the patient needs functional support or replacement.
- *Prosthesis control*: Motion capture algorithms are used to control prostheses, allowing patients to control them with their own movements. This can be particularly important in the case of prosthetic limbs, where algorithms interpret the movements of the remaining limb to control the prosthesis.
- *Monitoring accuracy and functionality*: Motion capture algorithms can be used to assess the accuracy and functionality of prostheses. They help evaluate the performance of the prosthesis in real time, allowing adjustments to be made to improve its functionality and suit the patient's needs.

In general, medical practice, motion capture algorithms are widely used for a variety of purposes, including diagnosis, monitoring, and rehabilitation. Here are some examples of their use [55,56]:

- *Diagnosis and Physical Assessment*: Motion capture algorithms are used to assess patients' physical condition and identify abnormalities in motor function. They can help in assessing coordination, balance, gait and other motor skills, which can be important in diagnosing various conditions such as nervous system diseases or musculo-articular disorders.
- *Monitoring physical activity and health*: Motion capture algorithms can be used to monitor physical activity and overall health of patients. They help track activity level, number of steps, exercise intensity and other parameters, which is useful in lifestyle management and fitness monitoring.
- *Rehabilitation and Physical Therapy*: Motion capture algorithms are used in rehabilitation and physical therapy programs. They help to assess and record patient movements during rehabilitation after injuries, surgeries or illnesses, allowing for the development of more effective and personalized treatment programs.

- *Evaluating the effectiveness of drug treatment*: Motion capture algorithms can be used to evaluate the effectiveness of drug treatment. They allow you to analyze changes in patient movements in response to treatment, which helps in evaluating its effectiveness and adjusting treatment strategies.

Medical serious games, or health games, often utilize motion capture algorithms to create interactive and effective methods of rehabilitation, training, or diagnosis. Here are some examples of the use of such algorithms in medical serious games [57, 58]:

- *Rehabilitation after injuries and strokes*: Game applications using motion-capture algorithms help patients perform rehabilitation in a playful way. For example, games can offer exercises to restore motor function after a stroke or injury, using motion data to assess progress and adapt the level of difficulty.
- *Therapeutic exercises*: Games can include therapeutic exercises to improve coordination, balance, or strength. Motion capture algorithms allow players to interact with game content through their movements, making the exercises more engaging and effective.
- *Workouts to improve fitness*: Medical games can incorporate workouts to increase physical activity levels. Motion capture algorithms are used to assess and record the user's activity, allowing for the creation of personalized exercise programs.
- *Diagnostic applications*: Some serious games use motion capture algorithms to diagnose certain diseases or abnormalities in motor functions. This allows for early detection and monitoring of changes in movements, which can be useful for professionals when performing diagnostics.

The use of motion capture algorithms in the field of medical rehabilitation represents a significant breakthrough that enables accurate motor tracking, personalized programming, and improved rehabilitation outcomes. The effectiveness of motion capture algorithms in medical rehabilitation is evident in several key ways. First is objective assessment, as motion capture algorithms provide objective data on patients' motor skills, namely clear real-world performance of prescribed actions. This helps professionals to more accurately assess and track patients' progress during rehabilitation. Secondly, personalization of programs makes it easier to create individualized rehabilitation programs that take into account the specific movements and needs of each patient. Third, motivation through interactivity - the use of motion capture algorithms in game applications or specialized training programs makes the rehabilitation process more fun and motivating for patients, which promotes more active participation in the treatment process. The fourth point is potential growth and improved outcomes. By more accurately monitoring and adjusting rehabilitation programs based on data from motion capture algorithms, better treatment outcomes and faster functional recovery can be achieved

2.5 Serious Games

The term "games" still causes 99% of people to associate it with entertainment. And it's an empty entertainment, a useless pastime. A time for business and a time for pleasure. But today the game principle is increasingly used in psychology, teaching, business, military and other spheres of activity. Scientists and specialists are increasingly using games to achieve very serious, not entertaining purposes. For example, today gamification is increasingly used in building business processes within companies. But this is only one of many forms of "serious games", as it is now customary to call the entire spectrum of the use of gaming techniques in non-entertaining areas of activity [59].

In the most general definition, the essence of serious games is the simulation of any real processes or events in order to gain primary experience or skills under simulated conditions. That is, the primary purpose of serious games is to educate and train. And don't be fooled by the word "game" - serious games are not always fun and enjoyable for the players. The term itself has its origins in the 1970s. But as such, serious games were first used by the military in the 19th century. Today it is called "staff games", and represents, in general terms, the formulation of the headquarters of the military unit or the theoretical combat mission, to solve which the officers must develop a certain sequence of actions and solutions. In "civilians" serious games were mostly used in education, and only since the early 2000s have they begun to blossom [60, 61].

Also, if we will analyze the scientific side of the issue, but in the last 5-6 years there has been an increase in research in this area. If we going to check, for example Elsevier article database with keyword “Elderly”, “Rehabilitation Games” and “Serious Games”, we will notice, that for period 2000-2010, there is 143056 results, but for next 10 years that amount will be 243594 results, which is almost 70% more. And this amount is rising.

As mentioned above, the variety of applications of serious games is quite large. The most popular ones include the following:

- *Educational games*. Mainly used in schools and universities. Help make the learning process more attractive.

- *Simulations*. Some simulated real-life situations designed to develop specific skills without any risks in the learning process. For example, simulations of different types of machinery or businesses, simulations of different situations in business, management or economics.

- *Motivational games*. Designed to encourage participants to change their behavior and attitudes through social interaction. Mainly used in politics, management, sales, diplomacy.

- *Rehabilitation games*. Used as therapy in psychology, psychiatry and medicine [62].

Figure 2.1. Examples of different Serious Games interpretations.

If earlier serious games were held more in the form of live communication with other people, now more often they find electronic embodiment, because computers allow in a convenient form to implement games for almost any task. In this regard, the possibility of using this kind of applications is quite in demand, and, as research shows, promising.

As real-life illustrative examples, such simulations can be used in a wide variety of settings and fields. They can be played anytime and anywhere, making learning games a flexible educational tool. Educational games facilitate the comprehension of complex topics and are not bound by the limitations of classical teaching.

1) Medicine

Studies have proven that video games increase the efficiency of work, for example, surgeons: professionals who play them make faster decisions and better understand what is happening at each moment of the operation. The interactivity of "serious games" increases the level of memorization and understanding of the curriculum. Games provide a realistic surgical experience, allowing surgeons to learn techniques such as suturing, knot tying and tissue dissection. They have a built-in evaluation system that tracks performance and provides feedback on areas for improvement. This allows surgeons to identify their strengths and weaknesses.

Other games model protein folding and help relevant experts find new ways to fight diseases. Serious Games are also useful to teach patients how to maintain healthy habits and fight disease. Some medical simulators are designed to promote health and wellness - for example, physical therapy games are used for rehabilitation. Some training simulators help manage chronic conditions such as diabetes or depression. For example, some simulators can be used to improve mental health by setting and achieving goals related to physical activity, social support and positive thinking. There are games designed to detect dementia in its early stages. They are often very simple and fun, but provide scientists with valuable data about how people navigate through space that can be used to develop new diagnostic tests [63].

2) Education

With Serious Games, you can learn many disciplines, from school subjects to specialized skills. For example, you can learn the basics of algebra through a series of puzzles and challenges. An example of specialized skills training is FlightGear, an open-source flight simulator. This program is used to train pilots and explore aircraft systems. Sometimes among Serious Games you can find special educational versions of popular entertainment games that allow you to study almost all school subjects [64].

3) Socially relevant games

Serious Games can be designed to raise awareness of social issues such as poverty, climate change or human rights. They can be used to educate players about the causes and consequences of these issues, and to encourage them to take action [65].

2.5.1 Serious Games features and structure.

In addition to knowing general information about this category of applications, it should be clearly understood that these applications do not have a common structure. Depending on what function and what task a particular application will perform, its composition can be absolutely unique.

For greater clarity, you can draw an analogy with ordinary computer games created for entertainment. For example, among them there are many types that depend on their orientation. By the way of control, by the type of camera, by the principles of gameplay and so on. These types can be both cumulative, where several categories are combined, for example, simulator and shooter, or sandbox and logical quests, and independent [66]. Nevertheless, each category of games will have characteristic features, construction, development and gameplay.

Regarding Serious Games, the same rules apply. Depending on the task under which the application is developed, you will be able to trace certain features, among which there will be both general and specific. For example, for the Serious Games for Rehabilitation category, Table 2.1 summarizes the general and specific features that should be presented and can be included in the application [67].

Table 2.1. Demonstration comparison of the main and additional features of the criteria of the two conceptual categories of Serious Games.

№	Criteria for rehabilitation games	Criteria of games for learning
	Main criteria	
1	Simple and intuitive interface	Simple and intuitive interface
2	Detailed but not overloaded with information prompts and training	Detailed hints at the beginning and gradual abandonment of them by the end of the game
3	Clearly defined and set unit tasks for the player	Carefully planned task sequences for the player
4	The complexity of a single task depends on specific needs and specific exercises	The complexity of the tasks increases gradually, from lesser to greater complexity
5	Clear and visual display of results	Clear and visual display of results
6	Ability to track overall player progress and by single task	Ability to track trends in player progress
	Additional criteria	
7	Interface stylization for a more pleasing visual component	Interface stylization for a more pleasing visual component
8	Possibility to integrate additional means (sensors, control devices) into the game process	Possibility to integrate additional means (sensors, control devices) into the game process
9	Game integrations for greater interest (story)	Game integrations for greater interest (story)
10	Various methods of increasing the player's motivation for long-term and periodic completion of tasks	Various methods of increasing the player's motivation to complete tasks on a daily basis

What is listed in Table 2.1 demonstrates the aspects that are characteristic of the two categories of Serious Games presented for the example. This table is a good illustration of the differences between the parameters, which are essentially similar, but still different in terms of execution and application, and include different functions.

If we talk about Serious Games in general, we can distinguish 4 main categories of features, by which it is possible to characterize any application of this type. Among them are: Management, Interface, Gameplay, Technological aspect. The generalized structure is presented in Figure 2.2, which shows both the main features and some additional ones [68].

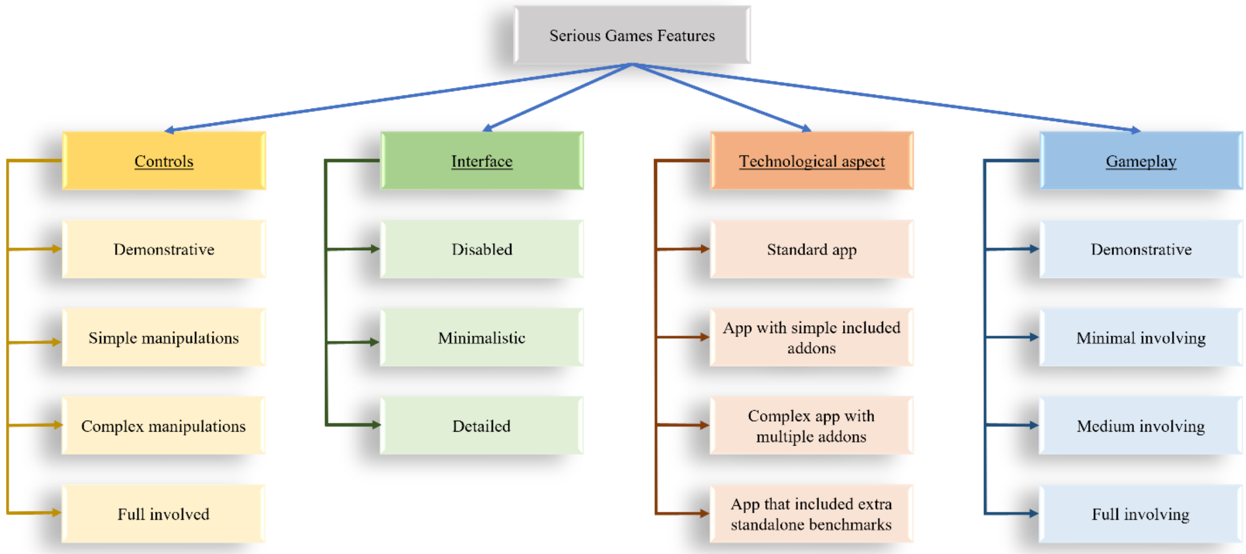


Figure 2.2. Serious Games main structure aspects.

It is necessary to elaborate on each of the presented characteristics in order to clearly understand those criteria and peculiarities of Serious Games construction, which will be used in further development and research.

2.5.1.1 Peculiarities of management realization

To begin with, it is necessary to think in advance about how exactly the user will interact with the application. In this case, as for any application, there are several options from which the main structure of the application will be built. The first option will be the one where the user will be shown the tasks in a demo form, while his interaction with the application in terms of direct control of it is reduced to zero. This control option is used when the system is developed for users with high level of physical or sometimes mental limitations, due to injuries (congenital or acquired) or age peculiarities. In these types of systems, the visual and game series is presented exclusively in the form of a video clip, or movie, where the player will only observe what is happening on the screen. This method of building Serious Games is used only in the direction of highly specialized games, or as an element of hints or training the player before the main task. By itself it is practically not used.

To summarize, it is possible to create a table of application control methods, and also to highlight the advantages and disadvantages of using one or another method, as demonstrated in Table 2.2. It should be clarified that the table will not consider standard control methods such as keyboard and mouse because they are assumed to be the default integrated control method.

Table 2.2. Application management options.

Management method	Advantages	Disadvantages
No control	- can be applied to severe degrees of user disability - does not require high computing power of devices - multiplatform	- demonstration function only - lack of customization flexibility - low retention - narrow focus - low motivation generation

Eye/voice control	- can be applied in case of severe degrees of user disability -capable of providing full control of cursors, or replacing them completely	- need for built-in or plug-in audio/video recording equipment - dependence on external noise and light conditions - need for individual customization for each device/user
Controlling body movements	- allow the whole body to be used as a controller - expand the range of rehabilitation techniques - Support motor skills and overall physical well-being - increase the variety of activities	- need for additional technical facilities - can be demanding on equipment capacity - has a minimum user state threshold -need for the presence of an assistant
Control by third-party technical means	- greatly expands the possibilities of monitoring and analyzing the user's condition - are able to diversify activities for the user	- need for additional hardware - need to customize devices - Limited platforms in use - need for an assistant

In essence, as shown in Table 2.2, there are 3 ways to manage the system. In the following, each of them should be considered in more detail in the paradigm of possibilities for use in the application under development. It should be clarified that this characterization does not imply consideration of the standard bundle of control devices (keyboard + mouse) due to the fact that by default any system should support this input method. Tactile control devices (tablet, phone) are similar to mouse use.

In the complete absence of user control, a number of problems arise that can often be critical in the realm of rehabilitation applications. Chief among these problems would be the extremely low repetition rate and low progress of the user themselves. Due to the fact that, in essence, the player cannot influence the process in any way, namely they cannot stop or start the system at the right moment, this can have an extremely negative impact on their progress. At the same time, in case of difficulties in one or another aspect or task, the user has no opportunity to repeat it, or to spend time on a longer consideration of all conditions. Due to the fact that the entire process of building an application is based on this "video" principle, the use of such systems is rational only in situations of training or demonstration of any aspects of the game.

The second method using eye-tracking algorithms or receiving and processing voice commands allows you to fully control almost any type of application. This method is also suitable for those users who for various reasons cannot use standard controls (keyboard, mouse, tablet/phone screen). The main problem with this method is that it can replace the usual controls, or act as an additional option, but nothing more. In addition, such algorithms are highly dependent on the environment in which they are used and on the receiving devices (microphone, webcam). We are talking about the quality of the equipment, the lighting in which it is used, the level of ambient noise. Also, the condition of the user plays an important role. In this case, we mean his eyes (whether there are various dysfunctions of the eyes and their motor skills), the quality of speech and diction, the capabilities of the speech apparatus (voice volume). In case of problems with any parameter, the system may not immediately respond correctly to commands.

The third method of control, in fact, is divided into two similar in meaning but different in execution. The first one is based on the fact that any action is performed by means of using additional devices: sensors, controllers, cameras, etc. In this case, there are many advantages. First, there is a high control over the state and actions of the user. Information from sensors allows not only to get full feedback on the results of the user during the game, but also to react adequately and in real time to his condition, for example, if the heart rate rises above the norm for a particular task, the application changes the pace, stops, etc. This allows a very flexible approach to each user individually and greatly expands the range of applications of a particular system. Secondly, in the case of using additional devices it is possible to diversify the range of tasks and exercises for users. By introducing various physical rehabilitation techniques and training methods for intellectual disabilities, it is possible to increase the efficiency of the rehabilitation process to a rather high degree. This method has certain disadvantages, among which are the increase in the cost of development, due to the need to develop new or adapt existing equipment, the corresponding increase in the cost of systems for purchase by end users, the need to understand the operation of systems for their correct use.

The second branch allows to achieve almost the same support result, but unlike the first variant does not require additional technical means. The meaning of this method is that it is based on special software algorithms that are able to recognize in real time the user's body position, actions and movements and subsequently interpret them as input commands to control the system. If the first type was based on technical additions due to various devices and sensors, the main feature of the second type is that a special algorithm built inside the system is responsible for recognizing and processing data. It can be represented in different ways: as a certain block of artificial intelligence, a neural network algorithm, a block of strict commands and conditions, an external control unit. Regardless of the representation, the essence of the work is a clear sequence of commands and actions: a video signal is input to the system, this signal is divided into fragments and processed by the "recognition system", then, depending on the result, the algorithm makes a decision, gives a command, and then the user sees the system's response to his actions, whether it is changing the cursor position, for example, or changing any in-game parameters. This control method appeared not so long ago, thanks to the rapid development of machine learning technologies and the development of neural networks. Despite the fact that it allows to speed up and, in some aspects, reduce the cost of development and operation, as well as to expand the range of possibilities a little more, it is also more dependent on the operating conditions (lighting, quality of input data, equipment parameters).

Usually, mixes of different variations and degrees of involvement of the player in various elements of control are used. For example, navigation in the menu can be done by pressing only 2-3 buttons or no buttons at all, then any task can be performed with a medium or complex degree of involvement, and then it is possible to introduce a complex control system, where the user himself can set various parameters, conditions of their fulfillment and so on. The most reasonable approach to the development of Serious Games is to use just the above-described mixed method of control. In this case, the main condition will be the task set before the user and the theme of the application direction as a whole [69].

2.5.1.2 Interface construction features

It's one thing how to manage, but it's quite another what to manage. The choice of interface is also an important task in development. In this case, there are not so many options: there is no interface, the interface includes only the necessary functions, the interface is detailed, displaying various settings, characteristics, systems, fully controlling the configuration and management of the application.

Before considering the variants of execution of the system interface (sometimes called shell, or visual) it is important to understand that in the design and development of any of its elements there are several main rules [70]:

1. **Interface naturalness**. A natural interface is one that does not force the user to significantly change the way he or she is used to solving a problem. This means, in particular, that messages and results produced by the application should not require additional explanations. It is also advisable to retain the system of notation and terminology used in the given subject area. The use of familiar concepts and images (metaphors) provides an intuitive interface to the user's tasks. However, when using metaphors, you should not limit their machine realization to a complete analogy with the same-named objects of the real world. Users remember the action associated with a familiar object more easily than they would remember the name of the command associated with that action.

2. **Interface consistency**. Consistency allows users to transfer their existing knowledge to new tasks, learn new aspects faster, and thus focus their attention on the task at hand rather than wasting time trying to understand the differences in the use of certain controls, commands, etc. By ensuring continuity of previously acquired knowledge and skills, consistency makes the interface recognizable and predictable. Consistency is important for all aspects of the interface, including command names, visual presentation of information, and the behavior of interactive elements.

3. **Interface friendliness** (the principle of user "forgiveness"). Users usually learn the peculiarities of working with a new software product by trial and error. An effective interface should take this approach into account. At each stage of operation, it should allow only the appropriate set of actions and warn users of those situations where they may damage the system or data; it is even better if the user has the ability to undo or correct the actions performed. Even with a well-designed interface, users can make errors of one sort or another. These errors can be of either the "physical" type (accidentally selecting the wrong command or data) or the "logical" type (making the wrong decision to select a command or data). An effective interface must be able to prevent situations that are likely to end in errors. It should also be able to adapt to potential user errors and make it easier for the user to correct the consequences of such errors.

4. **The "feedback" principle**. Always provide feedback for user actions. Each user action should receive visual and sometimes audible confirmation that the software has accepted the command entered; the type of response should, where possible, take into account the nature of the action performed. Feedback is effective if it is realized in a timely manner, i.e. as close as possible to the point of the user's last interaction with the system. When the computer is processing an incoming task, it is useful to provide the user with information regarding the status of the process, as well as the ability to interrupt the process if necessary. Nothing is more disconcerting to a less experienced user than a locked screen that is unresponsive. A typical user is able to endure only a few seconds of waiting for a response from his electronic "interlocutor".

5. **Interface simplicity**. The interface should be simple. This is not meant to be simplistic, but to make it easy to learn and use. In addition, it should provide access to the full range of functionality provided by the application. Realizing access to extensive functionality and ensuring ease of use are at odds with each other. Designing an effective interface is intended to balance these goals. One possible way to maintain simplicity is to present information on the screen that is minimally necessary for the user to complete the next step of a task. In particular, avoid verbose command names or messages. Ill-conceived or redundant phrases make it difficult for the user to extract essential information. Another way to create a simple but effective interface is the placement and presentation of elements on the screen, taking into account their semantic meaning and logical relationship. This allows the user's associative thinking to be used in the work process.

6. **Interface flexibility**. Ability to take into account the level of training and productivity of the user. The property of flexibility implies the possibility of changing the dialog structure and/or input data. The concept of flexible (adaptive) interface is currently one of the main areas of research of human-computer interaction. The main problem is not how to organize changes in the dialog, but what attributes should be used to determine the need for changes and their essence.

7. **Aesthetic appeal**. Designing visual components is the most important part of program interface development. Correct visual representation of the objects used provides the transfer of very important additional information about the behavior and interaction of various objects. At the same time, you should remember that each visual element that appears on the screen potentially requires the user's attention, which, as you know, is not unlimited. Ensure that the screen provides an environment that not only facilitates the user's understanding of the information presented, but also allows them to focus on the most important aspects of it.

Returning to the shell construction methods described in Figure 2.2, in the first case the structure of the application is obvious: the user does not select any parameters, all prompts (if any) are shown according to the scenario planned by the developers and in a certain time interval, the process of task execution is linear and does not imply any branches, the result of task execution (if any) is shown in the way it is planned by the developers and without unnecessary information. On the one hand, this system structure minimizes cases when a user cannot start an application, task, or activity correctly. In other words, the principle "Installed. Run. Play." On the other hand, this approach can only work in the case of an extremely narrowly focused system, which is oriented to a specific task and does not imply any changes inside or options for its completion. A variant of this execution may only be appropriate when a demonstration of what the user will need to accomplish in a particular task is needed. In other words, training, which can be completed only in the case, and the stages of which can be completed only if the user step by step performs the necessary actions. It is not reasonable to build the whole system structure on this principle [71].

The second method is at the same time the most common among software applications in general, and for Serious Games in particular. Its main advantage is its extremely high flexibility of execution and application. Depending on the situation, some of the rules described above can sometimes be omitted for lack of necessity, but in general should be followed to some extent. The method of minimalist interface due to its versatility and allows you to achieve the greatest response from the user. Its direct flexibility lies in the fact that different elements and blocks of the application can be made with different degrees of complexity of the shell. For example, when selecting an activity (if such a possibility is implied), the interface is shown, has certain possibilities of customization and selection of necessary functions. Further, directly in the activity itself, any elements may be absent at all. And on the result inspection window, information may be shown with a full range of information. All these variations and sequences can be completely different and help to increase the immersion of the user in the process of using the application. At the same time, the main disadvantage of this method is that it takes much more time to develop and design than the other two options. This is due to the fact that the variety of controls can be so strong that it can be difficult for the user to navigate in the application. This can happen for various reasons: illogical connections between menu items, excessive or insufficient informativeness, visual discomfort (selection of colors, shapes, effects), illogical location of contextual elements and many others. Therefore, it is extremely important, when developing any system, to spend a sufficient amount of time on interface design and engineering.

The third method is essentially a variation of the second, with the only difference being that all interface elements in any variant of its execution represent the most extended and detailed set of information presentation. This method takes place in cases where the user must know all the details of tasks and activities. For example, to display results and show them to a mentor/physician. Usually, such features are used as hidden functions, available only on special occasions, or to users with special access. If this method is used on a permanent basis, the application will be too overloaded with unnecessary information and problematic to use by ordinary users, but can be built in as an option for "advanced" functionality.

To summarize the variants of the control interface design, it is necessary to use a combination of all three above-described methods of construction to develop a multifunctional system for rehabilitation, but it is important to clearly understand in which cases it is possible and necessary to use them, in order to achieve maximum convenience of the system and at the same time good functionality and informativeness [72].

2.5.1.3 Technological aspect

Depending on how functional the rehabilitation application should be, there are different methods of introducing and implementing possible additional tools, both technical and software. In total, four such types can be distinguished:

1) Standard applications. This is the most common and simple type of implementation. It is characterized by the fact that all necessary functions are performed by means of the internal program code of the application. This method does not use additional third-party independent blocks, algorithms, control or registration devices.
2) Simple add-ons. In this case, there may be various one-syllable modules that are responsible for a specific function and can be disabled/enabled at any time by the user or mentor/physician. The type of execution of such add-ons may be either in software or hardware variant. As an example, such modules can be additional controllers, or various program functions, the absence/presence of which does not critically affect the main gameplay.
3) Complex multi-structured systems. These applications can be described as multilevel systems in which similarities are built between logical and functional chains responsible for different aspects of the application. This method is used when the range of tasks is so complex and multilevel that conventional algorithms may not be able to cope with the tasks. Therefore, there is a need to build different program structures, which can be both closely related and independent, but subordinate to a single structure. An example of such systems is complex monitoring applications that have to monitor in real time several groups of indicators that are taken when several groups of users perform different tasks. In such a case, different "branches" of the system are responsible for different tasks in order to distribute the load and increase stability.

4) Independent embedded systems and benchmarks. This structure is somewhat similar to the previous one, with the difference that instead of subsystem blocks, independent algorithms are used, or in other words, "programs in a program". A striking example of such systems are applications in which algorithms of neural networks, artificial intelligence, or multilevel blocks of fuzzy logic algorithms are embedded. Such systems are able to work independently and simultaneously with the main blocks. Such realization is reasonable in cases when it is necessary to provide multithreaded calculations, to provide various parallel processes, or in cases when high speed and flexibility of the system is needed, which is the advantage of such realization. The disadvantage is that such structures can be demanding to the computational capabilities of the used equipment.

The types of applications presented above do not imply that any application should follow a uniform structure in terms of the availability of augmentative tools and algorithms. In fact, in most cases, support and rehabilitation systems and applications include at least two methods of integrating additional tools [73].

2.5.1.4 Features of gameplay design and implementation

Separately and in more detail, it is worth considering the peculiarities of gameplay construction. The parameters described below will be in some sense similar to those presented in the interface and control sections, but they have their own unique features and are the main basis for building any application. Depending on what directions (rules) of gameplay construction will be chosen at the design stage, the set of additional design tools, including those described above, will also change.

In fact, this parameter represents the direct process of playing or working with the application. Unlike all the usual entertainment options, Serious Games are projects aimed at solving problems, not at getting pleasure. However, despite the fact that these games were originally created for learning and developing various skills, they use the same game design tools as entertainment games. Nevertheless, the main purpose of Serious Rehabilitation and Support Games is to help users train or maintain various aspects of health or life. If we consider the gameplay part in a structural way, it will be a collection of different aspects, including those described earlier. There are five aspects in total, and all of them will be considered from the perspective of rehabilitation games and apps specifically.

- Platform
- Game mechanics and pace of play
- Story
- Graphic design and sound
- Player engagement

It is now necessary to examine each of the above aspects in turn. Starting with the *platform*, it is important to know that in this case the choice depends directly on the medical or educational tasks that have been assigned to a particular, or group of, users. These options can be several: personal computer (with or without the use of additional devices or equipment), mobile platform (tablet, phone) or Web applications that are of the multiplatform use type. Depending on which platform is chosen as the main platform, the main aspect of management, interface, additional tools and overall task design will be selected.

Game Mechanics. This item will directly depend on the rehabilitation task that has been assigned to the user. If, for example, the system is designed to restore or support the muscular system, then predominantly all the activities inside and all the mechanics will be aimed at working through this problem. The activities themselves will be presented as simulations of physical exercises and actions. In case the system is aimed at learning, the tasks will correspond to exercises for working with cognitive functions and will be presented graphically. The point is that it is this aspect that is specific to Serious Games applications, around which the main design and development of applications of this type will be based.

Story. In terms of serious games, this aspect is highly situational. It takes place if there is a need to somehow diversify the use of the system for the user. The main benefit of introducing a story into a rehabilitation application is the possibility to increase the motivation of users to perform the proposed activities. Regarding the effectiveness of story add-ons in the Serious Games paradigm, it is difficult to say anything unequivocally. This aspect is highly dependent on the specific application and its requirements.

Graphic design and sound. Being an aesthetic aspect, it plays the second most important role after game mechanics. This parameter directly affects the perception of actions by the user, contributes to immersion and banal allows you to aesthetically support the player. Yes, on the one hand, any set activity can be performed in a conventional-schematic representation, but for the majority of those who use applications it is important what they see on the screen. If a person is visually uncomfortable, he or she will not be able to perform the task correctly and to the end, and the subsequent return to a failed application will only accumulate negative experiences and emotions. As in the case of the interface, the correct graphical display of objects, scenes, animations and other things will contribute to a better assimilation of the information received, and will increase the player's pleasure from what is seen on the screen. The same applies to the sound. Pleasant environment, corresponding to what is happening on the screen, various sounds when performing actions, music component.

Player Involvement. Although Serious Games for Rehabilitation and Support are initially used for a specific purpose, and therefore users should not have any questions about the need to use such applications, there is a need to maintain this motivation during the game. This can be achieved in different ways: a special style of addressing the user, special hints, rewards for the fulfillment of activities and so on. The main task of this aspect is to constantly and maximally involve the user in performing the proposed activities, which will contribute to the quality of rehabilitation activities [74].

3

Methods

If we talk about the system of building the research methodology, it can be divided into three main parts: Information, Rehabilitation and Development. In graphic form, this process can be interpreted as shown in Figure 1.

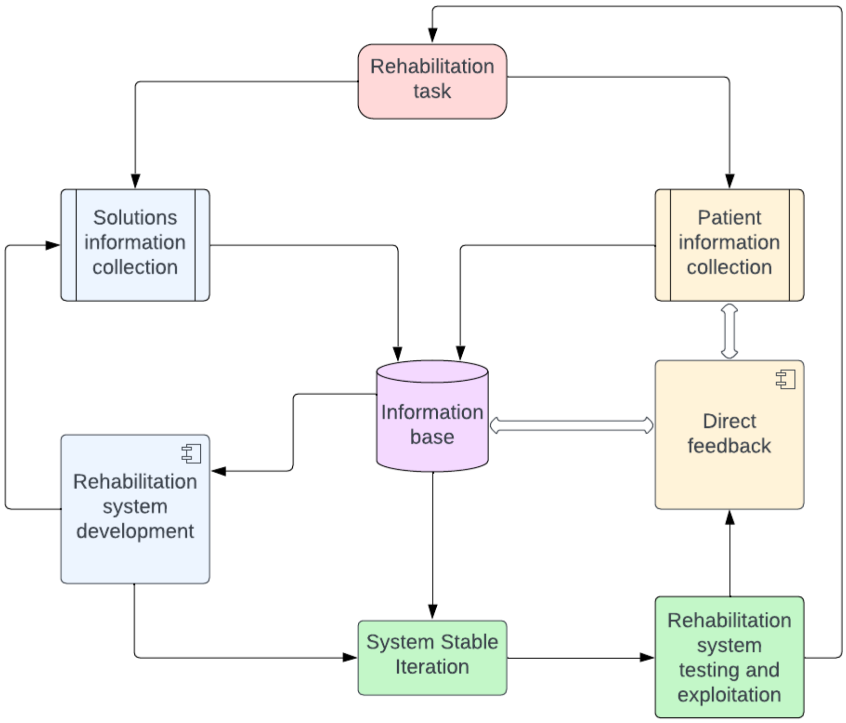


Figure 3.1. Main Methodology Diagram.

Any process always starts with the formulation of a rehabilitation task, after which the process is divided into two conditional directions: research of the necessary information concerning the user (initial data, rehabilitation directions, possible necessary parameters) and concerning the best program or technical solution for the task. Both processes are constantly interconnected, with a constant exchange of received and processed data, which increases the efficiency of development and minimizes possible errors.

3.1 Data Sources and Exclusion Criteria

First of all, for a deeper study of the issue raised in this dissertation, it is necessary to consider the sources of information extremely carefully and fully, for the description of this kind of systems. Before you begin, you must first determine a few key parameters:

- What areas of science are worth pursuing.

- What sources of information are acceptable.
- Which systems to look at first.
- What basic features of the systems to be searched for are worth considering.

Let's start in order. Regarding the scientific field, the first thing to understand is what kind of products to consider. Obviously, the first place to start is in the medical field of knowledge, since the products we are looking for are for rehabilitation and support. Nevertheless, it should be remembered that this classification should include only those systems that are a product of information development.

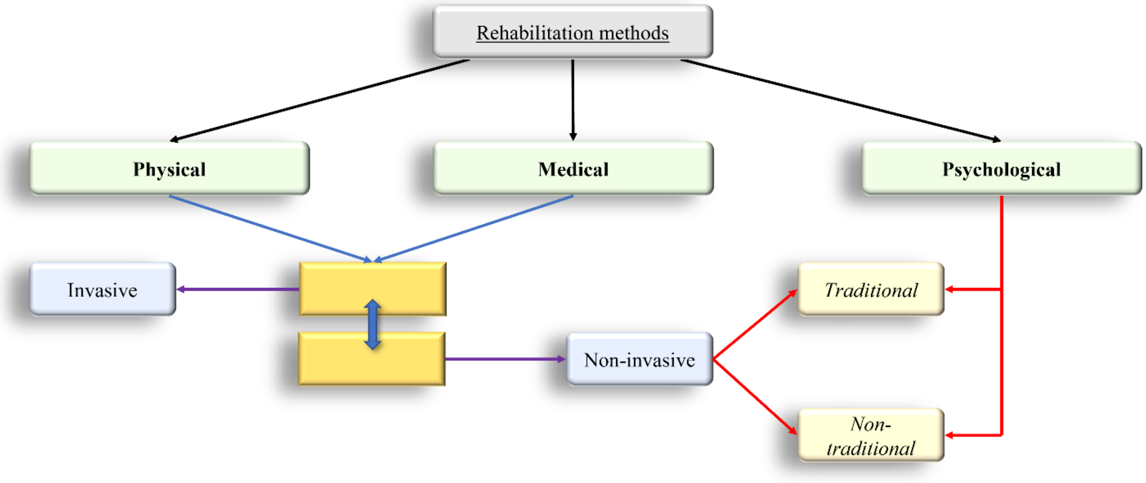


Figure 3.2. Structure of rehabilitation processes.

A close look at Figure 3.2 reveals the structure of the process and the concept of rehabilitation as such. Thanks to this diagram, it is possible to see that the information that will be needed for further research should be sought precisely in the area of non-traditional methods of rehabilitation procedures. Considering that research and data are of interest mainly in the technical field of knowledge, because the thesis presented here explores exactly the technical and software solutions of rehabilitation tools-assistants, so it is necessary to search in sources that represent the technical field in the first place, with the notation "related to medicine".

The second question would be appropriate to ask what sources this information should be found in. While working on this dissertation, it is important to use as reliable and profiled sources of information as possible, with a high level of credibility and scientific status. During the selection and preliminary search for information, it was decided to take data only from sources with a high level of information, namely internationally recognized scientific publishers. Also, as sources will serve articles from scientific journals, the quartile of which is at the level of Q1, Q2. Concerning the basic scientific sources for the theoretical data and reasoning, articles and statements of the profiled scientific editions, and also the specialized literature will be taken as well.

The third question is more complex. In terms of which systems should be considered and which should not, we need to decide on the direction of the study. This thesis will consider and present those solutions that aim to support users suffering from musculoskeletal problems, as well as those who need constant physiological support. In this regard, only those systems and solutions will be taken into account that are designed directly for the same purposes, but in some or other interpretations.

The answer to the question of what the main features of the systems will be considered, at this stage it is difficult to identify any specific ones. We can talk about the desired requirements, such as minimum requirements to the user from the technical side, or high accessibility and mobility. This question should be considered at this stage as a kind of general concept, which will correspond to the selected examples of systems under study.

Also, during the work with the data, it is necessary to introduce some restrictive framework, which should be adhered to in order to implement the primary filtering and sampling of information. The exclusion criteria described below will serve as such a framework.

Exclusion criteria:

- First criteria is **Population**. Despite the fact that as a population there are no restrictions on the use of rehabilitation systems, since such systems will work for the benefit of both needy users and healthy people. Nevertheless, solutions that are initially aimed at a healthy audience should be excluded. The rationale for this is that this study will examine the difference in efficacy of assistive systems in relation to traditional methods of support, and the involvement of healthy people may distort the overall picture of the evaluation.
- The second criterion is the **Age limit**. Again, considering that the systems in question have no age restrictions on their use, nevertheless, in this dissertation the effects will be considered exactly in elderly people, as well as in patients with serious problems of the musculoskeletal system, which under certain conditions can be regarded as similar situations. Therefore, this study will only take into account solutions that are intended for use by the elderly aged 60 years and above.
- The third criterion: the **Technical equipment** of the solution. As mentioned earlier, this kind of system is characterized by one advantage over traditional rehabilitation methods, namely the ability to minimize the necessary technical and material base. Considering that the systems considered in this dissertation are software and hardware systems, accordingly, we will primarily consider those systems that require only a personal computer or device for their use.
- The fourth criterion is the degree of **Mentor/doctor involvement**. As with any rehabilitation procedure, the assistive systems in question should allow the mentor or physician full control of the rehabilitation procedures. The only question is how explicitly a particular system can arrange this control. In this study, we will primarily consider those systems that can make the work of the preceptor as simple as possible, and make the process of monitoring the user as simple as possible, but at the same time allowing for the best possible diagnostic information.

The criteria listed above will help you choose and filter information sources more accurately. This will not only help to minimize research time, but also to select the highest quality information.

3.1.1 Search Method

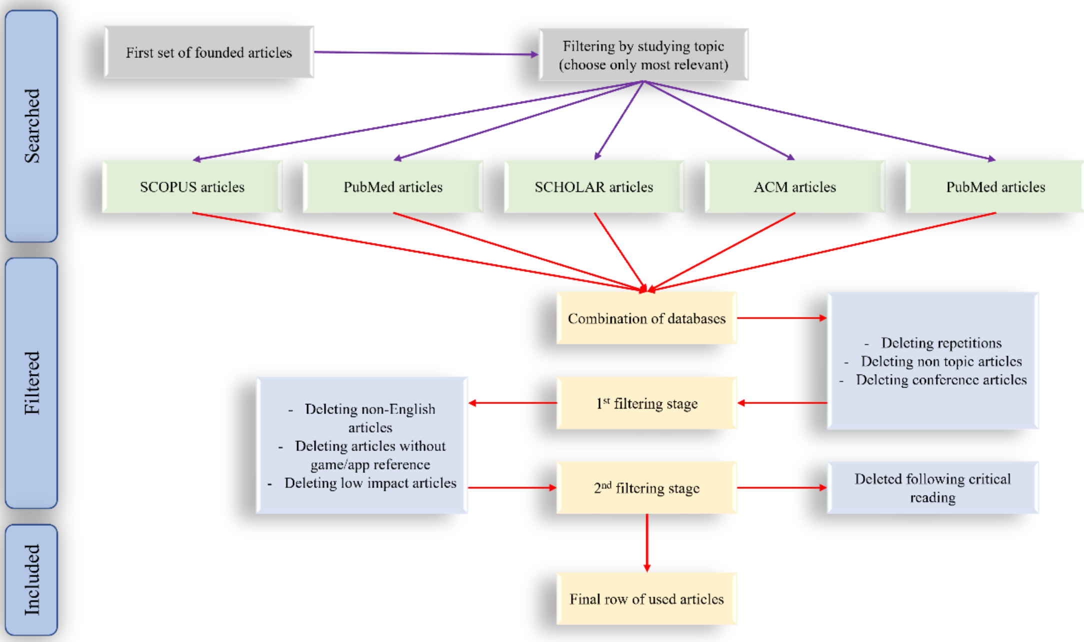


Figure 3.3. Diagram of the resources search algorithm.

The selection of information sources is a fundamental stage in the development of the project. Structurally, this stage was divided into several parts, which contributed to the final set of data used later, and which became the basis for the development of our own platform.

The first stage of information retrieval was the research of articles with "tags" of interest. In the first stage, articles were filtered by means of a search of the largest databases of scientific papers. The list of words, as well as the number of results obtained from each combination are presented in Table 3.1. The color indicates those categories of search queries and their combinations that were used for different cases of the study. For the case of the Physical block of the system the queries are highlighted in orange, for the case of the Cognitive block - in blue, and the queries that were relevant for both - in green.

Table 3.1. Results of search stage process.

Keyword	Database						
	ACM	IEEE	DBLP	Scholar	PubMed	SCOPUS	PsycInfo
Intellectual disability	18005	111	21	184000	21127	20655	63
Frailty	78654	1234	548	387900	29476	39067	6
Elderly	69579	987	1325	448300	33215	51566	109
Frailty (AND) games	13479	1868	2058	684900	21443	16111	6
Games for elderly	12254	1567	1679	982000	19899	14254	68
Frailty (AND) rehabilitation	6789	16874	2057	1059500	25684	7654	2
Cognitive	24113	26220	7164	1140000	270843	343373	22
Game	35751	27217	11409	1060000	15650	134404	0
Serious game	48082	2417	621	454000	947	7780	0

Mobile app	63687	5422	3416	281000	14196	19069	73
Executive Function	24686	60	70	1170000	21029	32104	809
Frailty (AND) rehabilitation (AND) games	15468	17682	2245	21800	12334	3122	2
Frailty (AND) Serious Games	135486	1776	711	47400	1034	5455	12
Physical Ability (AND) Frailty	97597	1039	650	353000	37468	43203	0
Neural network (AND) Frailty	68542	945	517	28900	1085	3460	0
Neurol network (AND) Serious games	13334	1324	239	92500	322	2292	0
Neural network (AND) Rehabilitation	101468	642	106	616000	98	1320	0
(Intellectual disability) AND (Game)	48991	33	4	21000	35	275	1
(Cognitive) AND (Serious Game)	62507	268	19	72100	211	982	2
(Intellectual disability) AND (Mobile App)	73440	6	1	10700	31	37	0
(Executive Function) AND (Serious games)	25463	12	1	17000	30	452	799
(Mobile App) AND (Intellectual Disability)	10405	7	2	16100	42	18	67

After receiving the results, the next step was filtering. Only those articles that were published in Q1-Q3 level scientific publications were relevant. The first step in cleaning the list of articles was to remove repeated articles from different databases, those articles that are not part of the topic under study, as well as works that are not scientific articles (notes in books, speeches at conferences, and so on). The second step was to remove those articles that did not fit the established structure.

This structure is a set of items that were compiled for several purposes, one of which was to select those articles that best fit the design concept that was defined in the submitted thesis. The main criteria for sampling are presented in Table 3.2.

Table 3.2. List of criteria for article quality analysis.

	Item number	**Description**	**Value**	**Weight**
About the text of the article itself (5 points)	1	Provide in the abstract an informative and balanced summary of what was done and what was found	1, 2, 3 (Bad disc, average quality, good quality)	1
	2	Give the eligibility criteria, and the sources and methods of selection of participants	1, 2, 3 (less than 10, more than 10, more than 50, 0 if no information)	1
	3	Discuss limitations of the study, considering sources of potential bias or imprecision	1/0 (Were they in study or not 0 - was, 1 - wasn't)	0,5
	4	Cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	1, 2, 3 (Bad disc, average quality, good quality)	1
	5	Was study or method based on existed solution	1/0 (New solution/ Based on existed one)	0.5
	6	Dataset used in the research is public or private	1/0 (1-public/0 - private)	2

Other Quality Metrics (5 points)	7	Application is public	1/0 (YES/NO)	1
	8	Innovation	1-2-3	0.5
	9	Testers shows better result using presented solution?	1/0 (YES/NO)	0.5
	10	Number of Citations/years	1-5 (Depend on year and citations)	1
Extra addition (2 points)	11	Platform	1, 2, 3 (PC, Mobile, Multiplatform)	0.5
	12	Journal/conference	1-journal, 0 - conference	0.5
Quality criteria		18 or higher	High	
		14-17	Medium	
		0-13	Low	

Each of the evaluation criteria was given a weight parameter, which corresponds to the importance and overall importance in the formation of the article. Table 3.2 directly shows the evaluation characteristics of the articles. Most of the criteria followed the PRISMA recommendations for systematic reviews and the authors added items ad-hoc.

It is also worth mentioning such an item as Innovation, which was added to the previous PRISMA criteria [83, 84]. This parameter was evaluated based on several criteria: the technology that was used to create the application, the basic algorithms used to create the system (neural networks, artificial intelligence, conventional software solutions, etc.), as well as taking into account the uniqueness and functionality of the application. The more comprehensive and functional in terms of technology an application is, the higher the grade level on a scale of 1 to 3.

The third stage of filtering was the evaluation of the remaining articles according to the sampling structure shown in Appendix A. In the end, after all stages of sorting, there were 48 articles in the residue, which became the basis for further research and development of our own system.

3.1.2 Data collection and Experiment Evaluation Methods

As the system is developed and tested, laboratory tests will be conducted at each stage to adjust the further course of development. It should be noted that one of the functional requirements for the system is that all data must be obtained and transmitted to the conditional "storage" in real time.

Also, the system itself must meet a certain structure, which will allow it to build the most effective process of obtaining and processing data. An example of such a structure is shown in Figure 3.4.

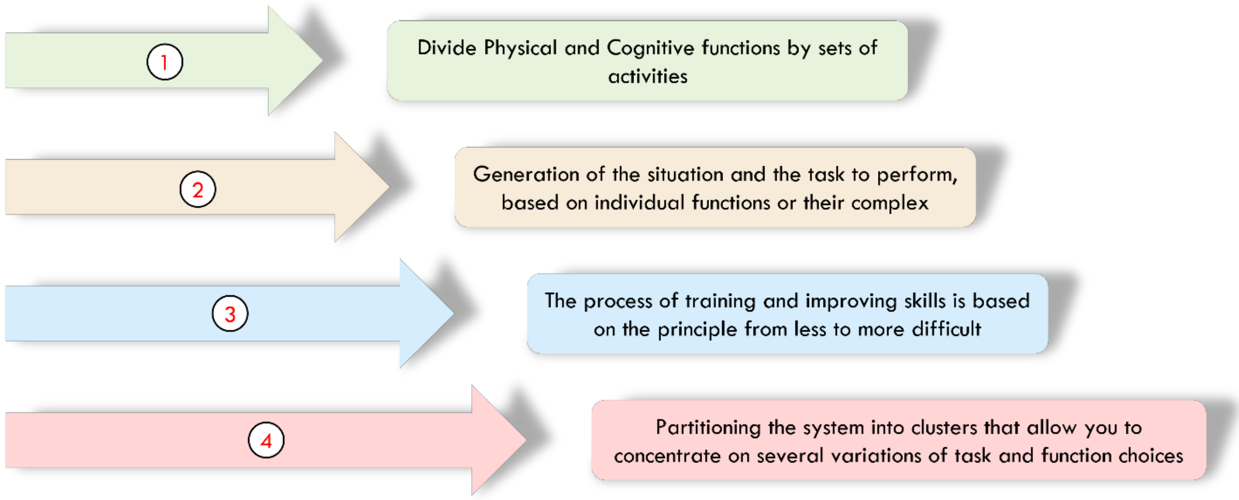


Figure 3.4. System evaluation structure.

Functionally, the testing process takes place in the direct presence of the developer as well as with one user in a single test procedure. All data obtained during the performance test are analyzed, and the necessary changes to the system are made immediately on the basis of this data. It is also important to clarify that all testing is voluntary, with zero chance of injury, both physical and psychological.

In the course of its work, the system collects data about the physical performance of the user. These indicators are exclusively physical data, which are the obtained coordinates of his body position in space. No personal or medical secrets are violated in the course of these studies. It should also be said that these characteristics are taken by analyzing the video from the camera used to track the movements. The video from the camera is not saved to local or cloud storage, nor is it used by the system in any other processes except for analysis by the built-in motion tracking algorithm. All user data privacy is ensured by the direct mentor/assistant/doctor who uses the system as a support and training tool.

The same applies to intellectual tasks. The results obtained during use are a characteristic of the user's time and quality progress. They can only be evaluated and disseminated with the permission of either the user or his mentor/assistant/doctor.

3.1.3 Evaluation Method

The data obtained during the use of the system will be evaluated in several categories:

- *Time characteristics*.
- *Qualitative performance*.
- *Physical outcome*.
- *Intellectual performance and Mental response*.

The analysis of each of these methods will provide a more precise direction for the development of the system. The data obtained will be used to adjust the various parameters, improve the activities themselves, and evaluate the prospects for the effectiveness of further use of the system.

If we describe in more detail, we should consider all of the above parameters separately. The temporal characterization has several key tasks. The first one directly consists in evaluating the speed with which users perform different tasks, how much they spend on navigation within the system, how quickly they receive a response from the application itself, and react to the changing environment. Based on this parameter, it becomes possible to understand and compare different activities with their traditional counterparts, thereby adjusting them. Also, the temporal characteristic will make it possible to create one of the methods of analyzing progress, which will be one of the indicators of system efficiency. The dependence of efficiency will be inversely proportional to the amount of time spent on the activity. If in the process of repeated use of the system the time indicators will be lower than the control indicators (first or calibration use), therefore we can talk about the positive dynamics of the user's progress and vice versa.

The second parameter, the qualitative result includes the characterization of the overall impression of the application: attractiveness for the user, potential for repeated or long-term use, comprehensibility and accessibility of the system, quality of the aesthetic component, evaluation of the system and management methods, construction of tasks, etc. This parameter is extremely important as it characterizes the main process of using the application. More time will be devoted to this evaluation item and more in-depth data analysis will be conducted. Which of the tasks were too complicated, which parameters or prompts were unclear, where the principle of building activities should be changed, in which cases the graphical and sound components should be improved. In other words, the evaluation of quality parameters will directly influence the development and subsequent update of the application in the direction that will be most optimal for the user.

The characterization of users' physical progress is rather a medical indicator, which forces the use of special tools for correct assessment. Therefore, the physical component can only be assessed by trained medical professionals. For this purpose, it is important to ensure that mentors/physicians can easily access the indicators and data that will be obtained in the process of the system. The analysis process itself in this case is carried out by evaluating different physical characteristics: speed, amplitude and accuracy of movements, general activity of execution, as well as access to the visual series (in special cases). By studying this data, the specialist will be able not only to evaluate the process of using the application, but also to point out various errors in software execution and gameplay, which can be improved in the future.

The last characteristic is similar to the physical component in terms of its importance and evaluation features, but requires a different approach to study. In this case, in addition to the speed characteristic, the correctness of execution, the high level of understanding of the task by the user and the educational potential are also important. Because of the fact that mental training is different from physical training, the methods of evaluation will also be fundamentally different.

This is expressed by the fact that the assessment of exercise performance may be based on speed and clarity due to muscle memory or an increase in the overall tone of the musculoskeletal system, but the cognitive task is assessed by both speed and correctness of these responses. In simple words, the user at the beginning of the rehabilitation process is performing a physical exercise that they are struggling to do. During a certain course of rehabilitation, the quality of performance improves, the time and quality characteristics improve (the exercise is performed faster and more clearly). The level of progress is assessed in the following way: the time of the exercise at the beginning of the rehabilitation course is compared with the time at the end of the course. The quality of execution is analyzed in the same way, for example, the amplitude of movements.

Now let's imagine that the user performs a task in which he/she takes the time to give a description of a picture, choosing from four proposed options. At the beginning of the rehabilitation process, he thinks over the answer for a long time, the choice is made with difficulty (he does not immediately understand how to choose, what to choose, etc.). After the training/support course, the speed of his/her answers increases, and the choice is made much faster and more confidently. This indicator is certainly important, but to evaluate cognitive parameters it is important to understand how many correct answers the user gave at the beginning of the course, and how many gives at the end. Therefore, when analyzing cognitive characteristics, it is important to consider both physical and temporal indicators, as well as to make a qualitative assessment of the result of task performance.

Thus, all evaluation activities of the results obtained during the system operation will be an important step for the design, maintenance and further development of the system.

3.2 Used Data Analysis

In the end, by analyzing and filtering various sources from different databases, a total of 62 sources were selected that passed all the criteria of the previously established selection conditions. Analyzing these materials, we can come to some interesting conclusions.

It is worth mentioning that the selection of information sources refers to the present period of Serious Games existence, which is described in paragraph 2.5. Such a decision was made for an understandable reason: this period describes the most technically and programmatically advanced level of these systems, which implies the use of the most advanced currently available public algorithms and protocols. In addition, as studies from different years show [60, 85, 86] at different time points different levels of performance, functionality and monitoring capabilities are required from this kind of products.

However, it is not only technological progress that has led to an increase in research into the use of additional software tools in medical rehabilitation. Global events such as the Covid-19 pandemic, for example, have also provided a strong impetus [87-89] has created a need to support and assist the population, including in the areas of leisure, physical activity and health, as well as the prevention of related potential problems due to isolation.

Finally, the articles selected during the filtering process were subjected to additional statistical analysis, which demonstrates various temporal and qualitative indicators of this data. Figure 3.5 demonstrates the distribution of articles by year of publication, starting in 2015.

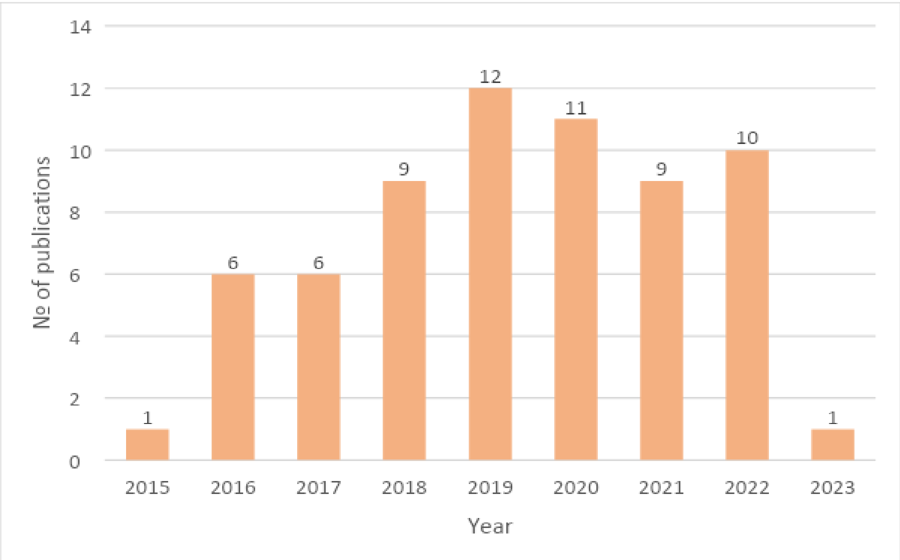


Figure 3.5. Number of published articles by year.

As can be seen from Figure 3.5, the largest peak in articles is between 2018 and 2022. This indicates several things: usually with the beginning of the next stage of the "technological era" in the first 3-4 years it is necessary to run-in new technologies, understand their capabilities and the set of areas in which they can be applied. After that the active research process and the processes of direct development and application of systems based on new algorithms are activated. [90]. The second indicator is that just in this period, the COVID-19 pandemic started from the end of 2019. In this case, there are two events: isolation, which increases the need to seek more leisure time due to the increase in free time [91], and the need to find new additional means to minimize the negative effects of both the pandemic and its consequences.

In terms of countries of publication sources, the highest number of articles were published by researchers from Spain, the United States and the UK, 15, 6 and 5 articles respectively, as shown in Figure 3.6. The second largest group of countries with 4-3 publications each includes Netherlands, Brazil, Portugal, Italy, Germany and China. The third group is Norway, Canada, Japan, Greece, Qatar, Czech Republic, Luxemburg, Australia, Finland, France with 1-2 articles each.

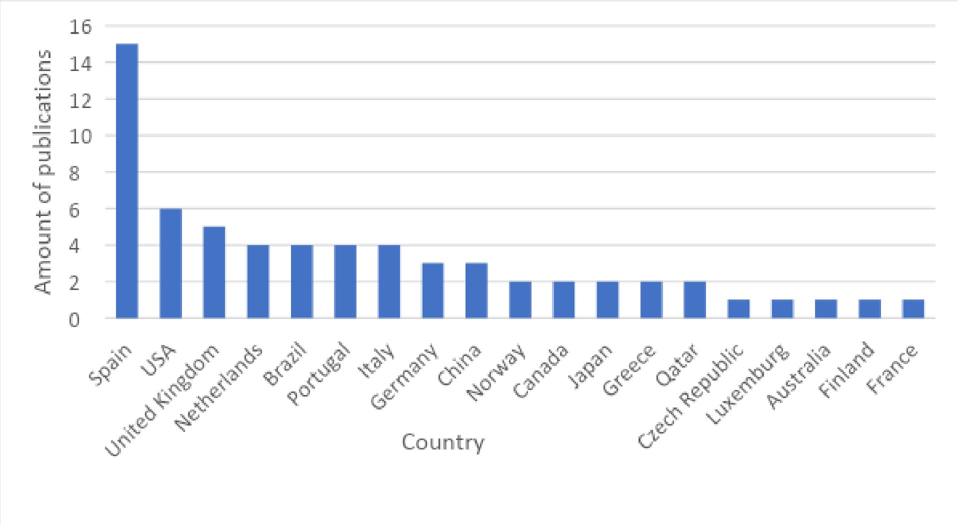


Figure 3.6. Number of publications per country.

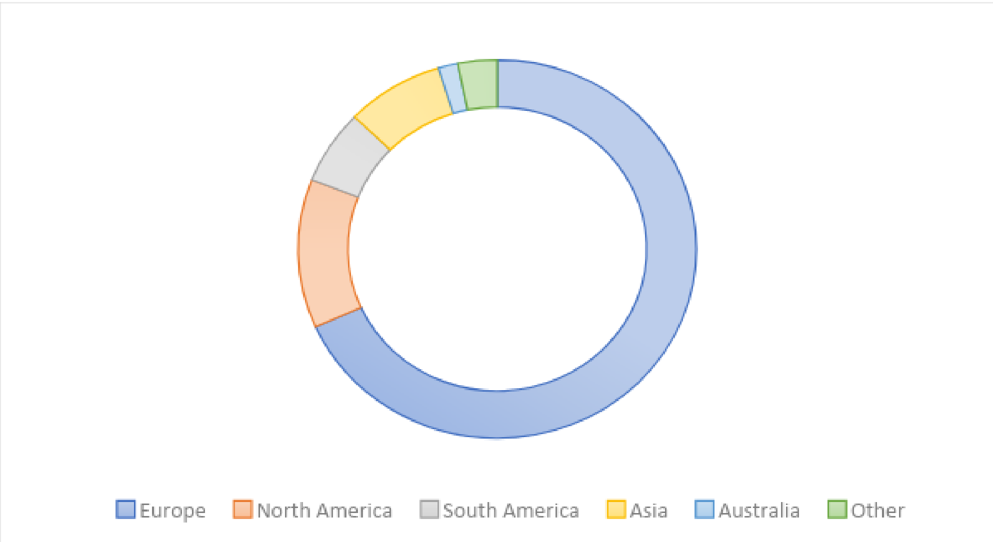


Figure 3.7. Number of publications per continent.

Figure 3.6 shows the overall publication rate in different parts of the world. In fact, both of these figures show the attitudes of countries towards the issue, which is evident even in this small sample. Medical rehabilitation receives the most attention in Europe with a publication rate of 68%, followed by North America with 13%. Next come Asia and South America with 8% and 6% respectively and close behind Australia and the Middle East with 2% and 3% respectively.

The scholarly sources used in this study that were screened and for which a preliminary evaluation characterization has been provided above are presented in Table Appendix A.

In order to qualitatively evaluate existing solutions in terms of Serious Games for people with ID, it is crucial to choose the right criteria for finding relevant materials. For the search process, the basic criteria that a source of information must satisfy, both technically and semantically, have been elaborated and defined.

3.3 Testing Procedure

As described earlier, each stage of game development involves several stages of testing. Initially, there should be three such stages: preliminary and target set of physical unit system tests, cognitive unit tests and aggregate tests of the whole system. The scheme of testing procedures is shown in Figure 3.8.

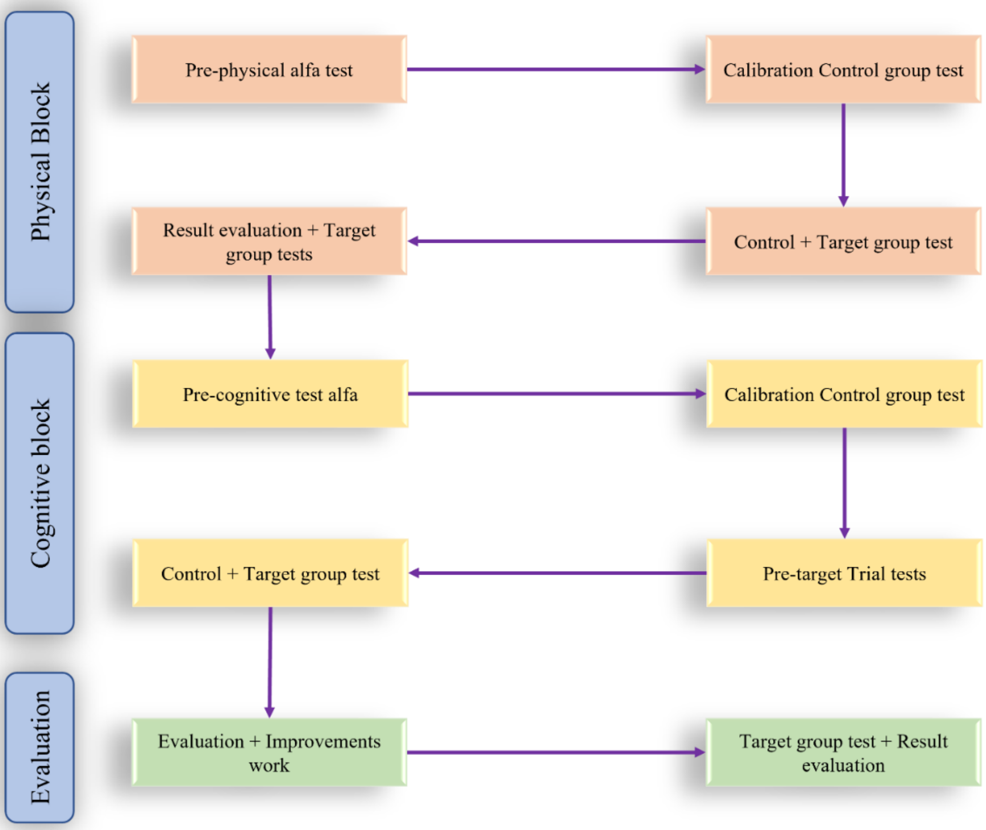


Figure 3.8. Scheme-plan of procedures for testing every block operability and efficiency.

The first stage is dedicated exclusively to the physical block of the application and includes four steps that have a clear sequence of actions. After the preliminary stage of work on this block of the system is completed, it is necessary to conduct preliminary tests, or alpha tests of the platform in its "raw" form (Pre-physical Alfa test). The task of this stage will be to evaluate the preliminary settings and the initial performance, response and overall stability of the system. At this stage, the developers of the system act as testers, and, if necessary, additional participants may be involved.

The second stage (Calibration Control group test) involves a group of people, from 5 to 10 people, whose task is to try out the finalized set of exercises of the physical block, to evaluate the presented activities according to several criteria, namely:

- difficulty;
- representativeness of the tasks;
- overall quality of graphic and sound design;
- the robustness of the system in terms of internal and external errors;
- visibility of the results;
- aspects that are controversial and require an additional source of independent evaluation.

This group, which will hereafter be referred to as the "control group" is composed of different genders, ages, physical and medical conditions, and specialties. This is done in order to obtain the widest possible range of opinions about the system being tested.

After the data collection of the second stage, it is time to evaluate the results and make adjustments to the system. After that, it is the turn of testing on the target audience, which falls under the criteria of paragraph 3.1. This "target" group consists of 10 elderly people, whose task is to test and evaluate the application in a working environment that is as close as possible to real use. Feedback from this group will be used in the final polishing of the block of tasks and on its basis the final estimates of efficiency and performance of the system are left. Also, based on the results of the analysis of this data, final adjustments and settings of this part of the application are made. It is important to note that the results of the use of the task force will be processed and evaluated by specialists in the field of rehabilitation of people with musculoskeletal problems, taking into account all the necessary medical norms and protocols.

All the results of the first stage of testing will be recorded in two forms: in the form of an oral survey and subsequent scoring, as well as in the form of a direct file with the results of using the application by a particular user.

After analyzing the results of the control group, adjustments are made to the system and then another additional testing stage is conducted to check the relevance and correctness of the improvements made to the system and its tasks. As soon as this stage is completed and all corrections are worked out, there comes the moment of control testing with the target audience. The final feedback of using this block is presented as a special questionnaire of users with their evaluations of the process of using the system, as well as indicators of the results of the application, in the form of raw data for further processing by a mentor/physician.

The second part of the testing dedicated to the cognitive block of the system will be tested in the same manner and order, but, in addition, during the control test with the target group, an additional quick survey sheet demonstrated in Appendix C. This is a small set of questions that gives an initial evaluation characterization of the application and helps to assess the concept of the visual part of the cognitive block.

It is worth saying that the main data that will be processed during the study of the application work will be divided into public and non-public. The results of the physical block of the system will be in the public domain, while for the cognitive block most of the information will be in the private domain. This is due to the peculiarities of the target audience, as well as the general policy of data exchange and analysis. Nevertheless, the information that is allowed to be demonstrated will be provided in the following sections, directly related to data analysis and demonstration.

4

Case Study 1: Physical Rehabilitation Block.

"Basic research is what I do when I have no idea what I'm doing."

Werner von Braun

If we look at the current state of simulation game technologies for education and training, we can see quite a serious impact of applications based on these methods on many spheres of medicine, education, society and science. For example, an article by David Crookall, [92] describes the reasoning behind the popularity of Serious Games, their usefulness and general perception. At the time of writing, Serious Games has already become somewhat of an established area of research and development, as evidenced by the founding of the Serious Games Institute at Coventry University in 2007, and the increasing number of articles, research and applications and systems themselves.

Nowadays, Serious Games are becoming increasingly common practice in many fields. Indeed, Serious Games have evolved from research experiments to an increasingly trusted medium for education, health and social fields. By bringing these fields of study together, there are more and more interdisciplinary opportunities to apply complementary tools, thereby enhancing the effectiveness of these very fields. From fairly simple origins of merging computational modeling and non-digital game-based learning, the field of Serious Games is now a nexus for a multitude of other disciplines.

For example, in Richard Duke's book [93] the idea of applying games in various spheres of life is presented as a romanticized fantasy, on the one hand, as a "Language of the Future", but already at that time there were many arguments in favor of the possible positive effect of such innovations. What we ended up with over time is that serious research and practice of serious games are beginning to form sets of templates for the environments in which they are used.

Given that the parallel development of medical rehabilitation measures and procedures is increasingly progressive [94]. The Serious Games field is also experiencing an upsurge. This is due to a combination of factors: the increasing level of computing capabilities and its dissemination, the search for more effective therapies, and the development of computer games [95] and their impact on society at different stages of history. All of this combined to provide the impetus that shaped the future of medical assistive applications.

4.1 Materials

4.1.1 Data and Literature Analysis

Before considering the various methods of creating and building such projects as platforms like Serious Games, it is first of all necessary to assess how much attention is paid to this topic in terms of research and actual application of such products.

To begin with, it is necessary to determine which time period should be used for analysis. Conventionally there are 4 such periods [75]:

- The period before 2000.

- 2000 - 2007.

- 2007 - 2015.

- 2015 - modernity.

The history of the use of computer games, of which the direction of Serious Games is a part, is divided into these stages due to several factors. The first of them is the influence of the development of computing technology and its various aspects. According to studies [76] every 7-9 years, technical or software methods emerge that bring about a kind of "technical revolution" in the computing environment, thereby opening up new possibilities for development and research. The second factor, is the very development of computer games and technologies of their creation. Although in some ways it follows from the first factor [77], it is nevertheless this aspect that is more significant. The third factor is the search for easier to implement methods and systems in different aspects of human activity [78, 79], which is worth mentioning in more details.

If we analyze the time frame from 2000 to 2022, we can see that approximately every 7 to 9 years the number of publications in the field of Serious Games in rehabilitation, for example, increases on average. To demonstrate this, by querying the Association for Computing Machinery digital database for "Serious Games in rehabilitation" and sorting the results by year, the following trend can be observed, as shown in Figure 4.1.

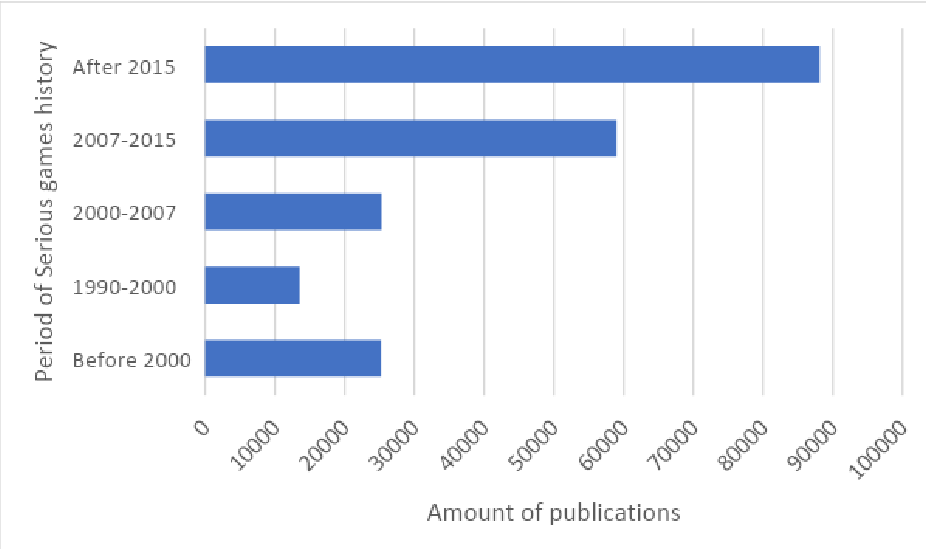


Figure 4.1. Trend of development of scientific interest in the field of Serious Games research.

This trend is also observed in the analysis of other databases and sources. This indicates a real demand for this kind of research. The development of new technical means, as well as the improvement of software algorithms and methods of creating various digital systems allows increasing the opportunities and paths of research directions by an average of 35-45% in one period.

In researching the topic of Serious Games and Rehabilitation, the main objective is to study and analyze 3 things: the medical industries in which such applications are used [80], the range of procedures in which these applications can be effectively used [81], and the very state and functionality of such products [82]. Due to the large number of different studies on the use of assistive systems in the field of medical rehabilitation, it is an important task to find and select a number of examples of studies that can be studied and used as a basis for research.

The work carried out in this direction made it possible to locate and identify a number of scientific documents that eventually made it possible to study various aspects of the creation and principles of operation of systems like Serious Games, thus making it possible to study the peculiarities of the creation of this kind of systems.

4.2 Methods

4.2.1 Hardware Specification

4.2.1.1 Used Platforms

The development and testing process took place on multiple platforms, to maximize the possible devices being supported. The equipment included the following samples, which are shown in Table 4.1.

Table 4.1. Equipment for developing and testing.

Element	Characteristics
1) Desktop PC	
CPU	Ryzen 7 3700x, s-AM4 3.6 GHz/32 Mb
GPU	NVidia GeForce RTX 2070 Super, 8 Gb
RAM	DDR4 32 Gb 2888 MHz
HDD	Seagate Barracuda 1 Tb
Web Camera	InnJoo FHD1080p (1920 × 1080) 60 fps
2) Laptop Lenovo LEGION Y-540-IPS15i	
CPU	Intel(R) Core(TM) i7-9750H CPU@ 2.60 GHz
GPU	NVidia GeForce GTX 1660 Ti, 6 Gb
RAM	DDR4 16 Gb 2888 MHz
SSD	INTEL PEKKW010T8L 1Tb
Web Camera	Integrated Web Camera 720p (1080 × 720) 30 fps
3) Desktop PC	
CPU	AMD FX 6300, 3.6 GHz AM3+
GPU	NVidia GeForce GTX 1050, 2 Gb
RAM	DDR3 8 Gb 1866 MHz
SSD	Seagate Barracuda 500 Gb
Web Camera	InnJoo FHD1080p (1920 × 1080) 30 fps
4) Samsung Galaxy Tab A5	
CPU	Qualcomm SM6115 Snapdragon 662
GPU	Adreno 610
RAM	4GB
SSD	32GB
Web Camera	8 MP, AF, 1080p, 30fps

The devices presented in Table 4.1 can be divided into two categories: devices for direct development and devices for targeted testing. This is done on the basis of a simple but rather important feature of development and use of any software components. Its essence is that while creating, say, an application like a computer game, which all Serious Games are, it is important to have the maximum possible computing power. During the development process, the benchmark of any project is often much larger than the one that will be released as the final product. While working on an application, various mechanics, developments, or even pieces of content can be added and cut if it's a game. In this case, the devices on which development is being done must have a high reserve of processing power.

The end-user situation is different. If we evaluate publicly available studies and statistics, approximately 55-70% of PC and tablet users are in the middle and below middle price segment, which means average and below average performance and computing power of the devices. In this connection, it was decided to choose the corresponding representatives of this segment as the systems for testing, the characteristics of which are shown in Table 4.2 under numbers 3) and 4).

Nevertheless, it was decided to set minimum and recommended requirements for using the system for both personal computers and mobile devices. Thus, the following parameters were selected for normal operation, described in Table 4.2:

Table 4.2. Minimum and recommended requirements for system operation.

Minimum for PC	***Recommended for PC***
OS: Windows 7 or higher 64 bit Processor: Intel Core i3 2.00 GHz or AMD equivalent Memory: 6 GB RAM Graphics: NVIDIA GeForce 450 or higher with 1GB Memory or AMD equivalent DirectX: Version 11 Storage: 6 GB available space Web Camera: 720p, 30fps Audio output source	OS: Windows 10 or higher 64 bit Processor: Intel Core i5 3.2 GHz or AMD equivalent Memory: 8 GB RAM Graphics: NVIDIA GeForce 750 or higher with 2GB Memory or AMD equivalent DirectX: Version 11 Storage: 6 GB available space Web Camera: 1080p, 30fps Audio output source
Minimum for Android	***Recommended for Android***
OS: Android 5.1 or higher *Other device-specific compatibility information is available on the Google Store*	

In addition to the hardware requirements, it is also worth mentioning the special conditions for using the system. In view of the fact that the use of the researched and developed platform of the Serious Games type, certain rules and requirements must be observed:

1) When performing the tasks of the physical unit of the system, make sure that the user has enough space to move and perform the tasks.
2) Due to the specific nature of the exercises and the target audience, have an observer/mentor/physician nearby in case of injury situations.
3) Have adequate lighting in the room where the platform is being used.

4.1.1.2 Used sensors

In addition to the webcam used in the system, there is also the possibility of connecting an additional sensor-controller, which acts as an additional means of control, as well as obtaining user data. This sensor is shown in Figure 4.2.

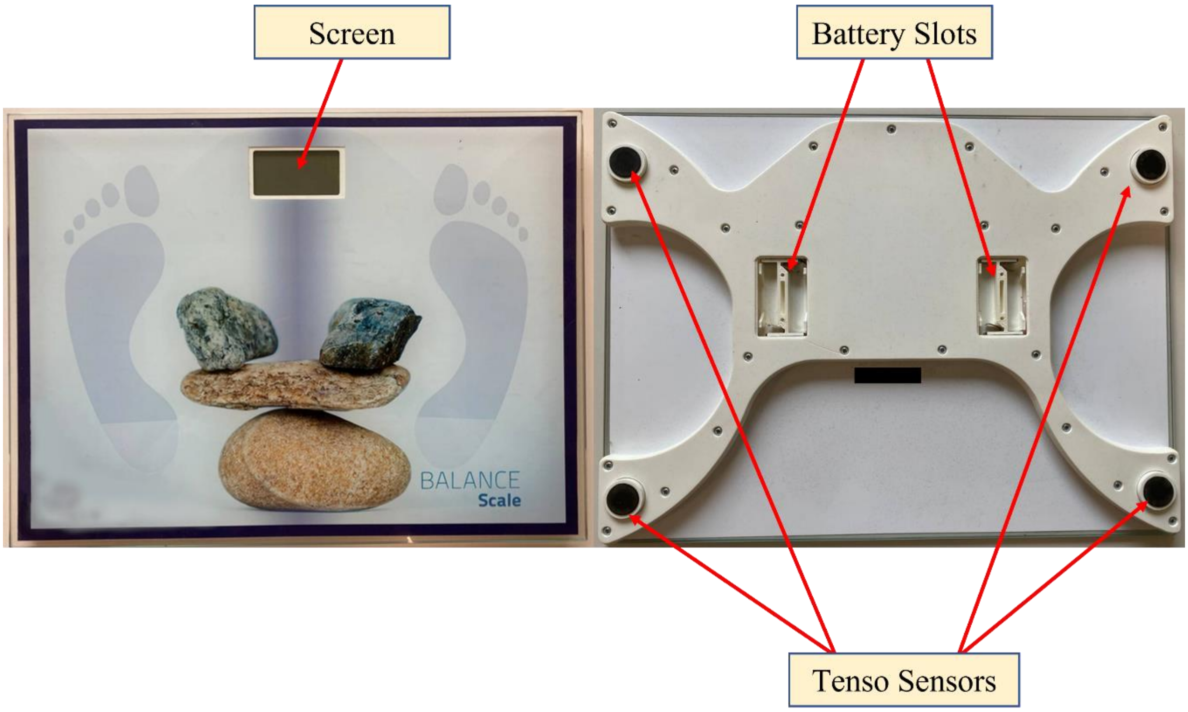


Figure 4.2. Additional sensor.

The essence of the sensor shown in Figure 4.2 is that it is essentially a controller operating on the principle of pressure. The control principle itself is quite simple. The device is based on 4 load cells designed for 50 kg each, which, when angled, allows the weight limit for use to be 200 kg. All of them are connected to a control board, which takes and memorizes the readings of each sensor together, and converts them into coordinates of points in space, ranging from -1 to 1 on the X-axis and Y-axis. The higher the pressure value on the sensor, the more the coordinate is shifted to a certain point on this plane. The absolute value of the pressure at a particular sensor is not used as such. Instead, an estimate is made of the percentage of the pressure limit from the current pressure, where the maximum is 100%, which corresponds to a coordinate value of 1 (or -1). An example of this interaction is shown in Figure 4.3.

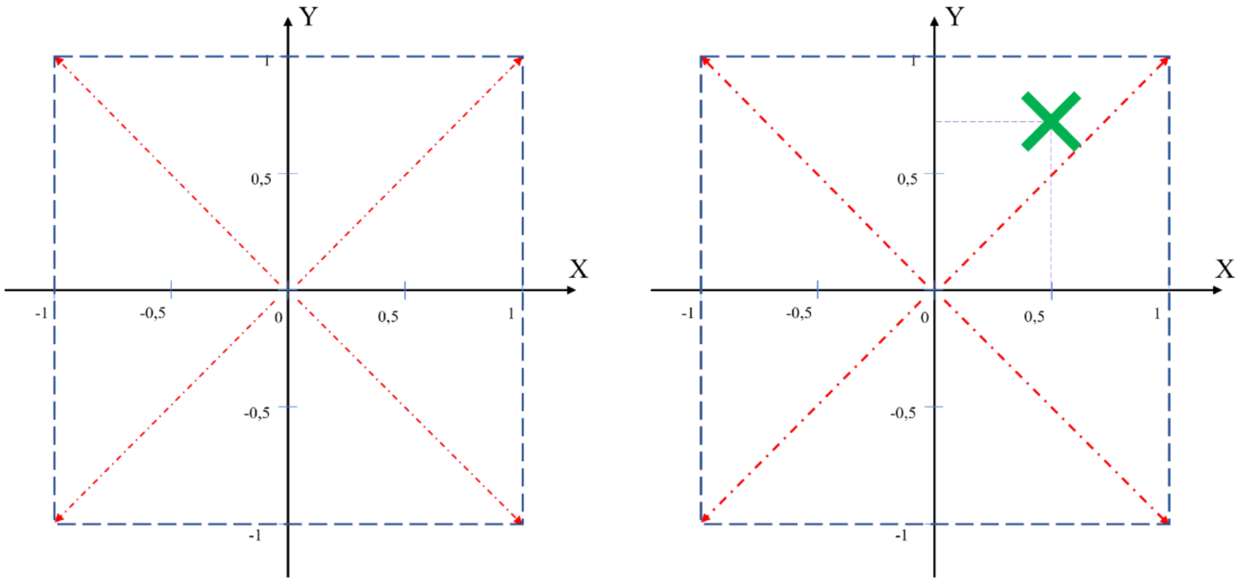


Figure 4.3. Tenso-sensors usage example.

Figure 4.3 (left) shows the general partitioning of space into a coordinate system. When force is applied to the controller (right), the system reads the amount of force from a sensor indicator, (in the demo case the upper left section of the plane), translates the percentage of force into a coordinate value, produces a coordinate characteristic (in the demo {0.5; 0.75}), and then issues a command to the control unit that the motion of the controlled object within the system should be forward, with a rightward offset.

4.2.2 Software Specification

4.2.2.1 Game engine

In the process of physical block development, it was decided to present it in the form of a computer game. Preliminary this option was worked out together with the form of a mobile application, but this format was not suitable for a number of reasons, the main of which was compatibility with the used neural network.

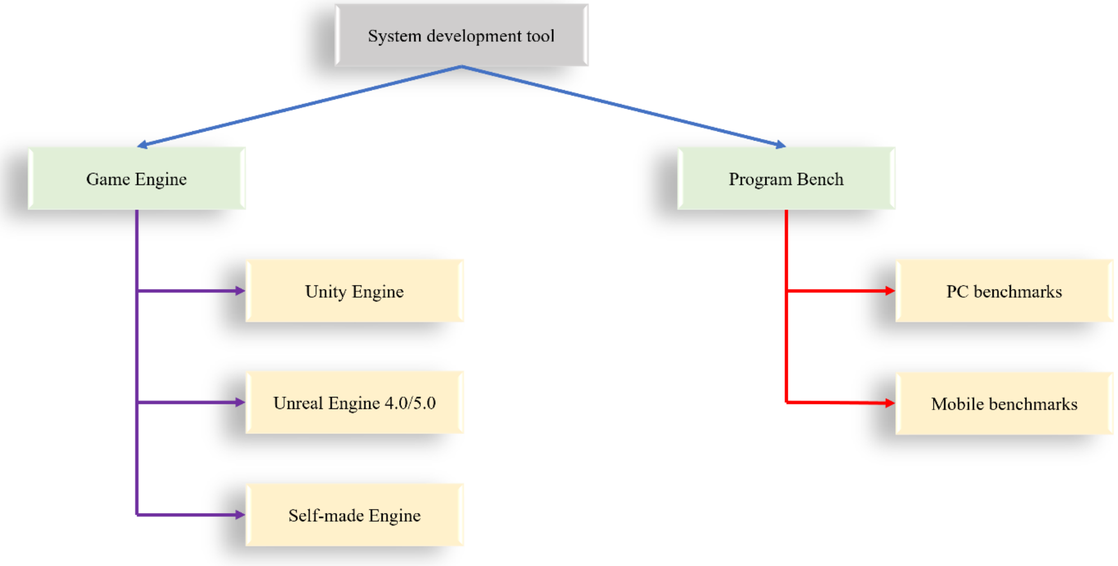


Figure 4.4. Scheme of development tool and benchmark options.

In selecting the required benchmark, the following were the necessary selection criteria:

- Ease of learning, handling and development.
- Possibility of deep customization of content.
- Ability to connect external modules.
- Flexibility of algorithm construction.
- Low power requirements.
- Possibility of source code universalization.

The main source of requirements to the development environment as well as to the used hardware was the criteria of performance and speed. Each variant of the development environment presented in Figure 4.4 has different ways of optimizing both the development process and, accordingly, to a different extent suitable for the tasks that were set at the beginning of the study.

The criteria listed earlier were chosen for a reason. First of all, the speed of learning is important, because it directly affects the speed of system development. Also, the ability to quickly and easily make adjustments or changes simplifies the process of developing and maintaining the system. Based on the needs, as a development environment was considered several options, presented in Figure 4.4. Further, Table 4.3 shows the main features, as well as advantages and disadvantages of each of the environments.

Table 4.3. Features of development environments.

Features					
№	Criteria	Unity Engine	Unreal Engine 4.0	PC Program dev. bench	Mobile dev. bench
1	Ease of use	Hight	Medium	Medium	Medium
2	Customization possibilities	Hight	Hight	Hight	Hight
3	Possibilities to connect external tools/modules	+	+	+	+
4	System requirements of development equipment	Medium	Hight	Medium	Low
5	Ability to integrate third-party libraries and algorithms	+	+	+	+
6	Support for integrated neural network algorithms	+	+ (from version 4.1)	+	Depends on the algorithm
7	Ability to develop on multiple platforms at once	+	+	+	-

8	Benchmark availability	Free	Free (partially)	Free (partially)	Free

Since the form of the system with the structure of Serious Games was initially adopted, the use of other benchmarks than game engines were immediately recognized as inexpedient. Therefore, the choice fell on 2 options: Unreal Engine 4.0 (at the time of development) and Unity. Both of them meet the requirements of system development to a greater or lesser extent. Ultimately Unity was preferred for a number of reasons, the main of which was the greater stability of the game engine itself, the larger number of existing libraries, and greater compatibility with the neural network used. Unity allowed for a more accurate implementation and further modification of existing libraries to customize the algorithm to the desired mode of operation.

4.2.2.2 Neural network algorithm

The basis of the system is an algorithm that uses a neural network to track and determine the movement of a player by processing his image from a web camera. In order to select the most suitable algorithm, certain samples of systems that could be used for the task were made beforehand.

Before starting the development, several directions were identified for the selection and further use of a benchmark that would allow the integration of a system for tracking and processing the player's movements. These choices were several:

- use a commercially available solution that can be purchased (hardware and program SDK);
- use a system that has software execution (algorithms or programs of commercial distribution option);
- algorithms using new solutions (neural networks, artificial intelligence);
- a system of own development based on one of the above three options.

In the end, it was decided to use a fourth option, namely to modify an already existing system in such a way as to adapt its capabilities as closely as possible to the needs of the platform presented in this thesis.

There were only a few algorithms available at the beginning of the research that met the requirements of the system under development. The following will demonstrate the options that were analyzed during the research.

The initial option was to use an already ready commercial solution based on the example of Microsoft Kinect or Nintendo Wii. This solution has one major disadvantage from an end-user and usage perspective: the player needs to directly own the controller device itself. In addition, there are various challenges in developing products for such systems, as well as their operation. On the one hand, the developer has a reliable and debugged platform that does not require time for customization and is immediately ready to work. On the other hand, SDKs and permissions of third-party developers to use their algorithms are required for normal full-fledged use. In addition to control by the creators of such platforms, a strong limitation of use is the technical capabilities of these platforms.

In addition, if you analyze the market of the above or similar devices, you will notice that despite a fairly high percentage of sales, in this period (2020-2023) the number of products developed and the overall popularity of such platforms is low, and in fact has become niche. It is this factor that makes app development not promising.

The second option is to use modern algorithms based on neural networks and artificial intelligence. This approach has several advantages:

1. *Flexibility and adaptability.* Neural networks can be trained on large amounts of data and adapt to different lighting conditions, diverse types of motion, and changing scenarios. This allows them to be more flexible than traditional algorithms, which may be less effective when the environment changes.
2. *Automatic feature extraction.* Neural networks can independently extract features from data. Instead of manually identifying motion characteristics, neural networks can identify key features, making them more adaptive to different types of motion without the need for manual tuning.
3. *High accuracy.* When properly trained on sufficient data, neural networks can achieve high accuracy in motion detection and tracking. This is especially important in security or traffic management systems where accuracy is key.
4. *Ability to learn from large amounts of data.* Neural networks can use large datasets for training, which helps them improve their performance with more information.
5. *Detection of complex patterns.* Neural networks are able to detect complex and non-linear patterns in data. This allows them to detect movements that may be difficult for traditional pattern recognition methods.
6. *Advanced prediction capabilities.* Some neural networks are capable of not only tracking current movements but also making predictions about future actions, which can be useful in various applications such as autonomous cars or traffic control systems.

However, algorithms of this type have many disadvantages and peculiarities that should be taken into account in the process of development and use. The most important disadvantage is the requirements to the initial data during the training process. In addition to the fact that the training of neural network algorithm is a rather long process, it is also necessary to manually select the correct source data, because the further accuracy of the system will depend on it. Also, the volume of the initial database pool is an important point: the higher it is, the more accurate and better the training will be.

Another disadvantage, and quite critical, is the narrow focus of the algorithms. The accuracy of neural networks is directly proportional to the number of tasks it has to perform. If the system is trained to serve several patterns, even if they are similar in meaning and parameters, the chance of errors in data processing is much higher than, for example, in the case of one single function. Therefore, algorithms based on neural networks can be effectively used for single tasks. It is worth saying that this problem can be circumvented by modularity of the neural network itself, allocating several separate independent structural clusters, each of which will perform a specific task. In this case, the efficiency of the algorithm decreases only by a small percentage, but the computational requirements for the system in which this algorithm is used sharply increase.

The third disadvantage of such systems is, as it was mentioned earlier, high requirements for the computing power of the device that will be used to operate the system. When more complex task assigned to the system, the more power system needs to process it. Speed and complexity are affected by several factors:

- Number of source data.
- Type of data.
- The form of the input.
- Time frame of processing.
- Form of output result.

Given the mix and form of these factors, there are various combinations of parameters that ultimately affect the computational needs of a system. This is fraught with the fact that excessively high requirements can limit various aspects of platform development, such as, for example, the platform used, the immediate tasks and applications, and the sets of in-system functions and capabilities.

If we consider the options presented above, it is the second one, namely the system design based on a neural network-based motion recognition and tracking algorithm, that has become the most promising. The main points and features of the used algorithms will be presented below.

In the course of researching various methods and principles of developing Serious Games-type systems, platforms using different types of algorithms, several fundamental features were revealed. Those systems where neural network or artificial intelligence-based algorithms are used in parallel with traditional development methods, the overall efficiency and average results were higher than conventional systems, or conventional methods of traditional medical rehabilitation.

During the design and further development of the system presented in this study, it was decided to use a similar implementation scheme: traditional rehabilitation assistant development methods with the use of additional neural network algorithms to increase the level of interaction with the system.

At the stage of starting the direct development of the system, it was decided to start with the neural network algorithm. There were two ways to do this: to start development from scratch, or to modify the existing platform for the necessary needs and parameters. Due to limited time and funds, the second option was chosen, namely modification of the existing neural model. At the time of starting this stage, there were several options:

- PoseNet: This is an algorithm from Google that uses neural networks to determine a person's pose based on an image or video. It provides high speed performance and can run directly in the browser, making it suitable for various web applications.
- OpenPose: The algorithm processes images using neural networks and provides body pose analysis using a method of identifying and linking key points.
- HRNet (High-Resolution Network): This algorithm works with high resolution images and applies deep neural networks to detect human pose. HRNet preserves spatial information for a more accurate representation of the relationships between key points.
- DeeplabCut: This algorithm trains models for pose tracking using teacher learning techniques. It allows the creation of custom models for pose detection in different scenarios.
- Stacked Hourglass Network: This method uses a neural network architecture based on the sequential application of hourglass modules, which allows accurate pose detection even in complex poses or conditions.

Among the listed variants, the OpenPose algorithm turned out to be the most attractive from the technical point of view, as well as the most suitable for the needs of this study. There are several reasons for this, one of which was its multifunctionality. In addition, rather easy integration and the possibility of flexible customization allowed to make the necessary modifications in less time.

The main feature of the OpenPose algorithm is that it was developed is a real-time motion tracking system. During the first stages of development, several different systems were tested that can produce human recognition in images, with both machine-learning and neural network-based algorithms having been tested. Even though this algorithm was most suitable for the task at hand, it still required a lot of tweaking, and is based on a trained Convolutional Neural Network (CNN). The system works with both single images and video. In the second case, the load on the system is somewhat greater, as a continuous storyboard with a rate of 30 frames per second (fps) is used. During adaptation of the OpenPose system to future platform, several functional changes were made to the algorithm, without changing the neural network itself:

• The hand recognition module has been disabled (fingers, palm).

• The face recognition module (eyes, mouth, nose, ears, eyebrows) was disabled.

• The storyboarding process was optimized, which allowed a stable 30 fps to be obtained (in the original state the rate was 18–24 fps, depends on input data quality).

It is worth to tell in more detail about the features of the finalized OpenPose. As mentioned above, during testing it became clear that at this stage all motion tracking functions are redundant. Therefore, the system was simplified, which increased its performance. The system was originally designed with 25 keypoints for the body, 21 for the hands and 70 for the face. In the modified system, only the body tracking unit is used, which significantly improves the performance and stability of the system. In addition, the system of building dependencies between points was slightly modified, which allowed to reduce the required interrelationships from 18 (without taking into account additional points of hands and feet) points to 15. An example of the new interconnection system compared to the old one is shown in Figure 4.5.

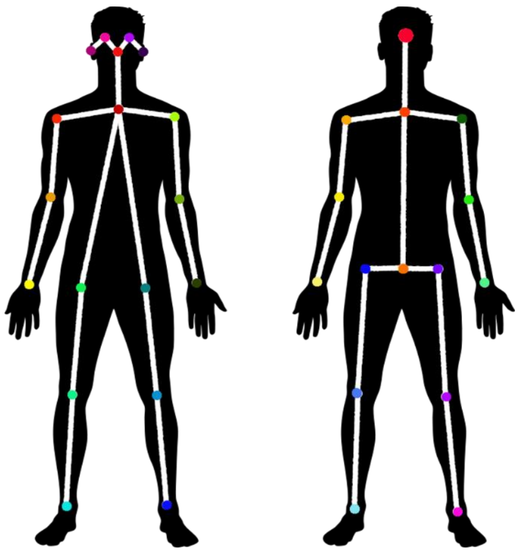


Figure 4.5. Demonstration of the location of key points of the used motion tracking algorithm. Unmodified OpenPose (left) and modified OpenPose (right).

As can be seen from Figure 4.5, the modified version of the algorithm has a more simplified and holistic structure. In addition, special dependencies have been created between separate groups of points, allowing to apply additional subsystems of data reading and analysis, which will be described a little later. Dependencies represent separate clusters of points (with the possibility of connecting additional point arrays to them, if necessary), which, in fact, represent separate body parts: arms (left, right), legs (left, right), torso, head.

In a nutshell, the OpenPose body position tracking algorithm works by selecting each frame individually from the video stream. The neural network then creates a kind of confidence map on the frame, which creates key points on it. From these points, the direction of the found body parts and their connections are calculated. After that, the points are “assembled” depending on the direction, and finally a “body map” is assigned to the frame. The result is a “skeleton” which is created directly in the production environment, and with which further manipulations can be carried out. As the algorithm uses a storyboard of the received image, the efficiency and accuracy of the system directly depends on the quality of the incoming video (cropped images).

The system is, therefore, highly dependent on the ambient light factor. The accuracy and speed of the algorithm is also affected by the resolution of the source image. The higher it is, the more accurately the neural network detects the key points of the body, which increases the overall accuracy, but at the same time, the speed of rendering these points decreases.

Body tracking algorithm was also integrated into the Unity game engine environment with the functions being based on the generation of 3D objects, which are tied to 2D image coordinates. This image is obtained from the output of the neural network. Then the X and Y coordinates are mapped, which allows binding objects within the system. For the system to work correctly in a game engine, the main task for the algorithm is to ensure the highest possible accuracy at the highest possible framerate. The modifications we made allowed us to achieve 30 frames per second, with a sufficiently high accuracy. It is important to note that the accuracy is also affected by the frequency of the incoming video stream. At 25, 30 and 60 fps (camera parameters), the rate of change in the position of key body points in subsequent frames decreases as the number of frames increases. Therefore, during the neural network operation for each frame, there may be “oscillations” of these points on the rendered skeleton. In the game itself, this translates into a fluctuation of the coordinates of each of the points being created. This optimization has reduced these oscillations to 0.4–0.9% of the error between frames.

4.2.2.3 Data Acquisition, Visualization and Processing.

As mentioned earlier, the platform has two methods of collecting information about the player. The first involvers the collection of game information (run time, points, reps), while the second involves the collection of information about the activity of the movements of individual body parts, as well as the player. This system takes the form of a built-in algorithm, which works regardless of the difficulty selected by the player and does not imply a shutdown function.

Although this information about movement activity is not confidential, notification about its collection for purely medical needs is provided before the start of the game. The movement data may be subject to medical secrecy rules and will not be available to anyone other than the treating physician and the player themselves.

Now here is more about the functions of the system, with the general principle for obtaining data being shown in Figure 4.6.

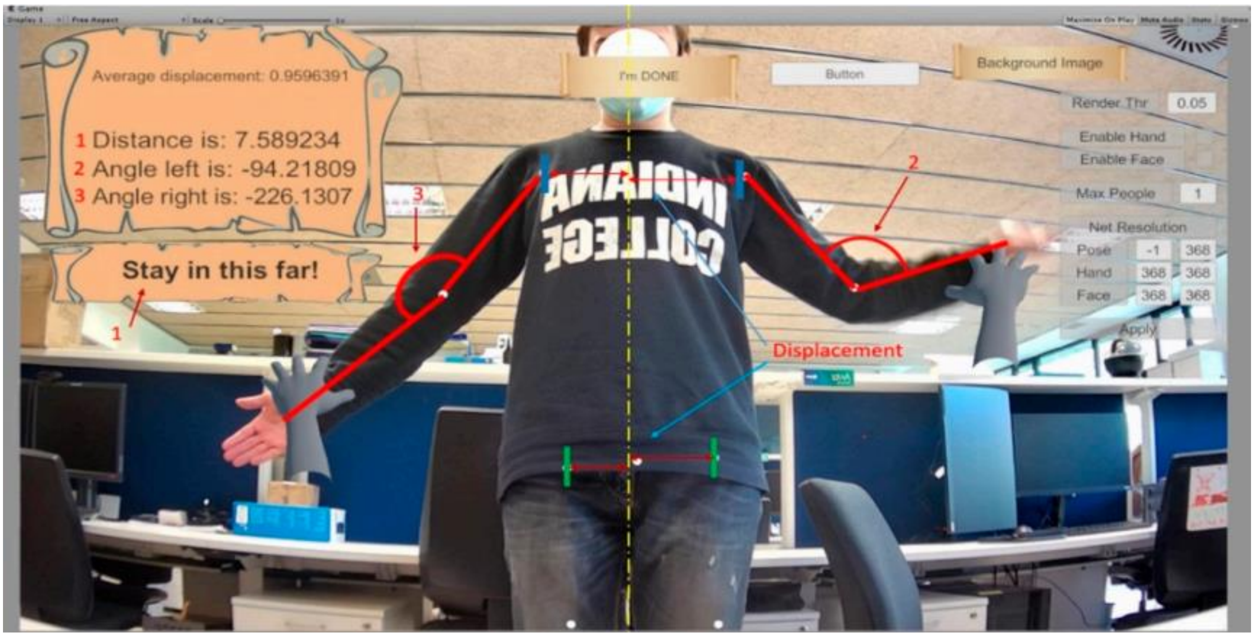


Figure 4.6. Example of displaying and capturing the required position parameters.

In total, the algorithm receives data on the following parameters:

- Angle between shoulder and left-hand forearm
- Angle between shoulder and right-hand forearm
- Left hand position
- Right arm position
- Hip position
- Shoulder position
- Head position
- Head rotation angle.

System works as follows. Inside the Unity environment, each of the key points, which are created by a neural network (OpenPose algorithm), are tied to the coordinates of the 3D space of the game scene. When fixing the player's movement, these coordinates change, but only in two directions, X and Y, while the Z coordinate always remains unchanged. Using this, each of the game scenes is constructed in such a way that when linking 3D objects to points of the neural network, these objects will also change only 2 coordinates.

The main disadvantage of the system is that it cannot correctly track complex movements in 3 planes. For example, the difference between the arm outstretched forward and outstretched to the side is tracked by the difference in distance between the arm outstretched forward and outstretched sideways, tracked by the straight-line distance between the key points of that arm. Thus, technically, there is a distortion of the limb length in the system, which can also affect the angle at certain positions.

An important aspect when gathering the above information on the indicators is that it is affected by the general lighting of the room which the player is in, as well as the camera position. It may be that lighting reduces the accuracy of body recognition by the neural network and at some moments, it may affect the objects inside the game scene in the form of objects "twitching" (each frame from the camera may give different coordinate positions of key points). In the second case, if the webcam is installed incorrectly, when the lens is excessively raised, lowered, or directed more forcefully to one side, the position may be detected with an error. To avoid this, a calibration level was created, whereby the player must set the lens and lighting correctly.

Despite the disadvantages of the system, it is not intended to obtain accurate values, but rather to track the player's activity. The main purpose of these indicators is to record activity and provide data for further evaluation and comparison of progress.

Next, will be shown the way how the system works. When you load a level and activate the body tracking algorithm, the activity logging system starts recording the key point coordinate readings for all tracked indicators. The recording frequency is 1 coordinate value every 1 centisecond, and the method for obtaining this coordinate for each of the parameters is different. Table 4.4 shows the algorithms for obtaining these values.

Table 4.4. Parameters recording methods.

Parameter	Value
Left arm position	Object X. and Y.properties coordinate recording
Right arm position	Object X. and Y.properties coordinate recording
Head rotation angle	Function of coordinates transform + Vector angle calculation
Head position	Object X.properties coordinate recording

Shoulder position	Object X.properties coordinate recording
Hip position	Object X.properties coordinate recording

The resulting values are written in the form of a data array, which, after the level is completed, is written in a separate file format—json. This method of saving makes it convenient to work with data both in a manual format and for algorithm processing on the server side of the platform. Next, Figure 4.7 shows an example of the graphical representation of the resulting data

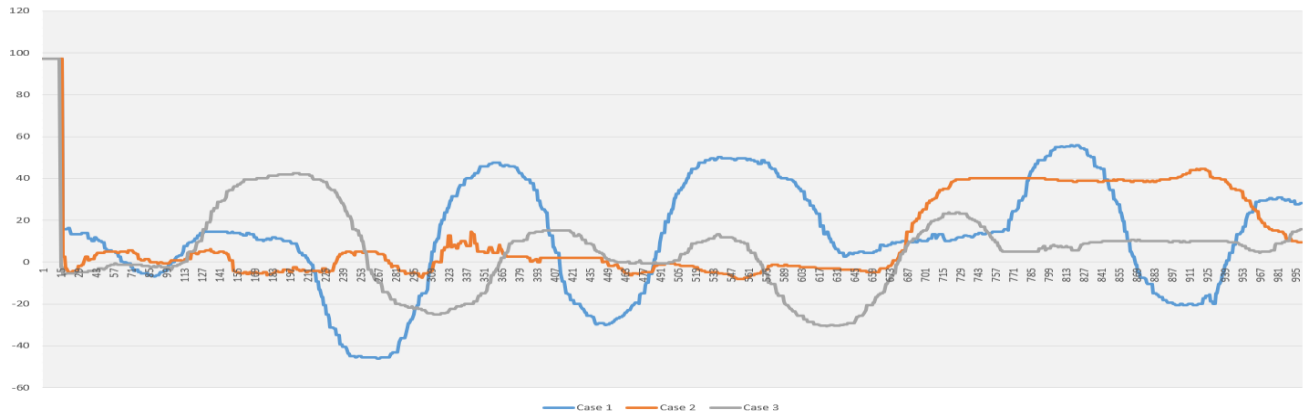


Figure 4.7. Visual representation of the data received.

Figure 4.7 shows the dataset of the hip position of one person in 3 different cases: Case 1 (blue) - normal pace of movement. Case 2 (orange) - the pace of movement is reduced. Case 3 (grey) - the play-er was inactive most of the time. The task was set for 10 repetitions of hip movement (5 to the left and 5 to the right). The amount of time spent on the exercise in both cases was 10 seconds. The values on the Y-axis are the deviation coordinate values and are shown in the form of positive and negative values, which also characterizes the deviation side: positive values refer to the right deviation, whereas negative values refer to the left deviation. Based on the information provided in Figure 4.4, it is possible to draw several conclusions in terms of physical activity:

- The timing of the player's movements, both the total number and each repetition individually;
- The maximum value of the deviation amplitude, which indicates the intensity of the exercise;
- The activity as a whole, based on the number of peak values of the deviation amplitude;
- The evaluative characteristic of motor skills, based on the direction in which there is a greater number of peak values of the deviation amplitude.

Thus, the parameters obtained from a player's activity make it possible to evaluate both his current activity during a given game session and to obtain an evaluation over time by comparing their motor characteristics. This information, in theory, should help physicians and the patients themselves to monitor the outcome and progress of the rehabilitation process for different degrees and types of musculoskeletal problems.

As a result of each of the tasks, the system stored all the data obtained in a special .json file, the information from which was used to process the results. All indicators obtained are shown in the form of a data array for each of the categories. An example of such a file is shown in Table 4.5.

Table 4.5. Example of retrieved data cluster

Body parameter	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
rightAngelData	-3.660	-3.660	-8.564	-8.564	-8.564	-7.300	-5.835	-5.835	-4.547	-4.547
leftAngelData	-82.022	-82.042	-82.006	-81.974	-81.974	-82.679	-82.825	-82.789	-83.523	-83.467
HeadAngelData	179.786	179.780	179.791	179.784	179.805	179.794	179.795	179.789	179.792	179.785
HipsData	8.276	6.507	7.878	7.878	5.987	4.728	6.099	4.788	6.159	6.159
HeadData	179.788	179.786	179.780	179.791	179.784	179.805	179.794	179.795	179.789	179.792
rangeData	6.908	6.965	6.997	7.054	7.043	7.039	7.091	7.139	7.150	7.209
shoulderData	-0.037	0.862	-0.509	-0.509	0.318	0.095	-1.276	-1.336	-2.707	-2.707
leftMoveData	-58.095	-58.103	-58.103	-58.103	-58.128	-58.115	-58.115	-58.138	-58.138	-58.138
rightMoveData	-56.344	-56.381	-56.383	-56.383	-56.145	-55.957	-55.951	-56.100	-56.107	-56.107
averageArmLData	60.127	-57.823	-58.518	-50.405	6.438	-19.626	-49.406	48.971	-53.573	-41.703
averageArmRData	77.494	-49.893	-56.770	15.153	-12.699	-33.412	27.298	-55.278	2.442	-2.859
averageHipsData	95.968	4.780	7.458	8.700	8.086	8.137	8.336	6.683	8.547	8.080
averageShouldersData	47.749	-3.716	-0.577	-0.610	-0.642	-0.603	-1.873	-0.038	-2.035	-1.135

There are 13 parameters in total:

- Right- and Left-hand angle data - information that allows you to assess the overall movement activity of the player when performing upper limb exercises;
- Head Angle and Head Displacement data - allows you to track the degree of rotation of the player's head. Useful for understanding the approximate direction of the player's gaze, as well as problems with general motor skills (for problems with the cervical spine;
- Range data - shows the general dynamics of the player's position in space. Useful for evaluating general activity, as well as for evaluating the player's movement during game activities;
- Hips and Shoulders displacement data - shows the dynamic displacement of the player's shoulders and hips, as well as the degree of this displacement;
- Left and Right Arm Displacement Data - the activity of the player's hand movement. Characteristics of upper and lower maximum deflection, smoothness, and accuracy of the movements;
- Average arm, hip, and shoulder movements - characteristics that allow the average position of the body to be estimated, as well as individual areas of the body. Useful when researching into temporary or permanent partial atrophy, palsy, or dysfunction of the muscles of a particular area of the body.

It is important to note that all parameters saved in the file refer to the value of the coordinate of a particular point, which is created by the motion tracking system. By default, the screen coordinate system in the Unity environment is [0%...100%] vertically and [0%...100%] horizontally. from the current screen resolution, which is set to 1080p (1920x1080 pixels) in the system by default. Given that all parameters are calculated relative to the median line on the X or Y axis, which is 50% and 50%, respectively, it appears that the screen space is divided into 4 segments, in which, depending on the exercise, the coordinates may record both positive and negative values. This indicates only the direction of movement (in the case of the hips or shoulders, "+" means right and "-" means left.

To assess exercise performance, it is necessary to select a benchmark example by means of which one can judge not only the correctness of a single activity, but also the quality of progress and how close it is to the desired result. In this regard, a "benchmark characteristic" was created for each of the exercises, which will serve as a reference point in the evaluation of results. For this purpose, each exercise was performed 5 times at the correct tempo and with the correct amplitude of movement, naturally as much as possible. Then, a general result was obtained from the 5 results, which became the "reference" for the system being developed. The following were chosen as the key parameters of these signals:

- Time to complete each task;
- Amplitude of the received signal (by means of direct Fourier transform);
- Frequency of repetitions;
- Repetition period;
- Jitter and Shimmer.

As an example, how to check and parse the signal parameters with their subsequent evaluation is shown in Figure 4.8, with the parameters providing referring to the reference result obtained for one of the physical block exercises.

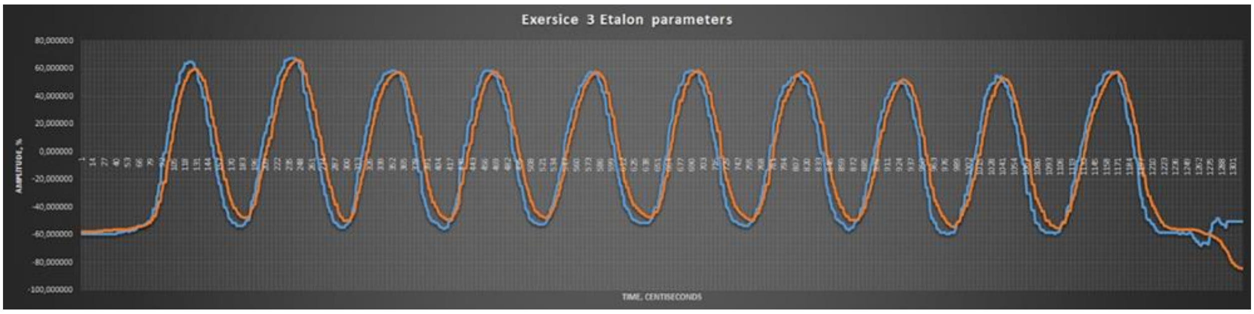


Figure 4.8. Data visualization example from physical block.

Additionally, to gain a clearer picture and better assessment of the results, it was decided to obtain a signal that corresponds to a very bad version of the exercise – namely, poor timing, incorrect amplitude, and speed of repetitions, as well as the presence of ex-ternal factors that could disrupt the procedure involved in obtaining results. An example of this exercise is shown in Figure 4.9.

Figure 4.9. The result of incorrect performance of exercise.

Even a visual analysis of the two graphs shows that Figure 4.9 provides a clear difference in amplitude and repetition time. To describe this example more accurately, Figure 4.10 and Figure 4.11 are shown below, which show the results obtained from one of the exercises in the normal view, and immediately after passing the game level.

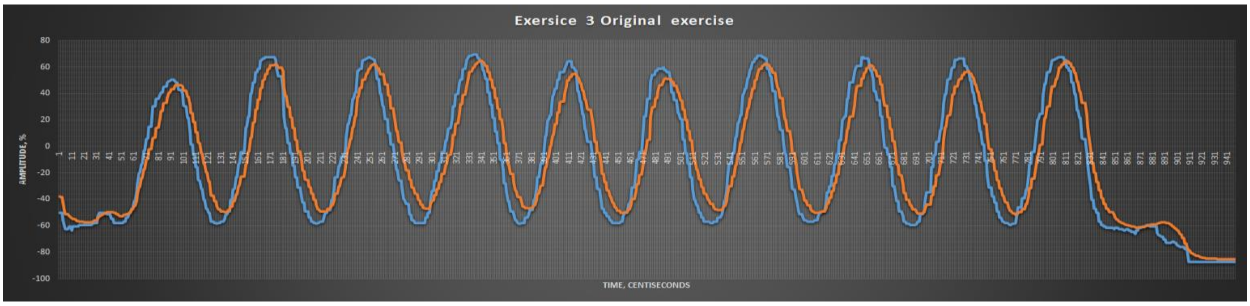


Figure 4.10. Result of normal performance in exercise.

In Figure 4.10 you can already see that the graph referring to this signal already more accurately resembles the reference signal. We can clearly see the even level of amplitude and time of each repetition.

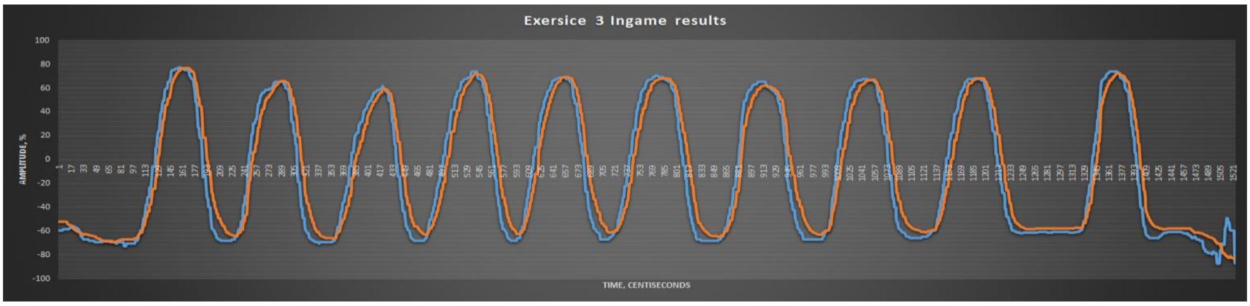


Figure 4.11. Result of game result performance in exercise.

Figure 4.11 directly shows the result obtained during the passage of the level on the game platform.

The cases demonstrated in Figures 4.9, 4.10, and 4.11 represent a rather convenient form of continuous signal for evaluation, which is convenient to analyze in terms of physical activity and its evaluation. On this signal, the amplitude on the X-axis is nothing but a characteristic of the absolute deviation of key points, which from the physiological point of view means how much the user moves the investigated part of the body in space. The temporal characteristic on the Y-axis indicates how fast the movements are realized. An example of a visualization of movement delays or any problems is well illustrated in Figure 4.9 at 4.31 seconds and 6.11 seconds, where a significant delay in movement execution at the first peak point and less delay at the second point can be clearly seen.

4.2.2.4 Architecture explanation

The architecture of the system is quite simple. It consists of 3 interconnected functional blocks, which perform different kinds of functions. The architecture diagram itself is shown in Figure 4.12.

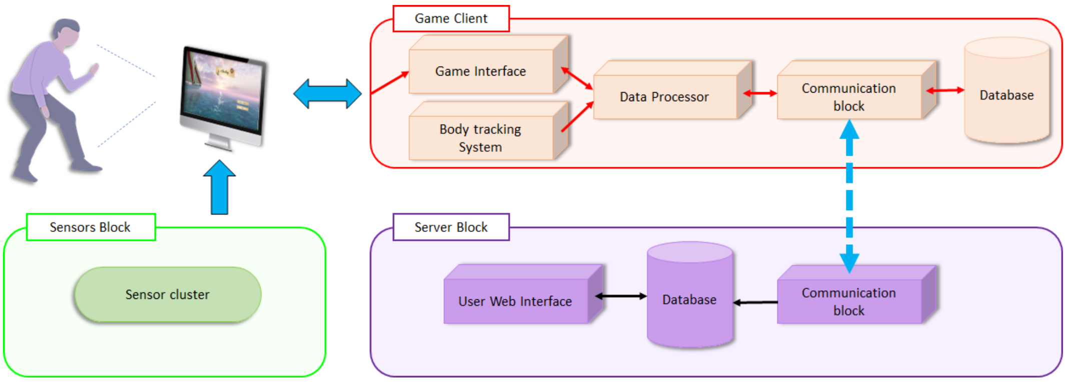


Figure 4.12. Physical block system architecture.

Order is the next. The Sensor connection block is responsible for direct communication of additional sensors or devices with the game platform client. This is done either by using the usual USB protocols, Bluetooth connection, or by using additional tools (expansion boards, Arduino boards, Raspberry Pi boards, and so on). The main and necessary sensor, without which the system loses its efficiency and usefulness in general, is a USB webcam. More about this device will be described later.

The server unit is a remote repository where all each player's progress during the game is saved. There is also the possibility of remote access to a special page, which shows the statistics of the player, his main indicators, progress in rehabilitation for a certain period. The demonstration of this information is intended solely for the attending physician, but, if necessary, access can also be given to the player himself. Any information received from the player is not confidential but falls under the rule of medical confidentiality.

The Game Client block is the game client itself, which the player or doctor installs on his personal or hospital computer, and through which the player's medical data is received and processed. It also includes a local data storage, which is essentially a backup copy of the data sent to the server. It is important to note that data processing in the game client, as well as sending them to the server is carried out in real time.

4.2.3 Physical Rehabilitation Block Structure and Implementation

It is worth mentioning that the structure of the system is divided into 2 parts: Physical and Cognitive blocks. Next, Figure 4.13 presents the general structural diagram of the Physical Block, namely the construction of levels, the connection between them and the general concept of the system.

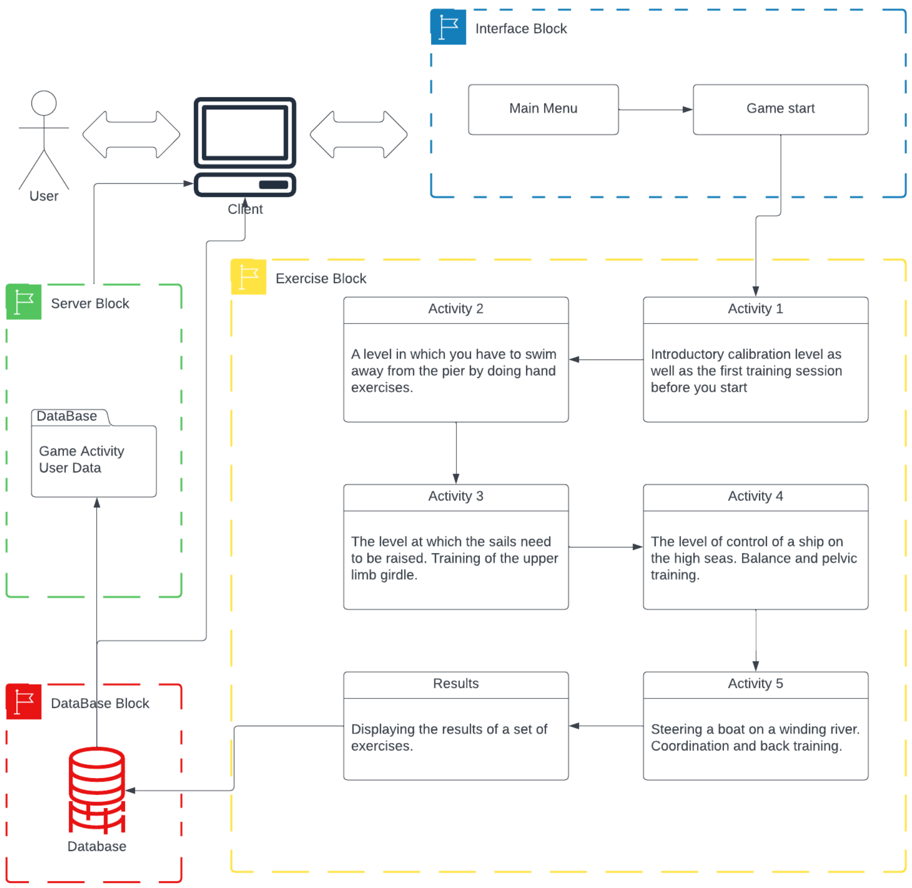


Figure 4.13. General structural diagram of the Physical block of the system.

As can be seen in Figure 4.13, the block is fundamentally composed of four main parts: the initial interface shell for controlling the system, the exercise block that includes all available exercises and activities, the database with all obtained user parameters, and the server block, which is a cloud storage of user and activity data.

4.2.4.1 System Structure. Interface block.

There are 2 main levels in this block. The main purpose and task of these scenes is to navigate the user, as well as to perform some introductory function in the activity itself and to set a certain tone of the narrative. It should be said right away that the levels of this block do not have any technical aspects underneath them, and act solely for navigation. Nevertheless, the general structure and visualization of each of them, along with a list of available elements, should be displayed.

a) Start screen.

Name: Main Menu.

Task: launching the beginning of the game.

Elements: "Start" and "Exit" buttons.

The level structure is shown in Figure 4.14.

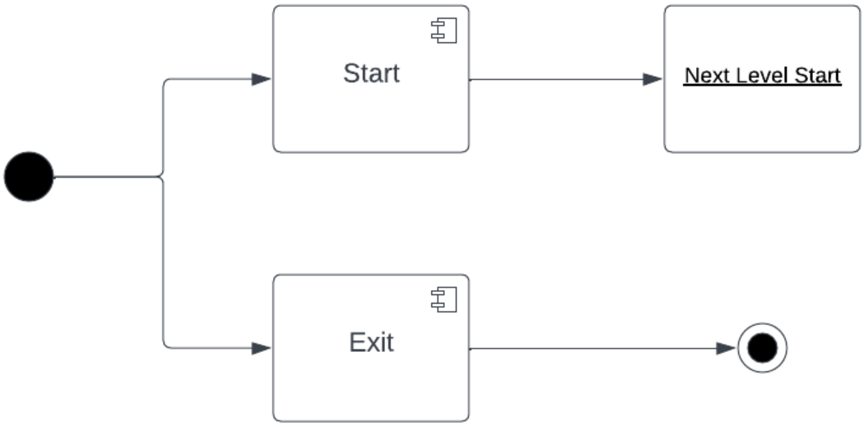


Figure 4.14. Structure of the initial screen of the Physical block.

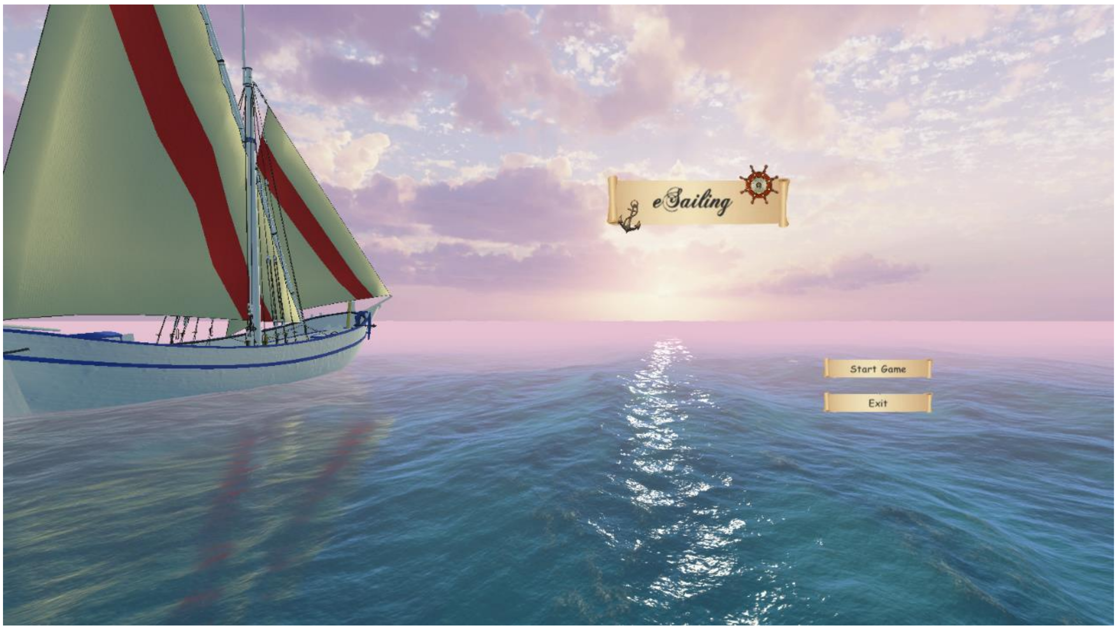


Figure 4.15. Visualization of the initial screen.

As described above, this level is just an initial welcome screen to further interact with the system and give it an aesthetic feel.

b) Name and complexity selection screen.

Name: StartLevel.

Task: Selection of the user name, initial explanation of the task, selection of the difficulty level.

Elements: Name input field, explanation, buttons to select difficulty "Base", "Medium" "Regata-pro".

The structure of the level is demonstrated in Figure 4.16.

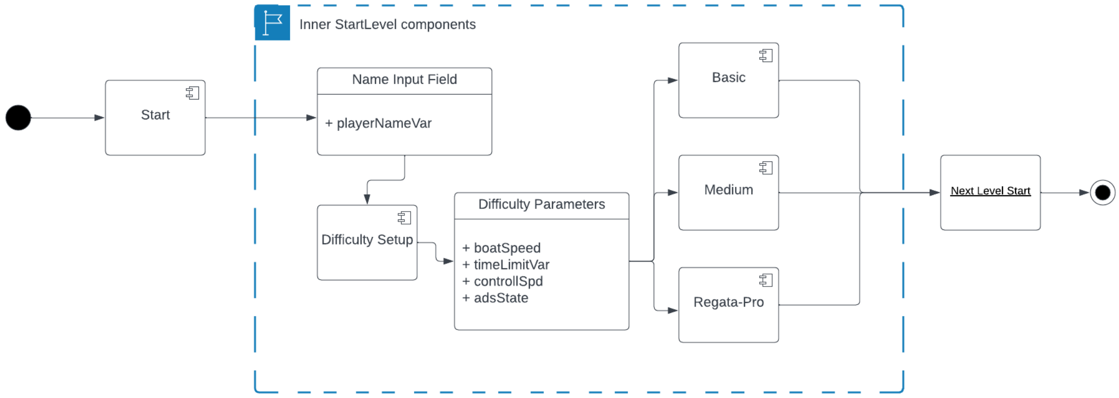


Figure 4.16. Structure of StartLevel.

Figure 4.17. Visualization of StartLevel.

This level is essentially the beginning of the game and the first stage of customization. First of all, the user needs to choose a unique name, which will be his authenticator, as well as a key tag in the database of the server part. After that, it is necessary to read the description of the tasks to be performed and choose one of three difficulties.

With a list of three tiers, each has its own key parameters:

1) Basic. A reference level of difficulty that will be scaled by the following parameters:
   - boatSpeed - initial boat speed parameter;
   - timeLimitVar - initial time parameter for each activity;
   - controlSpd - speed of system response to user control;
   - adsState - number and level of ads
2) Medium. The second level of complexity, which differs from the first one by the following parameters:
   - boatSpeed - increased by 15% from the basic one;
   - timeLimitVar - the time limit per level;

- controlSpd - increased by 20% from the basic one;
- adsState - appear only at the beginning of each level

3) Regata-Pro. Third level of difficulty.
   - boatSpeed - increased by 30% from the base level;
   - timeLimitVar - time limit reduced by 30% additionally;
   - controlSpd - increased by 35% from the basic one;
   - adsState - no hints.

Otherwise, this level is also an intermediate point between the basic system settings and the game itself.

4.2.4.2 System Structure. Task Block

a) Calibration activity

Name: CalibrationLevel.

Task: Adjust and calibrate the system to the current user. Allow the user to get used to the system's operation, in particular the motion recognition algorithm, and test the personal control capabilities of the system.

Elements: Field of display and calibration of key parameters, distance, exit button, button-activator of video camera image.

The basic structure of the level is demonstrated in Figure 4.18. The visual display is shown in Figure 4.19.

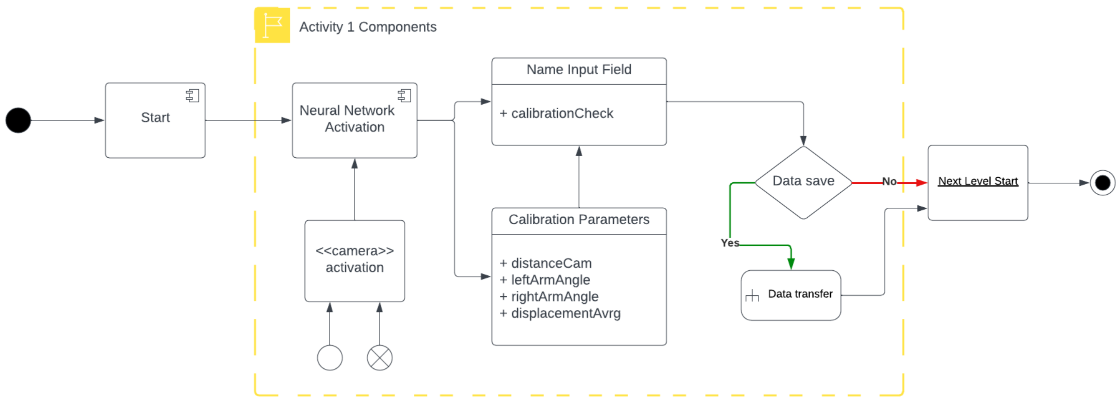


Figure 4.18. Block diagram of CalibrationLevel operation principle.

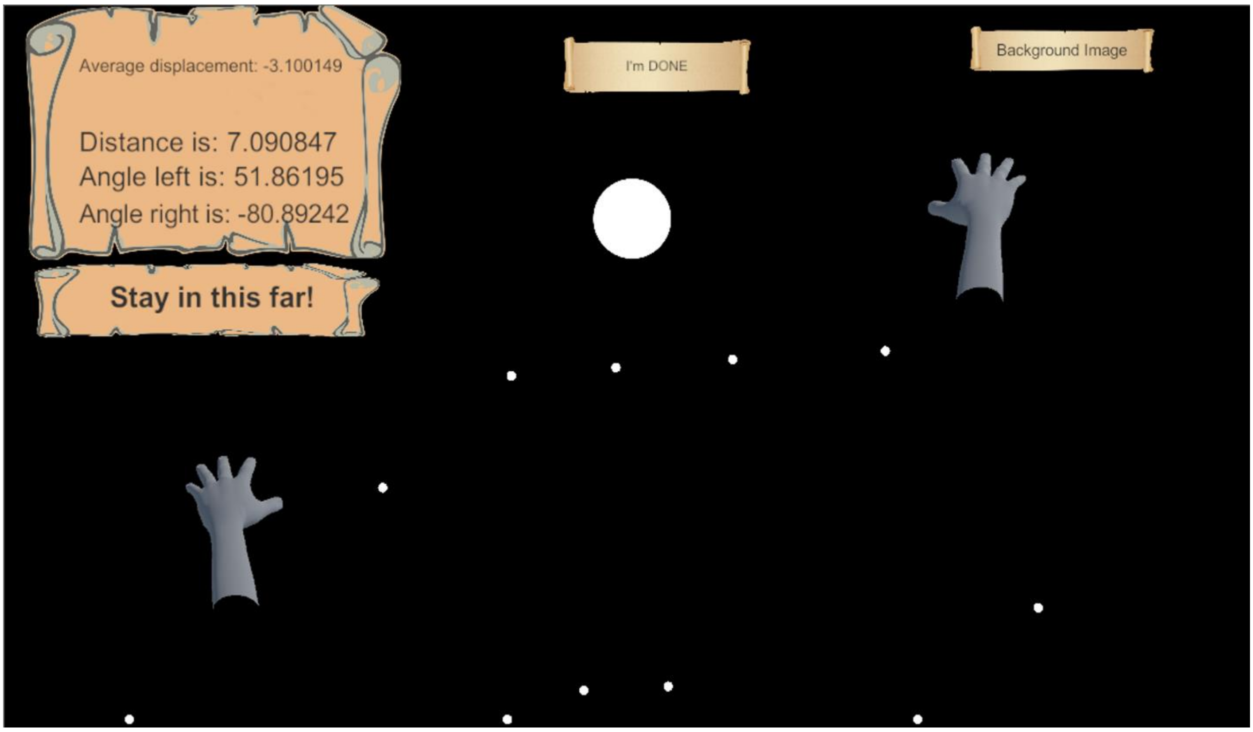


Figure 4.19. CalibrationLevel visualization.

After the main preparatory stage is completed, the first real activity is precisely the level of individual system customization. In this stage, the motion tracking algorithm is first connected and the user can fully appreciate the control capabilities.

As described earlier, the main task is to customize the positioning of the user in front of the webcam so that the recognition process is as correct and accurate as possible. For positioning, the user has 2 main parameters: Distance and Average Displacement. After running the algorithm, the screen space, or rather the camera frame is divided into 4 parts, in exactly the same way as presented in Section 4, paragraph 4.2.3. The Y-axis in this case is the median for calculating the position of key points from the center of the screen (parameter Average Displacement), as well as the main scale for determining the distance of the user from the camera (parameter Distance).

The process of determining the distance from the camera to the user is performed by comparing the value of the coordinate of the center of the key point corresponding to the user's head from the zero value of the axis coordinates. If the coordinate is in the range from 0.55 to 0.8 on the Y-axis, then the player is in the correct position to the camera, as evidenced by the corresponding message on the screen. This method has a disadvantage: incorrect installation of the camera, or too steep an angle can distort the image input to the neural network, so the lower threshold of the range was intentionally reduced to a value of 0.55.

The user's horizontal displacement is determined in a similar way, with the difference that there is no range of "optimal" values. In turn, the parameter Average Displacement, which should always tend to zero, is important. In the interface line, it can take positive and negative values, which means displacement to the left or right, respectively. The Y-axis is used as the basis of reference, the zero coordinate of which is compared with the coordinate on the X-axis of the key point of the dorsal division.

Once all calibrations are done, the user can continue to get used to the system for as long as needed. For this purpose, there are two "hand" elements that will act as a controller in future activities. In addition to this, the user can include a camera image in the background of the scene to help better represent the system's response to movement (an example is demonstrated in Figure 3.3 of Section 3). Ending an activity can be accomplished by pointing the right hand at the "I'm done" button and activating the exit trigger.

b) Level 1 Activity

Name: Level1Unmooring.

Task: Perform a coordination exercise in which you have to unmoor two ship ropes from the fasteners on the dock.

Elements: Timer, progress bar, active scene objects, activity end button.

The basic structure of the level is demonstrated in Figure 4.20. The visual representation is shown in Figure 4.21.

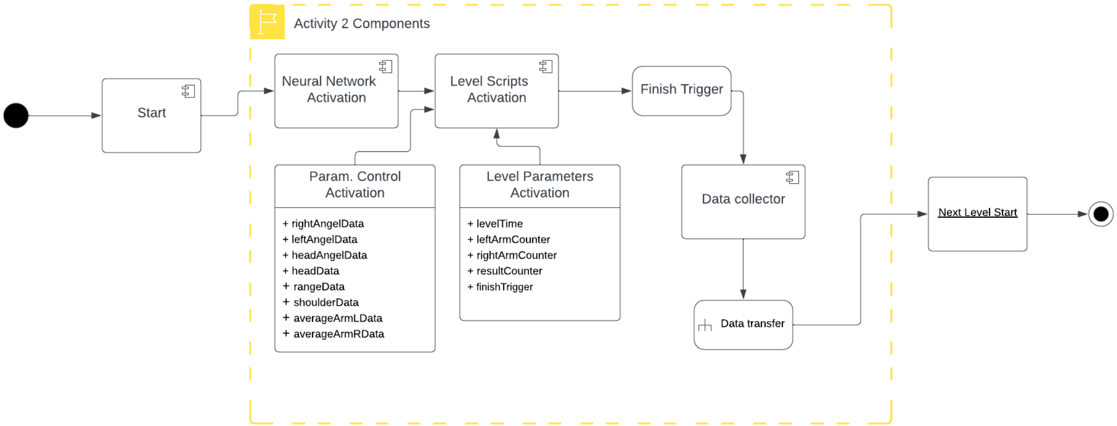


Figure 4.20. Block diagram of Level1Unmooring operation principle.

Figure 4.21. Visual display of Level1Unmooring level.

The principle of the level is to train the coordination of the upper limbs. There are two objects on the stage, around which you need to describe the infinity symbol with each hand. The level itself works as follows: in the normal state the ropes are red in color. As soon as the user puts the "cursor" on the rope, it lights up blue, indicating that the user has come into contact with the object. Next, one must describe a continuous movement (as demonstrated in the video in the initial prompt) until the rope turns green, signifying the completion of one movement. Once 10 repetitions for each hand have been completed, the level is complete.

c) Level 2 Activity

Name: Level2SailsRising.

Task: Perform a coordination and physical toning exercise that involves raising the sails on a ship.

Elements: Timer, progress bar, active scene objects, activity end button.

The basic structure of the level is demonstrated in Figure 4.22. The visual representation is shown in Figure 4.23.

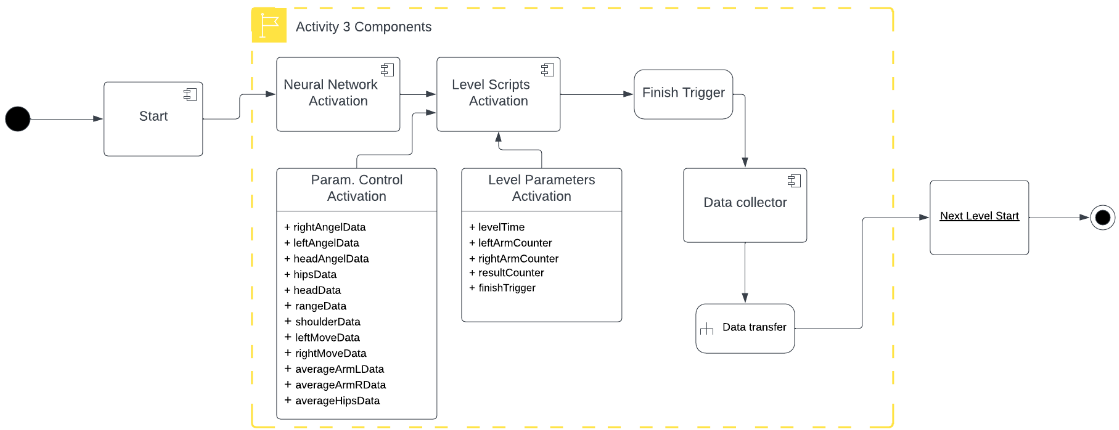


Figure 4.22. Block diagram of Level2SailsRising operation principle.

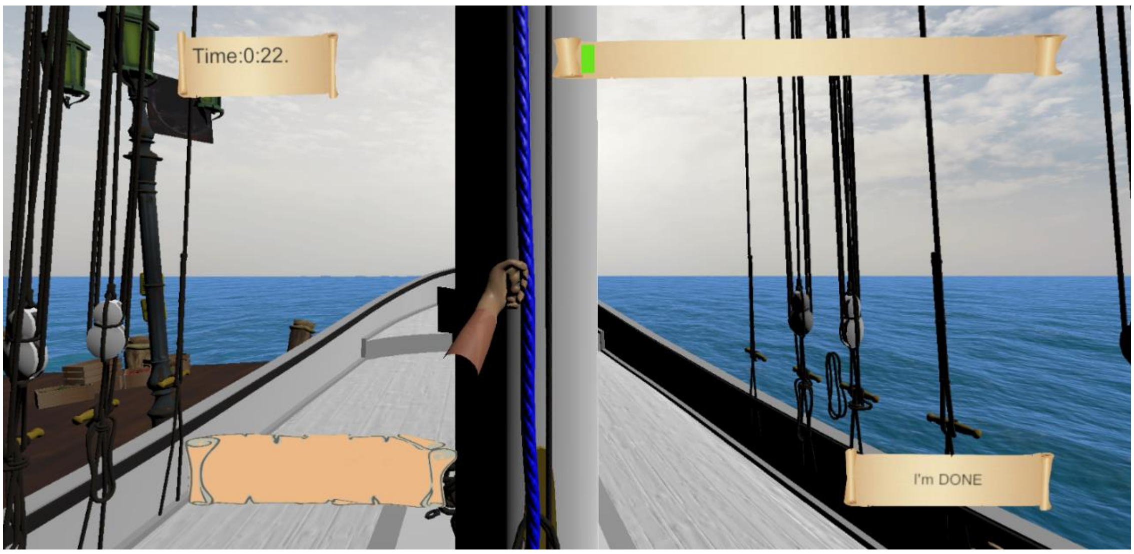


Figure 4.23. Visual display of Level2SailsRising level.

The essence of this level is technically the same principle as the previous one. The difference is that it involves a more complex set of movements and increases the level of physical activity of the user. From a physiological point of view, while Activity 1 used only the upper limbs, Activity 2 uses the entire upper limb girdle, including some parts of the back. From a technical point of view, the task is to pull the rope from top to bottom alternately with each hand. After completing 8 reps per arm, or 16 reps in total, the activity will end.

d) Level 3 Activity

Name: Level3OpenedSea.

Task: Balance and coordination training by steering a ship on the high seas.

Elements: Timer, progress bar, active scene objects, activity end button.

The basic structure of the level is demonstrated in Figure 4.24. The visual representation is shown in Figure 4.25.

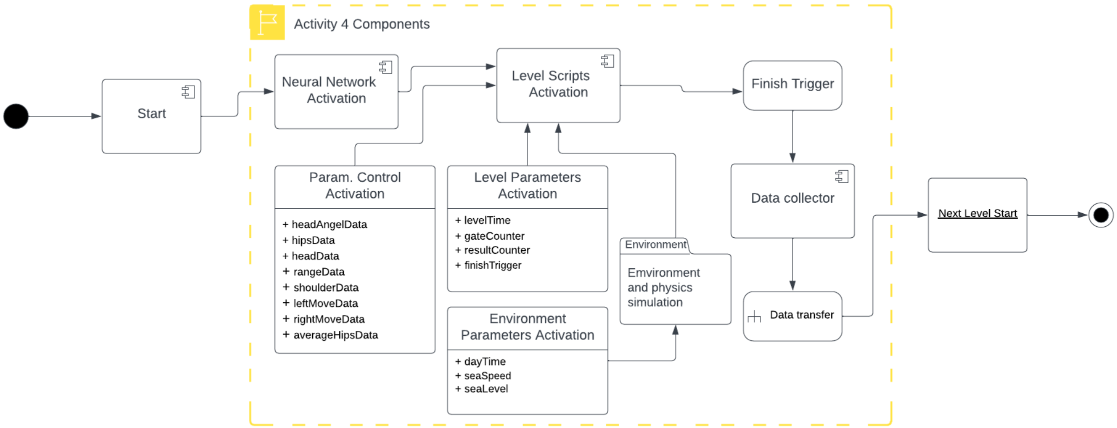


Figure 4.24. Block diagram of Level3OpenedSea operation principle.

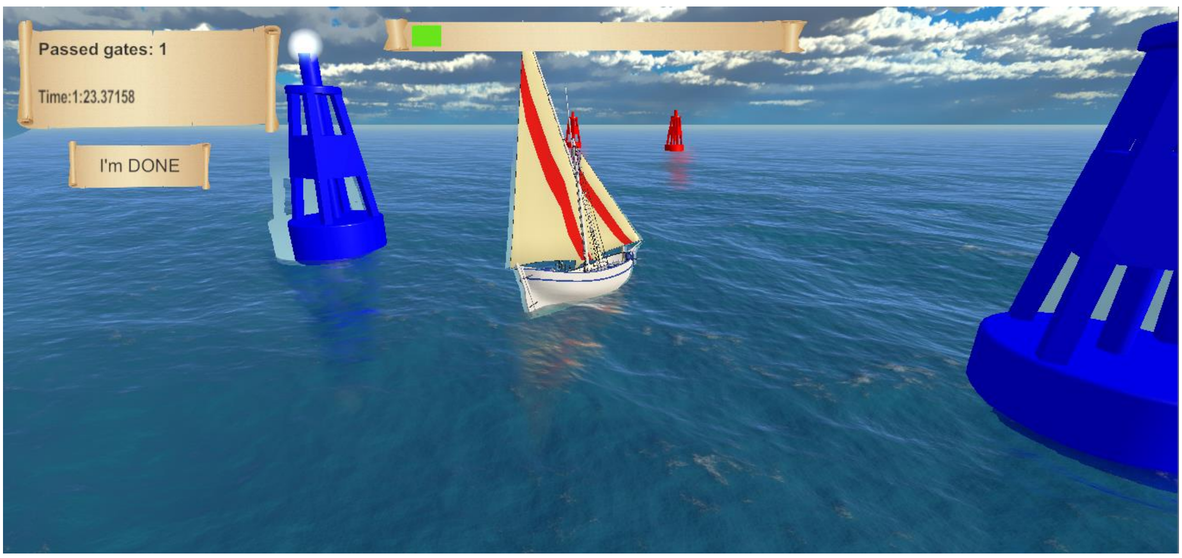


Figure 4.25. Visual representation of Level3OpenedSea level.

This level differs from the previous one in several concepts. The first change is the environment and the concept of the level. This time the user does not control an analog of his hands, but a separate object that moves in space. In this level, in addition to the usual systems, connects the environment control module and a physical model of the behavior of objects, which depending on the choice of complexity and some individual parameters of a particular user can interfere or contribute to the passage of the activity. For example, if you turn too sharply, the ship may turn upside down, or the gate through which you need to pass may sink.

In addition, the method of control is also changing. In previous levels, the control used was similar to PC control - the game "hands" are cursors. In this case, the control is performed by deflecting the pelvis to the left or right, and the degree of this deflection will affect the speed of the ship's rotation. The position of the body in the center point will contribute to the forward movement of the ship.

Level completion will be scored if the user guides the ship through 10 red gates. As the game progresses, they will turn green after passing, and will turn blue during the course of the game.

e) Level 4 Activity

Name: Level4RiverTrial.

Task: Practicing concentration and accuracy of movement by steering a boat in a winding river.

Elements: Intentionally absent.

The basic structure of the level is demonstrated in Figure 4.26. The visual representation is shown in Figure 4.27.

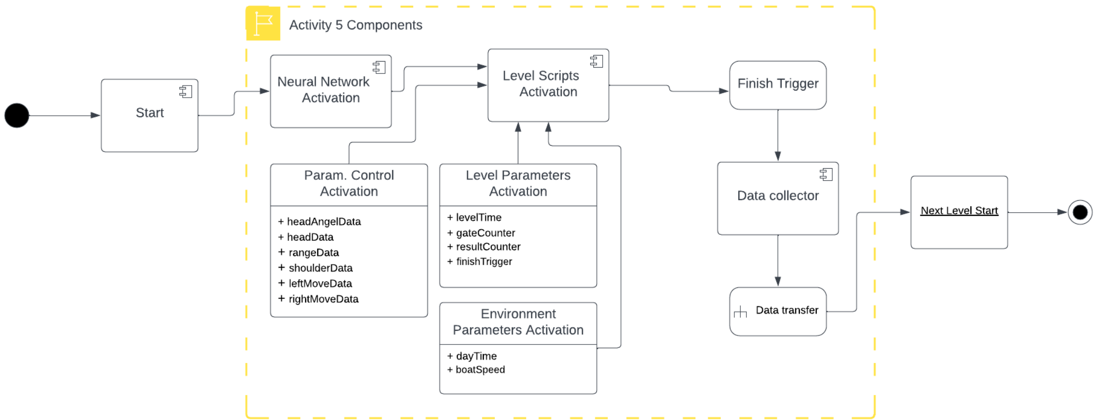


Figure 4.26. Block diagram of Level4RiverTrial working principle.

Figure 4.27. Visual display of Level4RiverTrial level.

The essence of this level is almost the same as that of Activity 4 - training coordination, balance and control of movements. In this case, the main focus is on the back, lower back and neck. In addition to this, the difficulty of the activity is slightly increased, namely the lack of interface and hints. This time the player has to follow the activity and the checkpoints he passes. Also, the amount of space in which the player needs to control the boat is much smaller than before, so you need increased concentration on the task. The final goal is 15 checkpoints, after which a table with the results of the whole game will appear. An example of such a table is shown in Figure 4.28, which also shows the player's parameters that are available for displaying to users.

Figure 4.28. Example of visualization of user results.

4.2.4 Data saving

In the presented system the algorithm of data saving for the possibility of their further processing was realized. It consists in the realization of sending and saving data on the server with the possibility of further access at any time. The principle of operation of this system is demonstrated in Figure 4.29.

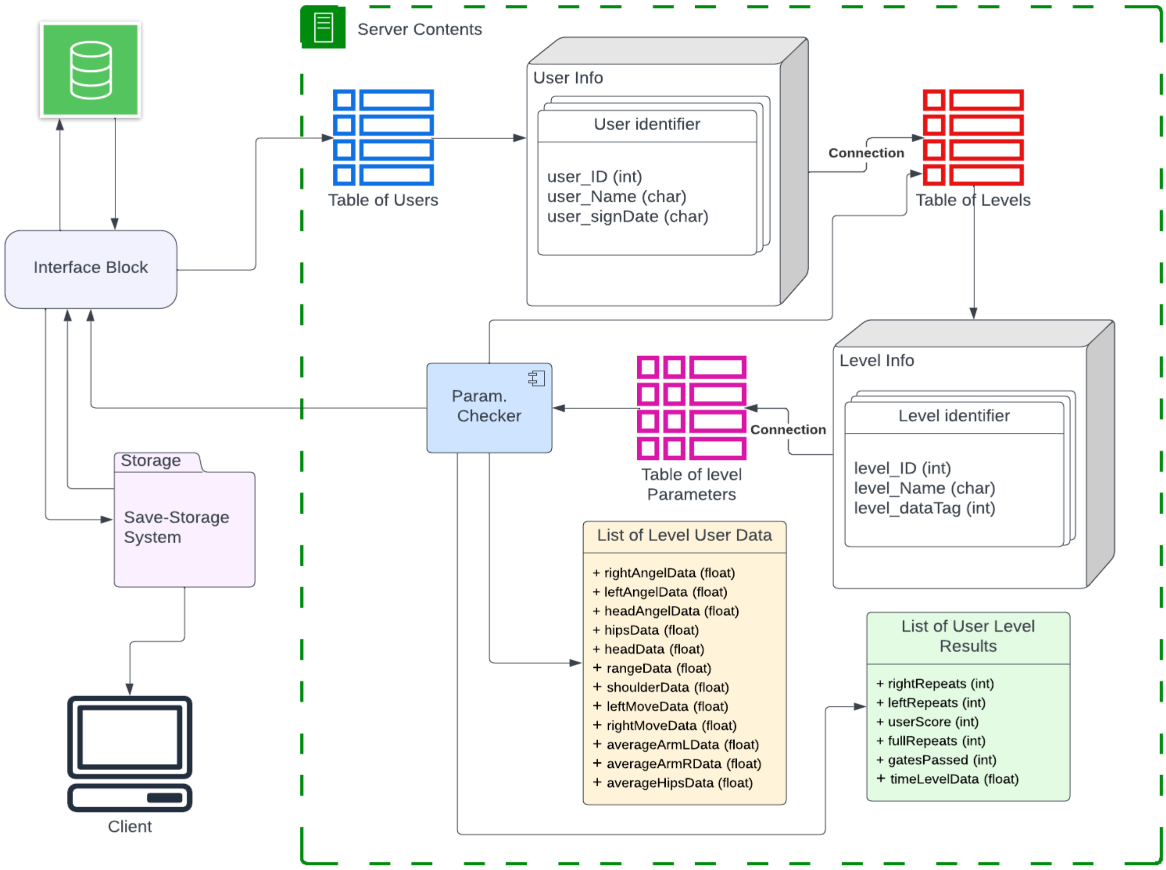


Figure 4.29. Block diagram of the principle of operation of the data saving and sending system.

The system is implemented as follows. Each time, after performing an activity, the system writes all the data that are key for each specific activity to a separate .csv file. Before moving to the next activity, the system reads the created file, which is unique for each activity, and sends the data to the server, creating a certain sequence of relationships. In addition to the sent information, a backup file is created in the user's local copy, which can be a replacement for the server data in emergency cases.

The information received by the server is recorded according to the following procedure and labeled according to unique tags. First of all, a list of specific unique users is compiled and they are given a name, identifier and the date when the information arrived in the database. The name is taken from the information entered by the user at the beginning of the game, the identifier is assigned depending on the order of data arrival and how many such users there were before.

Next, the system reads the information about how many levels have been passed and creates a separate list. After that, the data for each level is read directly and distributed into the corresponding blocks. However, there is one important point here. In Figure 4.29, the "List of

Level User Data" block as well as the "Level Identifier" block have certain data tags that must be written to the base display variant in the end. The point is that in the process of data capturing there is no selection of specific parameters to be recorded. For a complete picture of what is happening and the user's actions, all possible parameters are continuously recorded. In addition, there are the results of performing activities, and they should also be displayed. Thus, each tag of each parameter or result is read and, according to the tag, it is already recorded in the level-specific information.

Once recorded, any user who has access to the database will have the following data structure available to them: user - level - run parameters - results. This simple structure is designed to make it as easy as possible for mentors/physicians to access the data of any user of interest to them.

4.3 Results

This section presents the results of testing the Physical Rehabilitation Block. Structurally, the section is organized as follows: Brief description of the block, information about the users, numerical and graphical results, and analysis of the data obtained.

4.3.1 Information about players

Initially, 2 groups of players were formed: Test and Target. In Test group 10 volunteers were selected for the experiment, in the age range from 21 to 42 years. Five people between the ages of 60 and 75 were recruited to the Target group. The main data pertaining to the players are shown in Table 4.6 and Figure 4.30. As can be seen in Figure 4.30 and Table 4.6, the data provided show information on both physical parameters (height, weight and age, and the presence of any injuries) and social parameters. In the case of the latter, specifically what country the player is from will help better understand the results obtained by each of the players during the game.

At the same time, information about the presence or absence of injuries will also help to understand whether injuries in the past have an impact on current results.

Table 4.6. Players main parameters.

№	Gender	Age	Height	Weight	Spine or limbs problems	Country
			Test Group			
1	Male	26	182	72	Left clavicle fracture	Ukraine
2	Female	25	179	89	-	Morocco
3	Male	26	178	77	Left arm fracture	Pakistan
4	Female	42	167	55	Right wrist injury	Spain
5	Male	27	170	65	-	Spain
6	Male	25	178	72	Left shoulder injury	Spain
7	Male	31	173	78	-	Pakistan
8	Male	25	169	69	-	Colombia
9	Female	21	159	50	Right hip fracture	Czech Republic
10	Male	22	176	63	-	Italy
			Target Group			
11	Female	63	161	71	Pelvis injury	Spain
12	Female	67	170	76	Right hip fracture	Ukraine
13	Male	70	159	91	-	Spain
14	Female	65	164	61	-	Spain
15	Female	69	167	67	Right arm injury	Ukraine

The choice of this set of players was due in large part to the current, situation at the time of the study with the pandemic COVID-2019. Ideally, all tests should be conducted with participants within the age range of 60 to 85 years. Nevertheless, the data that was obtained with the set of players provided will help to qualitatively evaluate the results and more accurately adjust the system for the target age category.

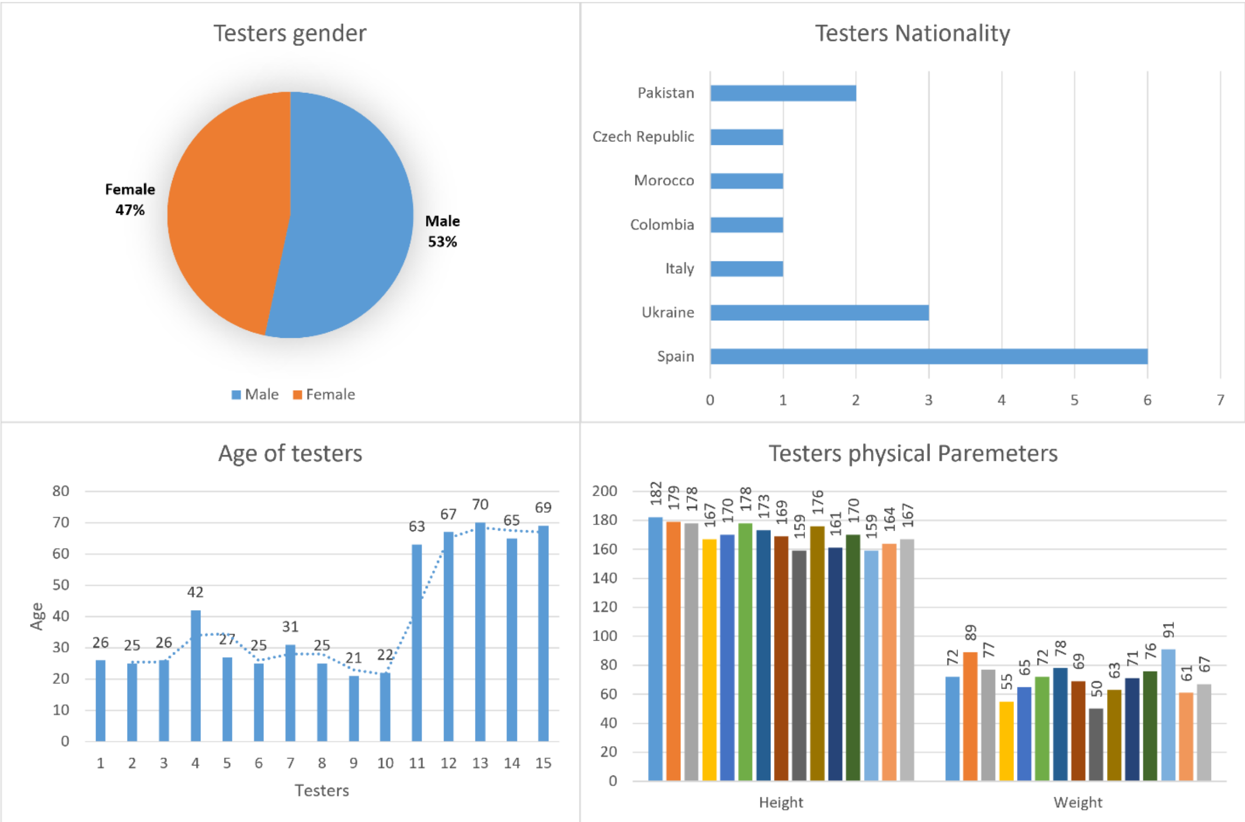


Figure 4.30. Main information about test participants.

As mentioned earlier, the procedure for testing the system was divided into two stages: obtaining players' performance during normal exercises and obtaining performance during direct play. During both phases, a total of six tests were conducted in each. The testing interval ranged from 5 to 15 minutes, depending on the test stage. The time interval between tests was 12 hours.

In the first stage, the players took turns performing five exercises while standing in front of the camera. The only information available was the task for the exercise, the number of repetitions required, and the distance to the camera in order to obtain the data as accurately as possible. During this phase, the system recorded the values necessary for each specific exercise, as well as the time of the exercise. The values were saved as a data set for each of the categories of interest.

The second stage differs from the first in that the players now directly used the game platform as a guide to action and exercise. All information about the latter was provided through the user interface. In this case, there was also a record of the parameters that were key for each level-exercise.

It is also important to note that this project was approved and accepted by the Deusto University Ethics Committee

4.3.2 Data Analysis

Received signals must be processed and certain characteristic data must be obtained from them. Therefore, the following parameters must be extracted from each signal:

a) Time parameter

Exercise time in total. This characteristic helps to ascertain how fast or slow the play-er performed a particular exercise

b) Amplitude parameter

Includes the value of the minimum and maximum amplitude of the signal. The main purpose of the measurement is to represent the player's activity during the exercise, namely to understand the spatial characteristic of the activity. Given that the amplitude value obtained during the analysis of the player's movements is shown in the percentage value of the deviation of the key points from the central plane lines on the screen, by obtaining this value, it is possible to judge, for example, how high the player raised their arms, how much they deflected when moving their hips, or how actively they moved in front of the camera.

c) Frequency of repetitions

It is also important to understand the frequency with which the player performed a particular exercise. This parameter can be obtained by several methods, but since the data obtained in the time and graphical representation is a sinusoidal signal, the most convenient method is the application of the direct Fourier transform, the formula for which is shown below.

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(j\omega)e^{j\omega t}d\omega \quad (1)$$

Obtaining this parameter will help you keep track of how often the player is per-forming the exercise. This parameter is also important for understanding the quality of the exercise (whether it is too slow or too fast), and therefore its effectiveness.

d) Shimmer and Jitter

Shimmer and jitter values are an estimative characteristic of the quality of exercise performance. Thanks to these parameters we can judge the quality of the periodicity of movements, both in terms of the difference in time of each repetition and the difference in the amplitude of the movements.

Jitter absolute: variation of fundamental frequency. The average absolute difference between consecutive periods:

$$jitter\ (a) = \frac{1}{N-1}\sum_{i=1}^{N-1}|T_i - T_{i+1}| \quad (2)$$

Jitter relative: average absolute difference between consecutive periods, divided by the average period:

$$jitter\ (r) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}|T_i - T_{i+1}|}{\frac{1}{N}\sum_{i=1}^{N}T_i} \quad (3)$$

where Ti are the extracted period lengths and N is the number of extracted periods.

Shimmer dB: expressed as the variability of the peak-to-peak amplitude in decibels, average absolute base-10 logarithm of the difference between the amplitudes of consecutive periods

$$shimmer\ (a) = \frac{1}{N-1}\sum_{i=1}^{N-1}|20log\ (\frac{A_{i+1}}{A_i})| \quad (4)$$

Shimmer relative: defined as the average absolute difference between the amplitudes of consecutive periods, divided by the average amplitude, and expressed as a percentage.

$$shimmer\ (r) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}|A_i - A_{i+1}|}{\frac{1}{N}\sum_{i=1}^{N}A_i} \quad (5)$$

where Ai are the extracted peak-to-peak amplitude data and N is the number of extracted fundamental frequency periods.

Having obtained all of the above parameters, it is possible to compare the results obtained, as well as judge the quality of the exercise. Table 4.7 directly shows the results obtained from four cases of Exercise 3.

Exercise 3 is taken as an example in this case for several reasons. First, all exercises in this block have almost the same visual characteristic of the output parameters, namely a sinusoidal signal demonstrating the amplitude of deviation. Secondly, given that users in their groups have approximately the same level of ability and physical condition, the demonstration of the results of a single user quite demonstrates the average picture for the whole group. When comparing a single result with the total group result in a particular exercise, the difference does not exceed 5-7%, which in the realities of the initial technical parameters is not critical in evaluating the results.

Table 4.7. Example of comparing the results of one iteration in Exercise 3.

Result	Time, s	Min. Amplitude, %	Max. Amplitude, %	Frequency, Hz	Shimmer Absolute, dB	Shimmer Relative	Shimmer, %	Jitter Absolute	Jitter Relative	Jitter, %
LEFT HAND										
Etalon	13.01	-68.15	67.52	0.859	11.78	0.029	2.886	0.076	0.064	5.344
Bad	9.46	-87.34	77.69	1.025	25.14	0.318	31.827	0.414	0.512	63.168
Exercise	9.41	-87.37	69.75	1.297	10.59	0.042	4.241	0.067	0.080	9.701
InGame	15.26	-87.34	77.55	0.806	16.29	0.033	3.280	0.164	0.118	8.438
RIGHT HAND										
Etalon	13.01	-84.37	66.29	0.8591	8.69	0.029	2.940	0.091	0.076	6.380
Bad	9.46	-85.22	76.35	1.025	25.04	0.373	37.262	0.389	0.477	58.548
Exercise	9.41	-85.04	64.78	1.297	16.67	0.056	5.568	0.084	0.102	12.228
InGame	15.26	-83.75	76.99	0.806	13.00	0.035	3.483	0.196	0.140	9.997

The data in Table 4.7 refer measurements of a single exercise performed once. Figure 4.31 shows a graphical analysis of the data obtained.

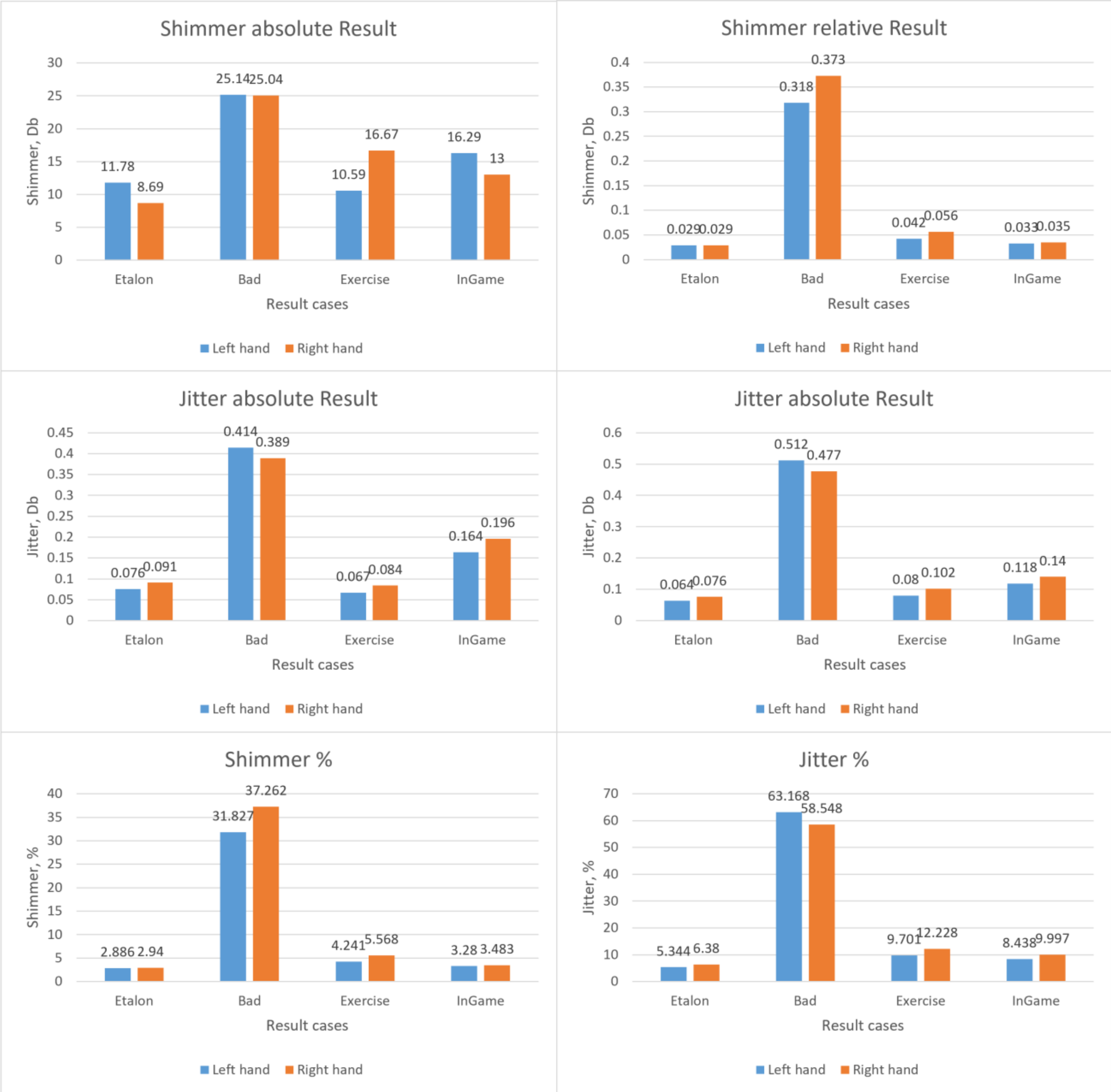


Figure 4.31. Visualization of the parameters of the result obtained.

As for the jitter and shimmer parameters, it is worth noting that the lower their values, the better the result obtained in the end. This will mean that the player performed the game exercise as clearly and correctly as possible.

Additionally, the time and amplitude parameters should be compared in a different way. The reference point is the value of the repetition amplitude of the reference signal, in this case the distance between the maximum and minimum amplitude of each repetition and the entire signal (values in Table 4.7).

In addition to comparing the results obtained from a single exercise, it is also important to understand the dynamics of those results. This is necessary in order to under-stand the efficiency of the system in repeated use, as well as to ascertain the parameter of overall efficiency. Table 4.8 shows the results obtained from Exercise 4 over six days with a 12-hour interval between exercises. Exercises are performed in normal exercise mode and directly in the game. The comparison is made according to the same parameters that were shown in Table 4.8.

Table 4.8. The results obtained from Exercise 4 in its two interpretations: game and usual.

Result	Time, s	Min. Amplitude, %	Max. Amplitude, %	Frequency, Hz	Shimmer Absolute, dB	Shimmer Relative	Shimmer, %	Jitter Absolute	Jitter Relative	Jitter, %
Ordinary Exercise										
Etalon	25.39	-19.4	19.7	28.55	0.44	7.91	0.044	4.398	0.590	0.241
Bad	12.41	-11.92	28.67	31.01	0.82	13.54	0.198	19.77	0.229	0.201
Try 1	11.24	-19.04	11.15	24.75	0.91	10.76	0.120	12	0.158	0.140
Try 2	10.94	-9.46	22.86	29.12	0.93	7.91	0.057	5.731	0.142	0.130
Try 3	10.61	-15.16	18.98	27.66	0.96	10.38	0.112	11.241	0.108	0.096
Try 4	10.54	-12.28	17.88	26.72	1.06	4.94	0.055	5.498	0.100	0.095
Try 5	10.44	-10.96	20.92	28.09	0.98	11.04	0.090	8.955	0.082	0.083
Try 6	9.18	-13.81	17.58	26.824	1.12	7.82	0.092	9.233	0.128	0.139
In-Game Exercise										
Etalon	19.27	-37.20	41.82	70.35	0.31	15.41	0.084	8.422	0.508	0.155
Bad	29.79	-38.53	38.27	63.08	0.28	17.85	0.178	17.770	2.758	0.484
Try 1	28.00	-45.05	58.12	80.16	0.21	19.83	0.136	13.585	0.330	0.077
Try 2	25.69	-45.06	46.28	76.19	0.23	13.40	0.092	9.168	0.223	0.050
Try 3	25.72	-39.05	49.01	83.95	0.19	18.02	0.182	18.24	0.545	0.127
Try 4	23.17	-42.46	44.82	70.47	0.3	21.70	0.196	19.573	0.368	0.105
Try 5	22.88	-43.91	46.9	74.81	0.26	21.39	0.162	16.153	0.952	0.254
Try 6	22.09	-22.68	26.4935	43.81	0.23	15.76	0.153	15.327	0.778	0.187

Table 6.3 shows the results obtained from Exercise 4 in two different interpretations: as a game level performance and as a normal physical exercise. Figure 4.32 shows a visual representation of the results.

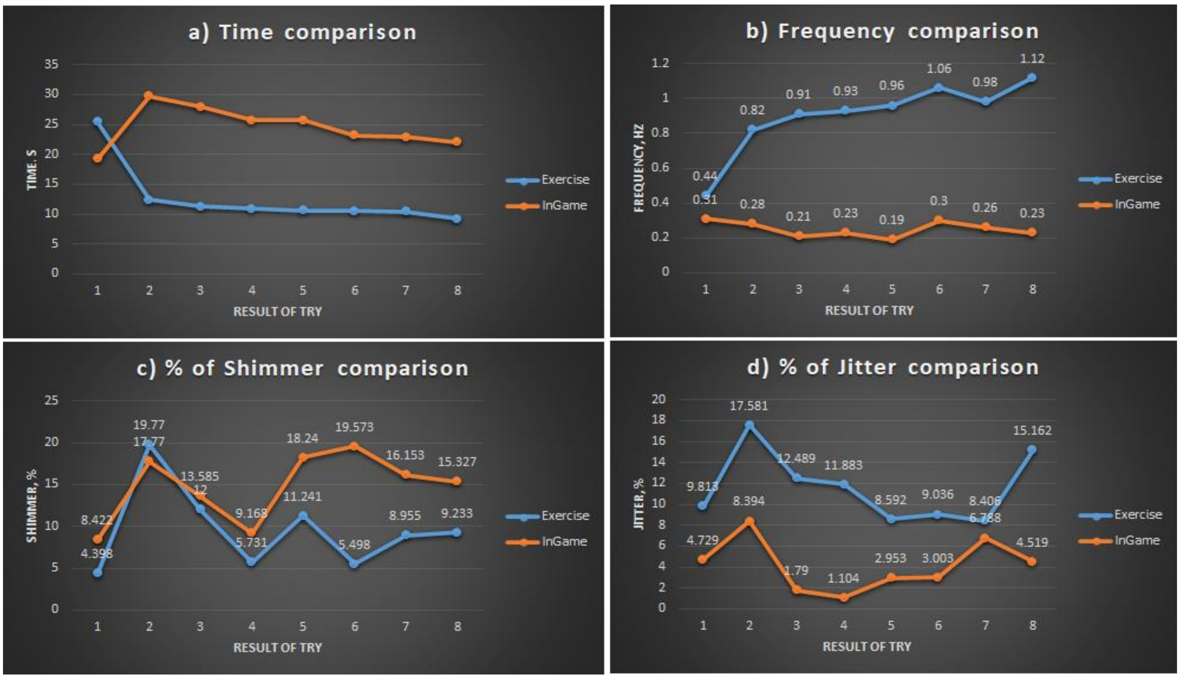


Figure 4.32. Visual representation of Exercise 4 result comparison in time, frequency, % of Shimmer and Jitter.

The effectiveness of the system can be judged following the first tests. One of the indicators of the system is time, which shows how fast the player completes a level. From this, it is possible to compile statistics on the player's progress, and this can be done by comparing it to the normal way of performing the exercise. In the example of the results obtained from Exercise 4 in Table 4.8 and Figure 4.32, the time value decreases in both cases of normal exercise and in-game level.

It is also important to mention that, given the waveform, Figure 4.32 b) is an important characteristic to evaluate. The frequency spectrum of the output signal, specifically its parameters from a physiological point of view, demonstrates how actively and correctly the user is performing the exercise. Figure 4.32 b) demonstrates the difference in frequency from the ideal in both the normal exercise and the game version. In the former case, a deterioration of the results and less interest in what is happening is clearly visible, while in the latter case, on the contrary, the result of actions and deviations decreases. An example of a separate Fourier transform result for a signal is demonstrated in Figure 4.33.

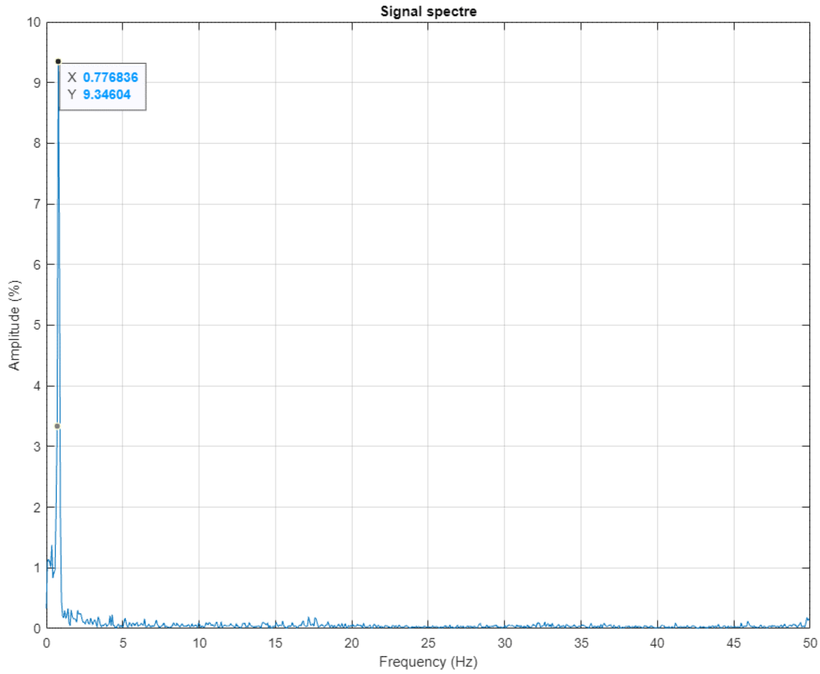


Figure 4.33. Example of Frequency Response for the output signal Exercise 4.

In addition, data that represent the progress of the exercise will also be important visual parameters. An example of such a data representation is shown in Figure 4.33. It shows the visual progress of the user in terms of the time and frequency components of the exercises. With each new attempt, they become more even, without artifacts and sudden changes in values, an example of which can be observed in the time interval from 3.5 to 4.5 seconds. For clarity, the time period is taken as 10 seconds long.

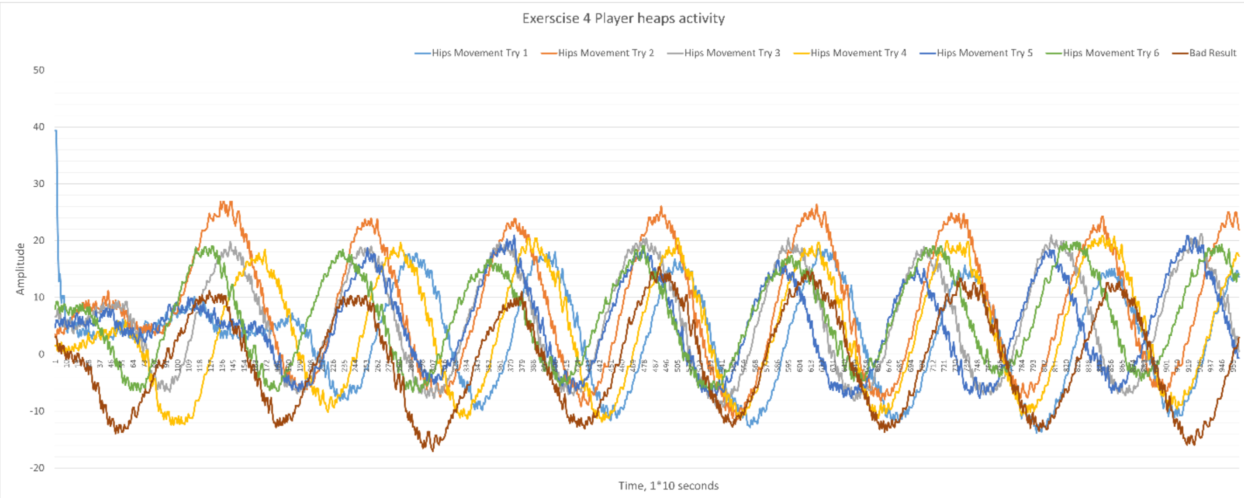


Figure 4.34. Example of visual comparison of different attempts of Exercise 4.

In essence, however, the time values for both cases mean a different situation. Figure 4.35 and Table 4.9 shows the progression of the results as a percentage.

Table 4.9. Players main results.

Result	Time Standard, s	Time Standard dynamics, %	Time In-Game, s	Time In-Game dynamics, %	Percentage of standard accuracy, %	Percentage of In-Game accuracy, %
Etalon	25.39	100	19.27	100	100	100
Try 1	11.24	55.73	29.79	45.30	44.27	54.70
Try 2	10.94	56.91	28	33.32	43.09	66.68
Try 3	10.61	58.21	25.69	33.47	41.79	66.53
Try 4	10.54	58.49	25.72	20.24	41.51	79.76
Try 5	10.44	58.88	23.17	18.73	41.12	81.27
Try 6	9.18	63.84	22.88	14.63	36.16	85.37

The data in Table 4.9 are obtained from the percentage ratio between the values of the reference and received signals.

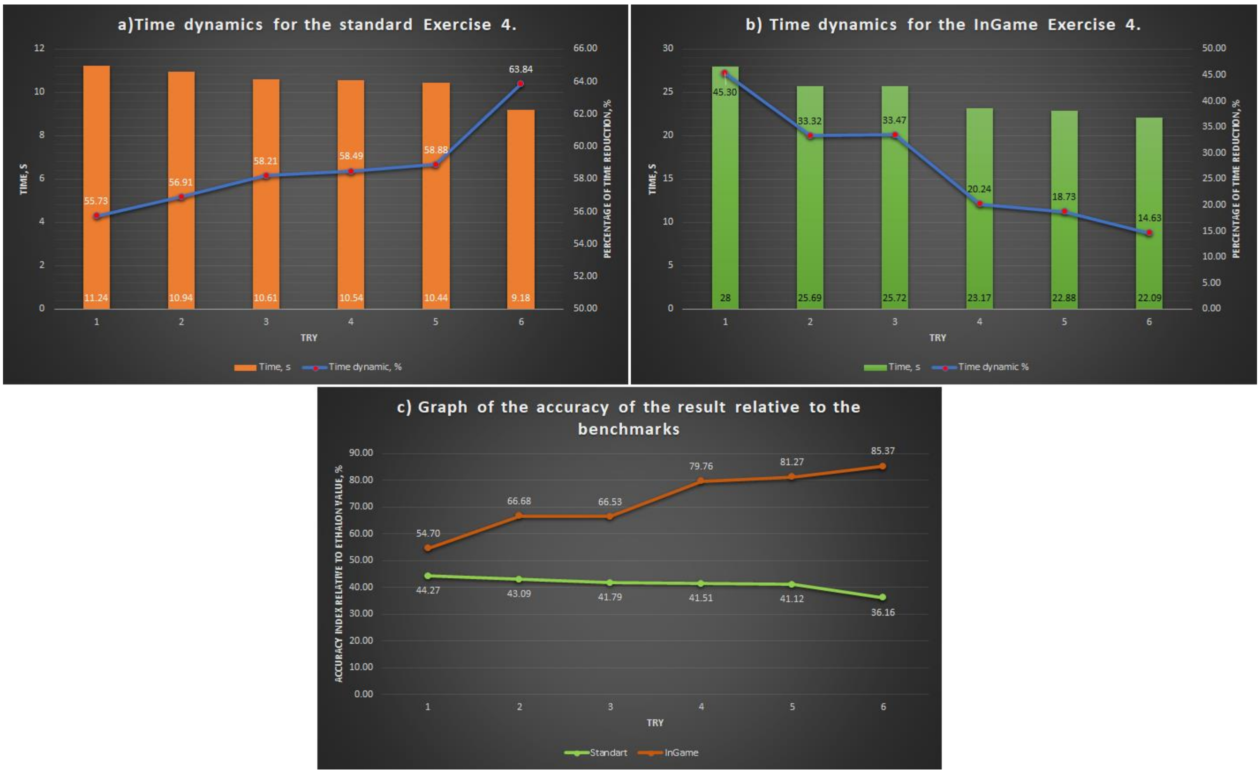


Figure 4.35. Comparison of both variations of Exercise 4.

Figure 4.35.a and Figure 4.35.b show the difference in time needed to complete Exercise 4 for each trial. In the first case, the Try 1 result differs from the reference by 14.15 seconds, which is 44.27%. This gap then increases with each new trial to 9.18 seconds, i.e., 63.84%. This indicates that this examinee is trying to finish the exercise quickly (there is no question as to the correctness of the exercise at this point).

The second case is exactly the opposite. This time difference is 10.52 seconds, 45.3%, and the time difference decreases to 3.61 seconds, which is only 14.63%, unlike in the case of the standard exercise. Based on this result, we can conclude that by choosing an interpretation of the exercise based on the platform developed, the player will have a greater motivation and desire to perform the exercise more correctly.

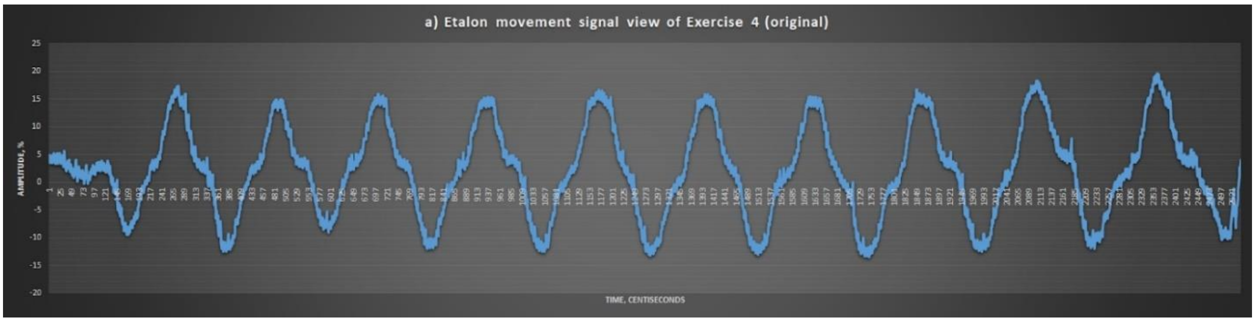
Even though in both cases the exercise time is reduced, the case of the In-Game result shows that the platform developed justifies itself as an additional tool for rehabilitation proposes. This is due to the fact that by introducing a certain kind of activity, such as, in this case, steering the ship through the control points, the person focuses not just on completing the exercise, but also on performing it as correctly as possible. This is also greatly helped by the presence of a visual response to the player's actions.

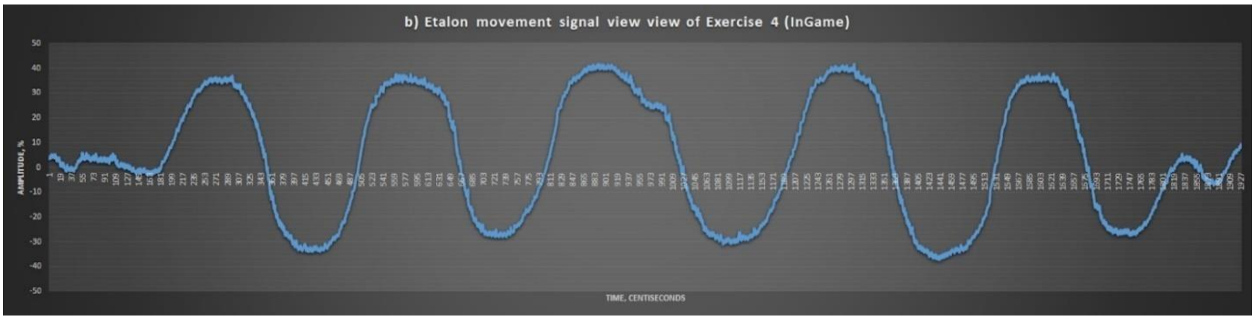
The same pattern is observed in the case of the frequency of exercise. The frequency response of both cases shows that while in the case of the normal exercise the player tries to perform the exercise faster each time, the In-Game case allows to regulate the tempo of the movements at the same level.

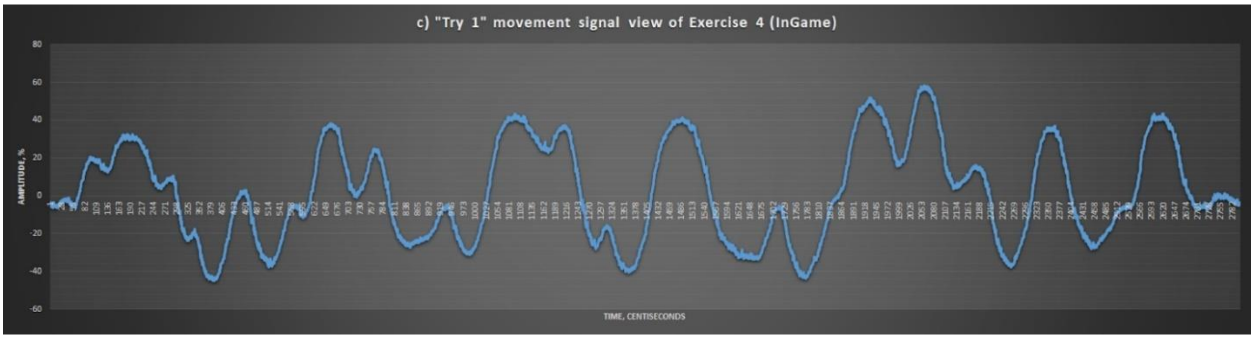
The Jitter and Shimmer values are also indicative of a certain kind of results. Due to the peculiarities of the game level for Exercise 4, there is a need to control the period of each repetition by the game itself, which allows you to bring the time of each repetition to the median value. Calculation of these parameters is an important part of the system because they mainly control and regulate the dynamics of the player's movements, which allows you to monitor and regulate the rehabilitation process more accurately.

As can be seen in Figure 4.32, in general both interpretations of Exercise 4 evidence a similar progression of results. Nevertheless, it should be noted that with respect to some specifics, Exercise 4 is somewhat different in nature in these two interpretations. While in the case of the simple hip movement, the main goal is the precision of the movement – namely, the most similar values of the amplitude of the movement, the period of each repetition and the total time of the movement – in the game version, the key goals are some-what different.

Based on the peculiarities of Level 4 (which is the interpretation of the Exercise 4), the number of repetitions is 10, with 5 hip movements each side, while for normal performance it is 20, with 10 movements each side. However, this reduction in repetitions is compensated by the fact that the player is not limited to this number. Since the goal of the game level is to steer the boat through 10 gates, and not just 20 moves, the player can do more to achieve this. An example of how this works is shown in Figure 4.36.







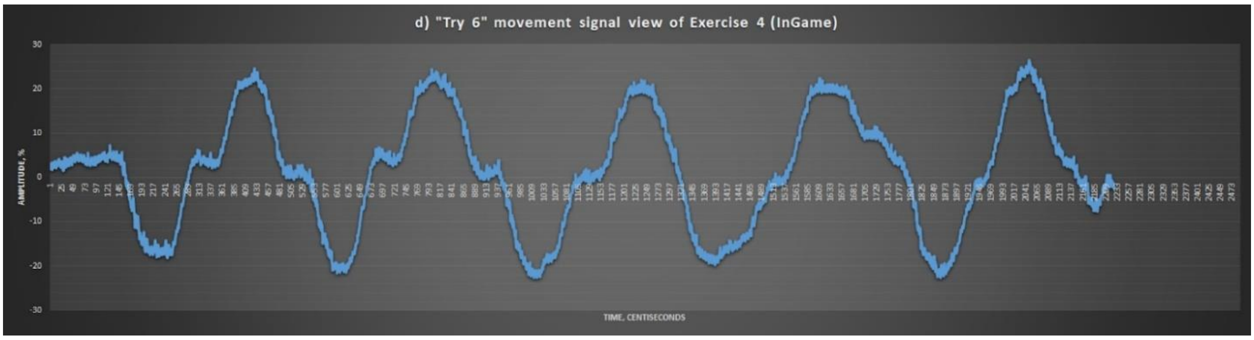


Figure 4.36. Example of the difference in the pattern of movements for different interpretations of Exercise 4.

Unlike the usual physical interpretation of Exercise 4, the In-Game version forces the player to focus more on the quality of the exercise. Considering that the boat is steered directly with the hips, the number of repetitions will be determined by the player's level of dexterity and control. In the "ideal" performance of this exercise, the movement pattern (Figure 4.36.b) is similar to the physical performance movement pattern (Figure 4.36.a). As you can see in Figure 4.36.c, the first attempt to pass the level required far more movement for the player, although after passing the same level on the 6th attempt (Figure 4.36.d), play-er significantly improved their score. Instead of 18 moves, they needed 10, which is a 44.4% increase. At the same time, the level completion time also improved, whereby the score improved from 28 seconds to 22.09, which is 21.1% better than the 1st tries.

In the case of a normal exercise, the time score indicates that the exercise was per-formed faster with each new time, to perform it faster. These rules of analysis also apply to Exercise 5 since they are similar in their nature and the way they are performed. At the same time, the game interpretation of the first three exercises does not differ in mechanics from the physical one, and so in this case a direct comparison of the indices given in Tables 4.8 and 4.7 is provided.

4.4 Summary

This stage of development demonstrates the process and structure of creating a game application for the Physical Rehabilitation Unit of the system presented in this thesis. The result of the development is an application consisting of two structural and 5 functional applications for the support and rehabilitation of users with musculoskeletal problems.

During this phase of the study, an algorithm based on a modified and altered neural network system called OpenPose was developed and tested. The version presented in the study is more optimized in terms of performance and requirements to device parameters. Also developed and tested is an algorithm for registration of outgoing after work processing by neural network, which is a sinusoidal amplitude-frequency signal of movement of key points of the user's body. The presented variant of the algorithm of registration and tracking of movements is prepared and ready for implementation in the development environment of the game application.

The test results obtained in the course of the analysis show an increase in results even in the short term of using such systems. In terms of accuracy and time to complete a task, there is almost a twofold improvement in the results. At the same time, the level of activity increased by almost one third, which indicates a positive outlook for the use of such a system.

5

Case Study 2: Cognitive Rehabilitation Block

" Many cognitive psychologists see the brain as a computer. But every single brain is absolutely individual, both in its development and in the way it encounters the world."

Gerald Edelman

The definition of cognitive disability (CD) according to the American Association on Intellectual and Developmental Disability [97], refers to a disability characterized by limitations in intellectual functioning and in adaptive behavior of a person that appears before 22 years of age, considered as the developmental period. Intellectual functioning is understood as a mental capacity for learning, reasoning or problem solving, between others. Adaptive behavior includes conceptual, social, and practical skills that will allow to per-form adequately daily living skills (eating, dressing, cleaning, etc.), occupational tasks, self-care and healthy living, agenda management, money use ability, transportation usability, and other aptitudes [97]. Finally, it means to be able to cope with an independent life.

The AAIDD also considers other factors that may determine the disability. For example, the community, and language or cultural issues. Anyway, the functioning of these persons might improve if they receive personalized support.

CD appears when the development of the brain is disrupted before or during birth, as well as during childhood. One of the most frequent causes of CD is Down syndrome (DS). It is associated to some health, a physical feature that gives a characteristic appearance [98].

It is interesting to notice that, because of the improvement of medical care, persons with CD, including DS, present an increased life expectancy which require the promotion of a good quality lifestyle [99–102]. This is a challenge when it is considered the developmental cognitive impairments associated with lifelong intellectual disability and, moreover, the variability of cognitive functioning across individuals [103]. With greater survival rates reported among people with CD, there has been an increase in physical, cognitive, and mental health challenges [104].

The executive function is a key element in human development as it is a multidimensional construct that includes response inhibition, working memory and cognitive flexibility [105]. Moreover [106] indicated that working memory, shifting and inhibition capacity, facilitate other EFs such as planning and problem-solving. Among the general population, good executive function performance, and particularly self-regulatory capacity, is linked to the ability to suppress inappropriate behavior and seek conduct that is better adapted. A good result in executive functions in the early life stages encourages healthy social relationships in adulthood, better levels of employment insertion and a lower response to risky behavior [107, 108]. Together with other cognitive functions, response inhibition is a process that aims to promote cognitive performance adjusted to one’s environment, and this is a key component in self-regulation processes [109, 110].

There is a growing body of literature exploring the nature of executive functioning in individuals with CD [111], but research is inconsistent regarding the relationship between executive functioning and general intellectual ability [112]. The relationship found may depend on the population studied and the measurements used to examine executive functioning and intellectual ability. There is considerable evidence pointing to the decline of executive functioning in the aging process [113]. Individuals with CD may show levels of executive functioning commensurate with their developmental level [114]. Recent studies suggest that individuals with CD have difficulties with EF, but there are differences in assessment measures, thus better understanding of these characteristics and validated tests for this population will aid in assessing the effectiveness of interventions [115].

A positive correlation has been found between executive and adaptive functioning in individuals with CD [116]. Deficits in executive functioning have been linked to challenging and offending behavior [117]. Adults with CD may be more at risk of developing dementia in old age than expected, especially those with DS [118–120]. Therefore, early detection of dementia can be challenging in persons with CD [121]. It has also been suggested that people with DS show executive dysfunction and behavioral and psychological symptoms in the pre-clinical stages of Alzheimer disease (AD) and which may precede loss of memory [122]. It has been suggested that one indicator of AD in persons with DS is loss of daily living skills [123], and boosting their cognitive reserve is vital. For this reason, taking into ac-count the changes in executive functions in the adult population with DS, it is extremely important to assess the decline of these functions in people with DS, as it could contribute to early diagnosis of AD onset and its treatment to promote a better quality of life [124].

A systematic review shows a positive impact of serious games for people with CD, both in relation to cognitive, social and communication skills [125]. The most common type of game in the literature is serious game, but the studies are more focused on the development of cognitive abilities rather than of adaptive skills [126]. The use of new technologies facilitates interactive learning that allows to reinforce the learning carried out through the different platforms and helps to develop new learning. Among them is the use of Serious Games. These solutions help in the training and adaptation of people with CD, as well as allow for more accurate monitoring of their condition. Using such systems, it is possible to teach people who require assistance in adapting to society due to different circumstances using the most accurate examples, but most importantly, they allow them to monitor their performance remotely.

5.1 Materials

5.1.1 Data and Literature Analysis for Cognitive Rehabilitation Block

On the other hand, the direction of cognitive research also deserves separate consideration. First of all, the scientific work or article must be of technical nature, containing in its composition a technical and experimental description of the proposed solution. Whether it is a mobile application or other engineering product aimed at user use. It is also important to describe the target audience for which the solution is in-tended.

As shown in Table 3.1 the search was performed in the following 7 databases: ACM (Association for Computing Machinery), IEEE Xplore database, DBLP computer science bibliography, Google Scholar, PubMed, SCOPUS and PsycInfo. The results of the search are shown in Table 3.2, which also shows the whole number of articles that included one or a combination of several keywords.

Inclusion criteria:

- Population: Adults (18+) with ID.
- Intervention: Digital solutions based on Serious Games, acting as support, and learning assistants. Applications for mobile platforms and personal computers (PC).
- Publication source: Journals included in the following data base: ACM "Association for Computing Machinery," IEEE Xplore database, DBLP computer science bibliography, Google Scholar, PubMed, SCOPUS and PsycInfo.
- Time Period: Papers published since 2015.
- Language: English.

Exclusion criteria:

- Population: (1) the diagnosis of an ID was not explicitly mentioned; (2) people diagnosed with cognitive disorders, acquired cognitive or neurological impairments, blindness, or physical disabilities.
- Kind of document: Conference proceedings/abstracts, editorials, dissertations/theses, or published in non-peer-reviewed journals.
- Language: A full text was not available in English.
- Intervention: Applications for entertainment, leisure, or other entertaining events.

It is worth determining for what reason in the Inclusion criteria the year parameter to search for articles is defined as 2015 or newer. Such a time interval of 5-7 was chosen due to the fact that about this period is necessary for the development and implementation of new technologies in the creation of computer games and similar systems.

Also, a comparison of the number of results for any of the keywords suggested by the authors for a similar time period, for example, 2009-2015, will show that since 2015 the number of research and development in the direction of games-assistants has rather increased. Specifically, each article is described in more detail in Appendix B.

Based on the results of Appendix B, it is possible to assess which functions the researchers emphasized most often. This information is shown in Figure 5.1.

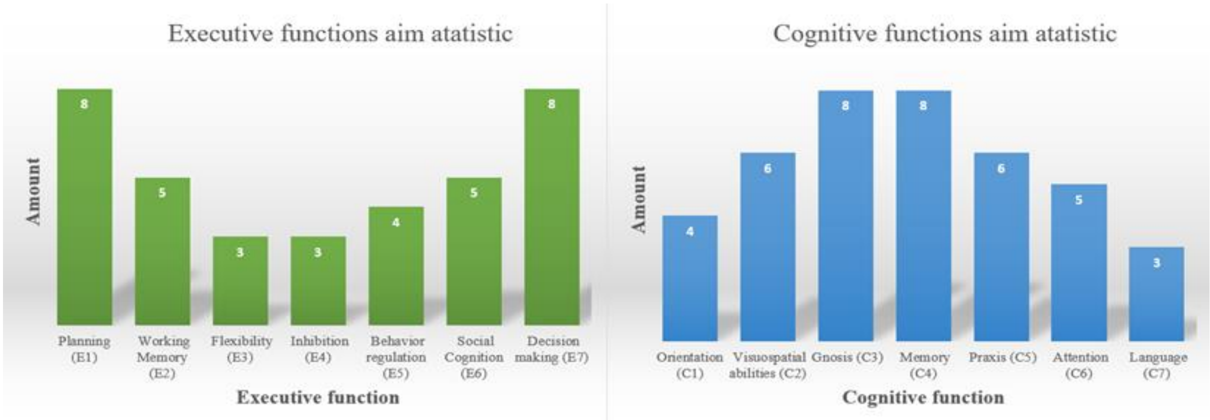


Figure 5.1. Statistics on the focus of research in relation to the main Executive and Cognitive functions.

Figure 5.1 illustrates well which functions the authors of the articles pay most attention to. Thus, among Executive functions the most emphasis is placed on Planning (E1) and Decision Making (E7), and among Cognitive functions - Gnosis (C3) and Memory (C4).

Appendix B shows the result and structure of the primary analysis of the items used. Thanks to this stage of analysis and the additional evaluation criteria introduced, it was possible to identify the most relevant articles, which became the basis for the study presented. More in-depth is presented in the results section.

The articles selected for this study in the sorting process had to include one of the most important parameters, namely the presence and description of a developed and tested application from the Serious Games category. Based on the data presented in the studies used, an analysis of these applications was made, and both a technical and functional report on the solutions, methodologies and goals pursued by the authors was com-piled.

During this analysis, it was important not only to understand the technical part, namely in what year the study was made, the anticipated platform, technical characteristics and so on, but what is more important is the condition and characteristics of the target audience. Appendix B demonstrates the criteria according to which the authors of this article will conduct future research and develop their own solutions.

Figure 5.2 (b) representing statistics about what percentage of device platform selected articles were found. Based on the information received, an equal number of platforms hit personal computers and mobile devices. 20% was allocated to multi-platform use.

Also Figure 5.2 and Figure 5.3 illustrate the main points of the analysis of the items in Appendix B, respectively, including the age group of participants considered in the selected studies. In Figure 5.3 it can be seen that the age group which has been most studied is the one corresponding to young adults (18-44 years old). Number shows how many articles include a certain age category.

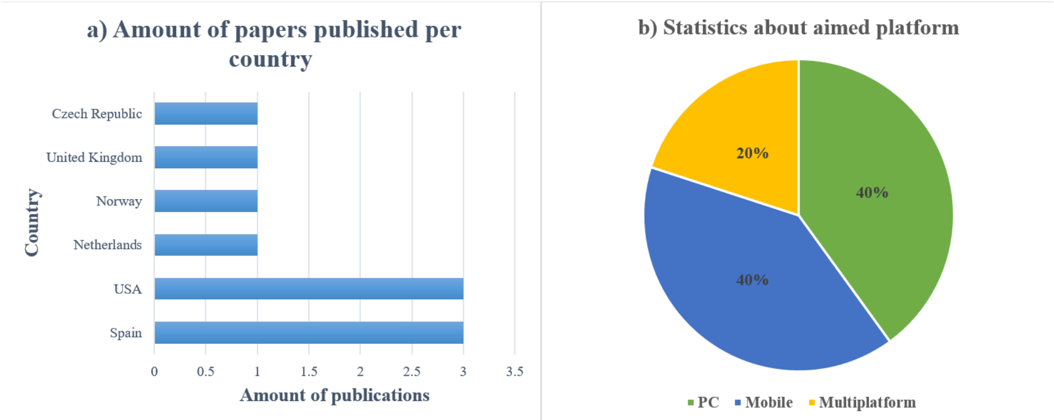


Figure 5.2. Results of reviewal: (a) Number of papers published per country; (b) Aimed platform statistics.

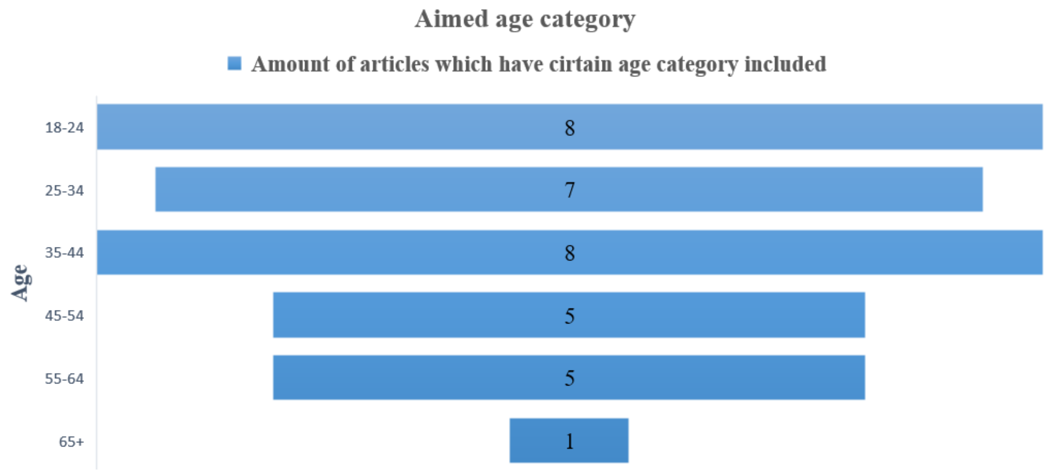


Figure 5.3. Aimed age category.

5.2 Methods

5.2.1 Hardware Specification

Given that the Cognitive Rehabilitation Block is a stand-alone part of the main system, and as the Physical Rehabilitation Block, it is intended to be used on any kind of device, so it has been designed as a multi-platform Web application. In this regard, information regarding the specification of the hardware on which it is recommended to run has been given earlier, in Table 4.2, Paragraph 4.2.1 of Section 4.

5.2.2 Software Specification

The Cognitive Block is a separate system that is independent of the Physical Block, so it can be used separately and independently. The initial target platform was mobile devices, due to the peculiarities of the construction of tasks, their meaning, ways of management and target audience. At the same time, in order to broaden the range of possible users, the following decision was made.

If the Physical Unit requires a personal computer (PC), due to the rather heavy computational load, as well as low or limited mobility of users (meaning mainly the fact that exercises and tasks must be performed within a limited space), in this case, the Cognitive part of the system requires almost no serious computational aspects, which allows to increase the mobility index and expand the list of potential devices to run.

Therefore, Web-source Benchmark was chosen as the main platform, which allows the development of multi-platform applications that can be run and used on almost all platforms. As minimum parameters, Table 3.4 in Section 3 described the minimum requirements for all platforms.

5.2.2.1 Cognitive Block operation Principle.

In essence, despite the fact that this block is also an application of the Serious Games family for medical rehabilitation, there are still differences from the Physical block and they are quite fundamental. If the latter was based on neural network algorithms, on which a shell in the form of veiled physical exercises was built, then in the case of the Cognitive block the main feature is an algorithm for evaluating and adjusting the system in real time depending on the progress of the user. The principle of its operation is demonstrated in Figure 5.4.

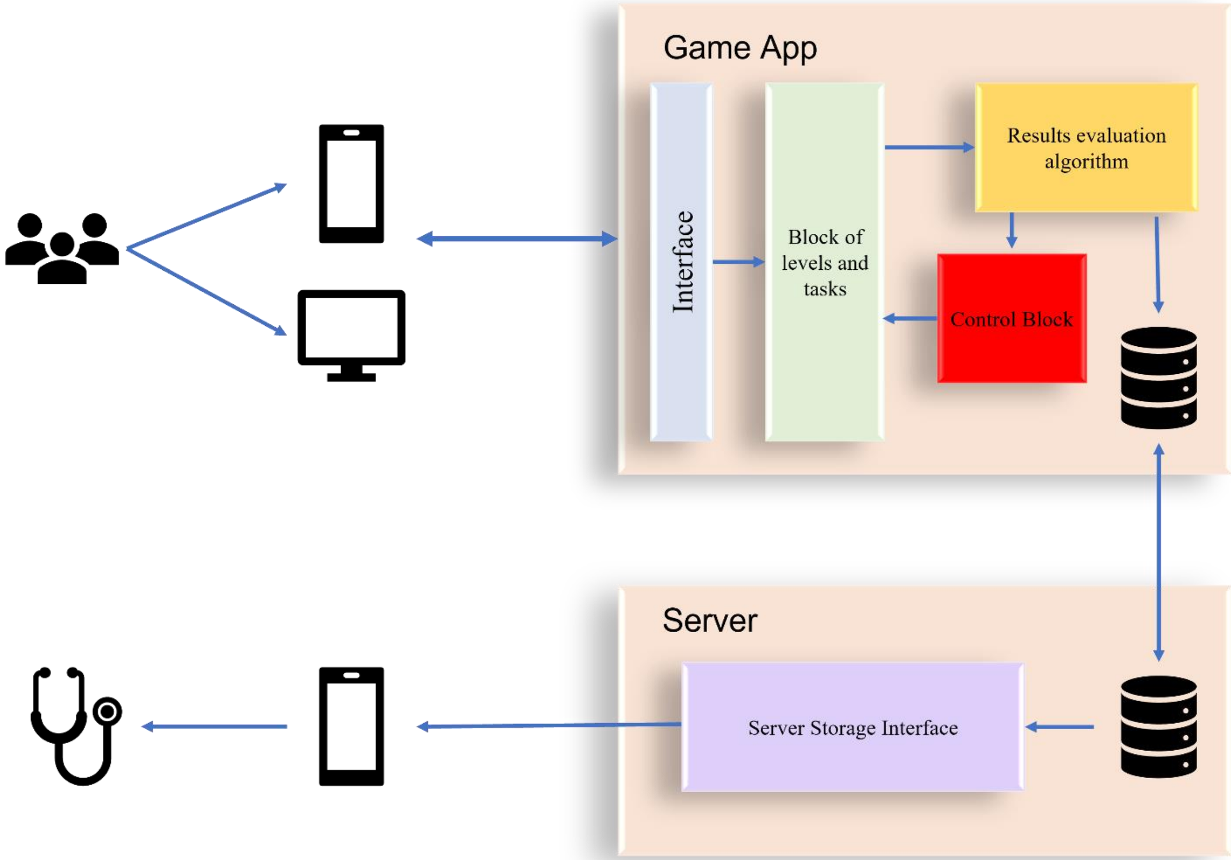


Figure 5.4. Cognitive block main structure.

The principle of operation of the whole system is very similar to what has been done in the Physical Unit, except for the regulation of the parameters of the levels and tasks. The regulation is performed as follows:

1) The input of the level and task block receives signals that the user generates by manipulating the interface.

2) All this data passes to the score and result sampling algorithm unit, which evaluates the generated data according to certain standards:

a. Each level has two main initial parameters - initial time and minimum number of clicks on interface elements.

3) The algorithm compares the generated user result with the initial parameter as a percentage and makes a judgment accordingly:

a. If the user's time is 30% or more higher than the original time, the next level increases the original time by 10 seconds, and the final score is lowered by 1 level out of 5

b. If the user's time is less than 15% or more of the original time, there is no change in time, but the final grade is increased by 1 level.

c. The number of clicks works the same way as above.

4) Once a judgment is made and all tasks are completed, the scoring algorithm sends the resulting activity results to a database on a shared server (in some cases saving locally if possible).

5) The results from the server can be downloaded at a new launch of the platform, or at the request of persons with this type of access.

In a simpler version of the functional block diagram, the estimation algorithm is presented in Figure 5.5.

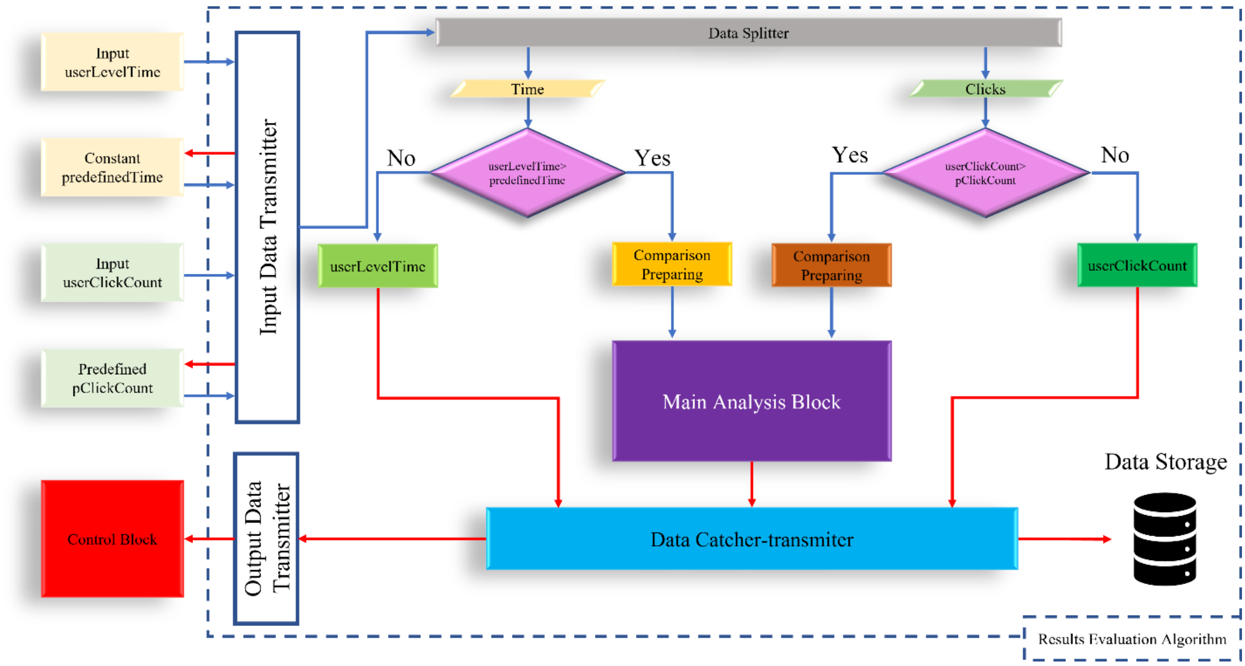


Figure 5.5. Principle of operation of the evaluation algorithm of cognitive block user results.

Despite the rather complicated description, in reality, the algorithm works quite simply. For example, one of the level-activities has an initial time parameter of 2 minutes and 4 seconds (124 seconds) and a parameter of the number of clicks needed to complete the task. This parameter is chosen based on the difficulty of the level, the number of actions required, and various health metrics. After completing the level, there will be 2 options: either the user's time is less than the set time, or more. In the first case, the usual recording procedure is started to save and then analyze the dynamics of the results. But in the second case, the evaluation algorithm is already connected.

By default, the comparison algorithm is set to 5 minutes for most default levels. This figure is taken from the preliminary block testing procedures at the development stage, as well as the recommendations of the specialists with whom the block concept was developed. Nevertheless, the parameter of "necessary" time can be changed by tutors practically at any time, depending on the general and initial results of a particular user and for a particular user.

The essence of the comparison is as follows: during the execution and immediately after the task completion, the system splits the initial time parameter into 3 large sections. The length of these sections in the time parameter is calculated according to the principles of building systems using fuzzy logic, namely 3 sections of 33% of the original, each of which has 4 key points. Comparison of the input parameter with the parameters of these points will determine in which interval the compared value is located, and to which of the states it is closer. For example, as it was said earlier, the user completed the task in 120 seconds, which took 300 seconds. (In Figure 5.3, the time parameters are shown in absolute values for example only. In reality, all parameters are unique for each level and are set separately). The input time is in the "Medium" range. The system considers this as a good result and passes it into the data saving algorithm, straight to the Data Catcher-Transmitter (Figure 5.5). If, on the contrary, the input time is 300 and the required time is 120, the system connects a calculation block and calculates by how many percent the input parameter differs from the required one.

The outcome of this algorithm is how much the system will ultimately praise the user for good results, or tailor further tasks to the individual's needs.

5.2.2.2 Features of block construction

Unlike the Physical Block, the Cognitive Block has a number of features that must be observed in the design and development process. To begin with, this block is designed to be used by a target audience with special needs. Therefore, the most important criterion for the development of this kind of system is its simplicity. The simpler, the better. This is expressed in the fact that the interface should be as simple as possible and unloaded from a visual and functional point of view. A lot of interface elements can distract from the task at hand and shift the focus of the user. In addition, it is necessary to have a clear, well thought out and at the same time maximally visual system of training and hints to which the user should have access at any time of using the system. At the same time, however, it is important not to overload the prompts with a lot of text, but to integrate graphic images to enhance the associations and better comprehension of the task.

Also, unlike the Physical Block, although the Cognitive Block has a theme and a short narrative story, in order to engage the user more (the storylines of each block will be described in more detail in Section 4), part of the cognitive training does not involve skipping even one exercise or task. In the Physical Block, despite the connection of the narrative, the omission of individual tasks is allowed. This is because, depending on the physical condition of each individual user, there may be situations in which some movements, ligaments or exercises are problematic or impossible to perform in their entirety. In the case of the Cognitive Block, each new exercise cannot be started until the previous one is completed. This is done due to the fact that the whole block is divided into clusters of exercises: several clusters of 5 exercises each. Each cluster is a single complex of training tasks that can only work effectively in conjunction with each other, and their separation entails a decrease in the effectiveness of training and rehabilitation.

In addition, a non-standard decision was made in terms of visual design of the Cognitive Block. Each of the clusters of exercises, which were mentioned earlier, differs from each other and its own thematic design, unlike the Physical block, where the theme and visual design has a uniform format and style. Here it is done in order to make it more intuitive for the user to understand which of the clusters he is currently on, showing both progress and the conditional changeability of the game environment. In addition to this, in consultation with specialists in working with people who are the target audience of the Cognitive Training and Rehabilitation block, it was decided to use a not quite standard approach in the design of the graphical part of each of the levels, namely the use of non-standard neural network-generated images. An example of such images is demonstrated in Figure 5.6.

Figure 5.6. Example of used design of one of the levels of the Cognitive Block.

5.2.3. Cognitive Rehabilitation Block Structure and Implementation

In this section, the technical and conceptual part of the platform for support and cognitive rehabilitation will be presented. The whole system structure will be described in terms of the conceptual design of the activities, their working principle and interaction with the user. The basic principles of operation, functionality and task of each activity included in the system will be explained.

As discussed previously, the system is divided into two functional blocks. Next, Figure 5.7 presents the general structural diagram of the Cognitive Block, namely the construction of levels, the connection between them and the general concept of the system.

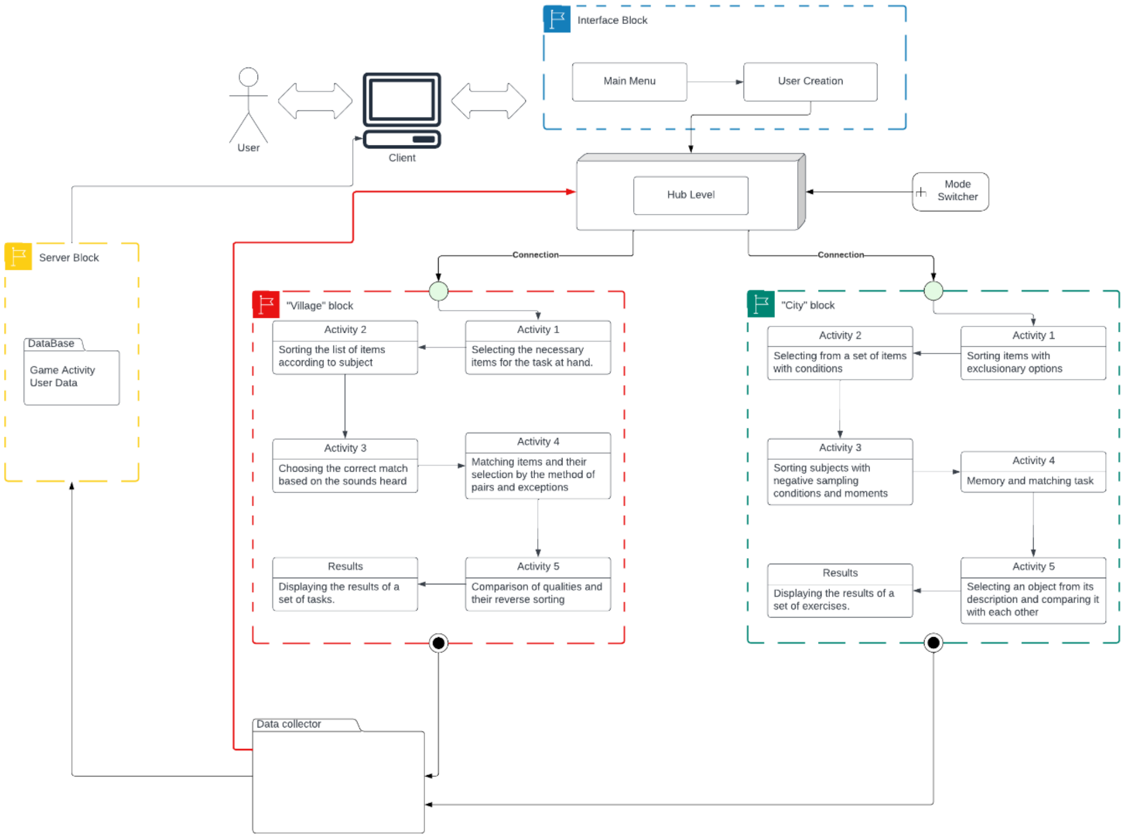


Figure 5.7. General structural diagram of the Cognitive block of the system.

As can be seen in Figure 5.7, the block is fundamentally composed of four main parts: the initial interface shell for controlling the system, the tasks block that includes all available exercises and activities, the database with all obtained user parameters, and the server block, which is a cloud storage of user and activity data.

5.2.3.1 System Structure. Interface block

There are 3 main levels in these blocks. The main purpose and task of these scenes is to navigate the user, as well as to perform some introductory function in the activity itself and to set a certain tone of the narrative. It should be said right away that the levels of this block do not have any technical aspects underneath them, and act solely for navigation. Nevertheless, the general structure and visualization of each of them, along with a list of available elements, should be displayed.

a) Start screen

Name: Main Menu.

Task: launching the beginning of the game.

Elements: "Start" and "Exit" buttons.

The level structure is shown in Figure 5.8.

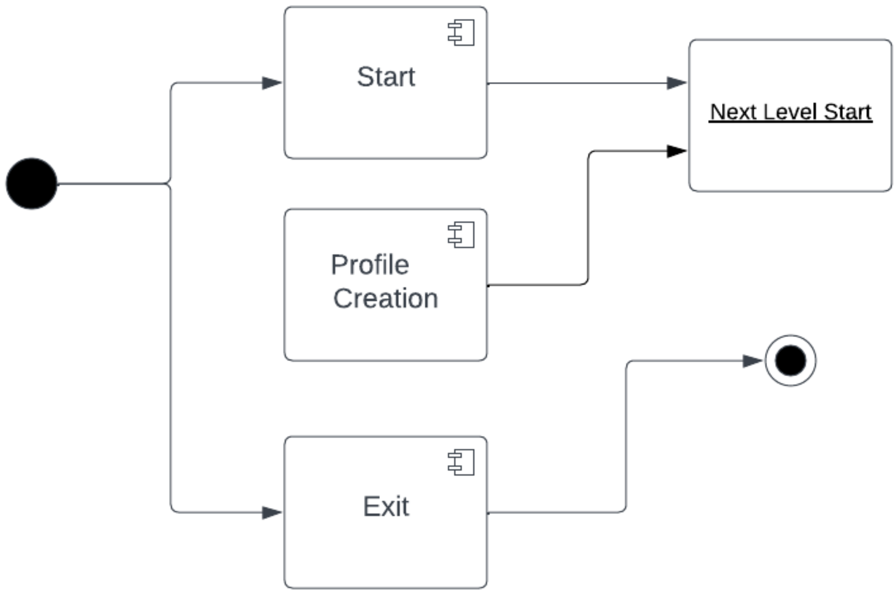


Figure 5.8. Structure of the initial screen of the Cognitive block.

Figure 5.9. Visualization of the initial screen.

As described above, this level is just an initial welcome screen to further interact with the system and give it an aesthetic feel.

b) Profile creation screen

Name: UserCreation.

Task: Selection of the user name, avatar, описание целей упражнений и системы.

Elements: First and last name selection field, avatar selection field, advanced options selection field, navigation buttons.

The structure of the level is demonstrated in Figure 5.10.

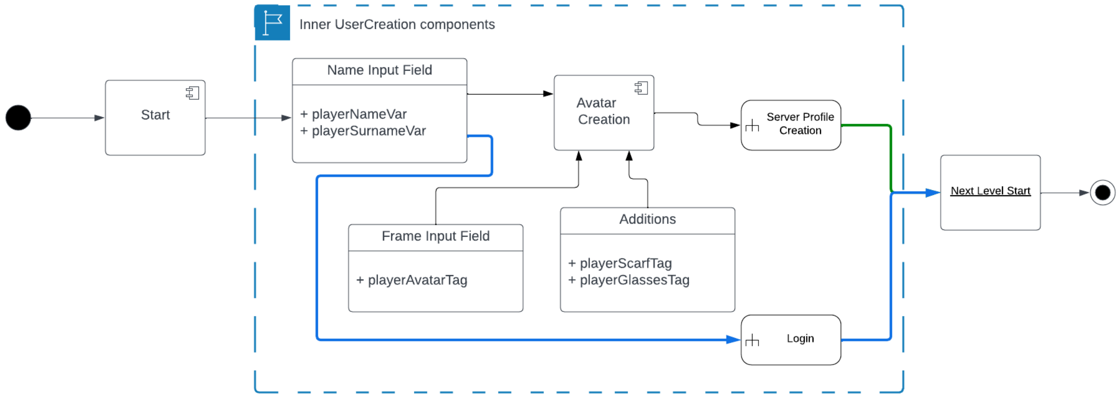


Figure 5.10. Structure of UserCreation level.

Figure 5.11. Visualization of UserCreation level.

The main task of this level is to create a new user profile, or log in to an existing profile, using unique identifiers. In essence, the Username acts as the login and the Last Name as the password.

When creating a profile, the user is required to select one of 15 standard stylized avatar image options, and specify additional options such as a scarf or glasses if desired. Once the account is created, the user can proceed to start playing the game.

It is important to specify that this process should be performed exclusively with an internet connection. In case the game uses a local copy, the registration step can be skipped, however, in this case, the data will only be saved locally, and only for the duration of the current game session.

c) Hub Level

Name: HubLevel.

Task: Serves as the main navigation window.

Elements: Selecting blocks and levels with activities. Game settings window.

The structure of the level is demonstrated in Figure 5.12.

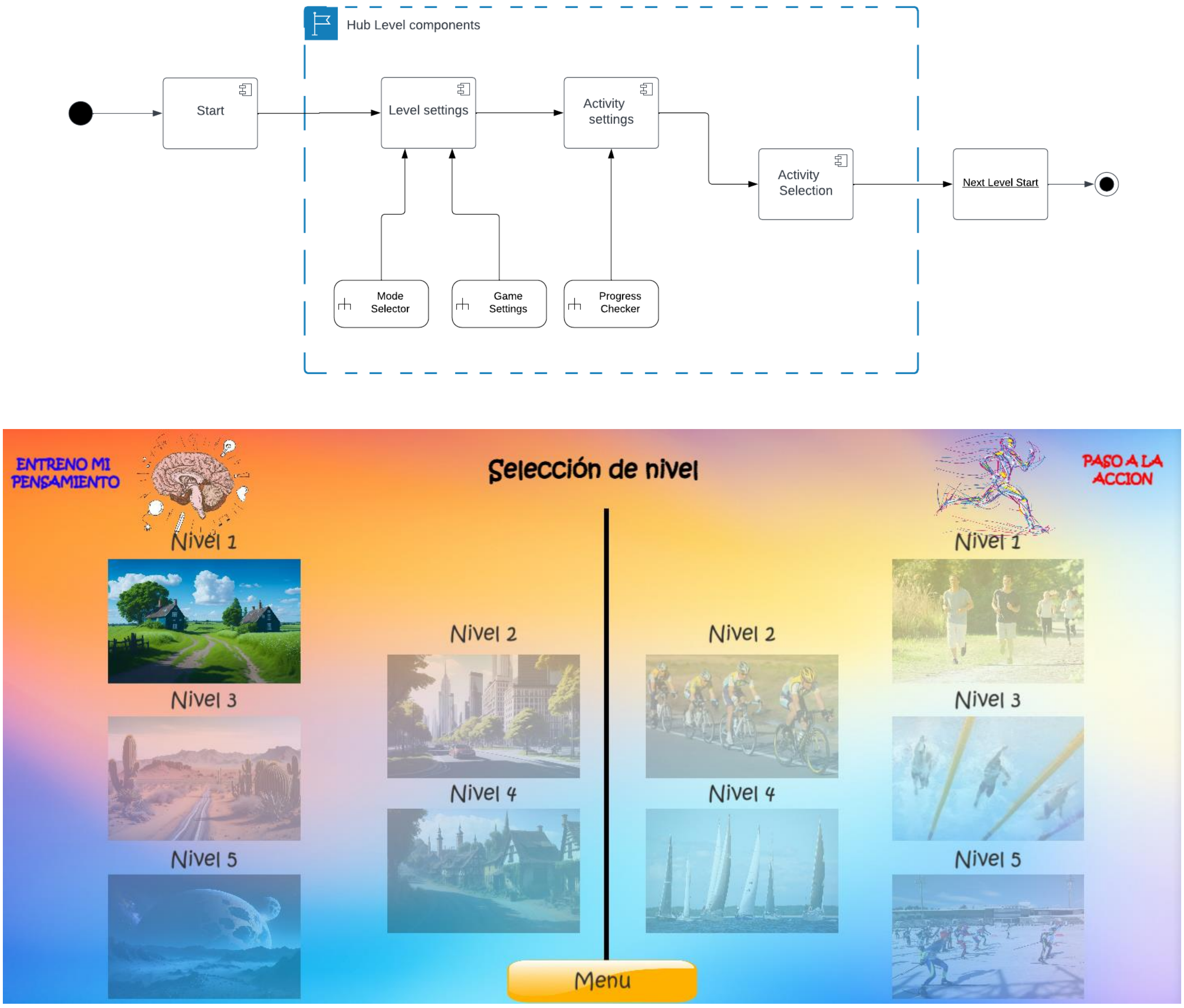


Figure 5.12. Structure and Demonstration of Hub Level.

This level has the function of navigation in the game. Initially, the user sees a screen divided into two parts: on the left a set of Cognitive Functions training and development levels, on the right an Executive Functions training block (not implemented at the moment). The navigation structure is quite simple: if the user has just started using the system, he/she will have access only to the first level, while all other levels will be blocked. When clicking on a level icon, there will be 1 activity inside (total of 5 activities per level). As you complete the activities, more and more opportunities and quests will be unlocked. At the end of each level, the user will be able to observe the final screen, where both numerical results and visualization of the effects on the screen will be available.

5.2.3.2 System Structure. Task Block

a) Home Block. Activity 1

Name: PackItems.

Task: From the list of items presented, select those that match the description presented in the initial screen of the level.

Elements: Window with items, control buttons.

The basic structure of the level is demonstrated in Figure 5.13. The visual display is shown in Figure 5.14.

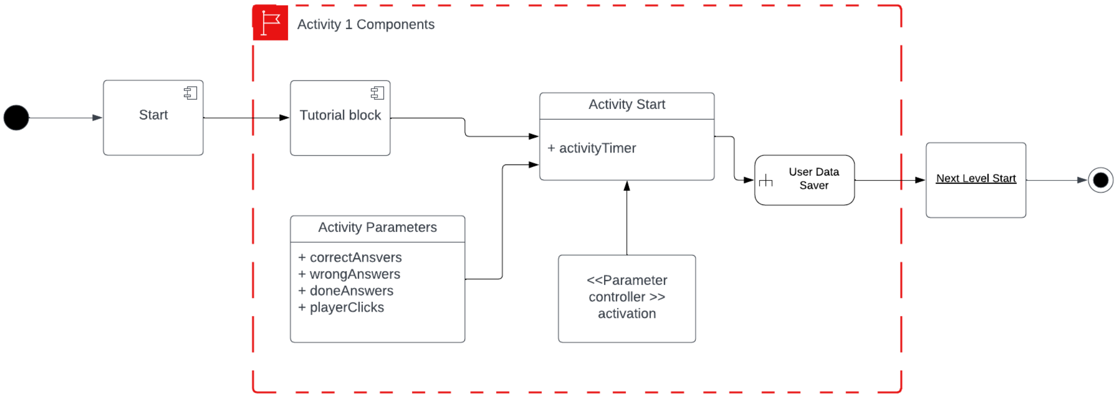


Figure 5.13. Block diagram of PackItems operation principle.

Figure 5.14. PackItems visualization.

The essence of the level is that from a set of different items it is necessary to choose those that fit the task set in the initial clue. There is a pool of 15 items to choose from, which the user needs to select by pressing the corresponding buttons: suitcase - take, cross - don't take. This level is designed to train associative thinking, as well as a general understanding of the need to use things correctly.

b) Home Block. Activity 2

Name: SortItems.

Task: Sort the items according to their belongings.

Elements: Window with items, control buttons.

The basic structure of the level is demonstrated in Figure 5.15. The visual representation is shown in Figure 5.16.

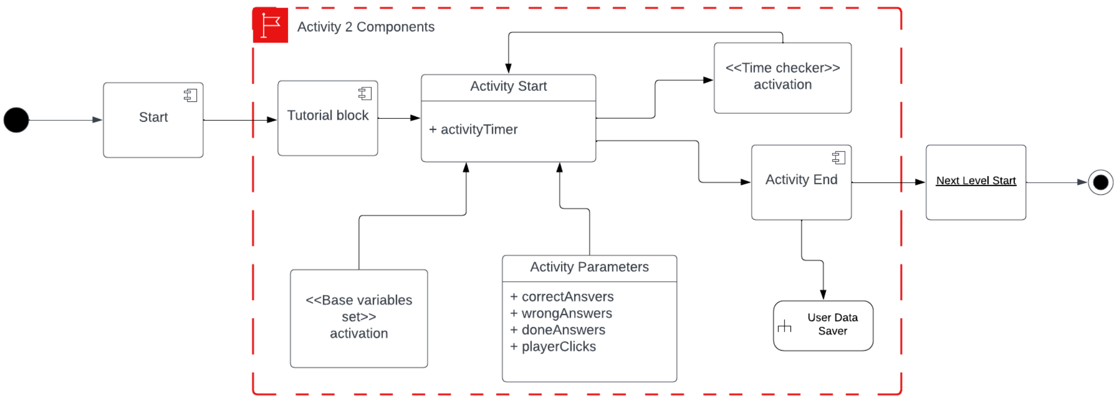


Figure 5.15. Block diagram of SortItems operation principle.

Figure 5.16. Visual display of SortItems level.

The principle of the game is almost the same as in activity 1. In this case, the user needs to sort the items shown on the screen according to their belonging: edible or inedible. Out of 15 items, 10 are food.

c) Home Block. Activity 3

Name: SoundChoose.

Task: Choose a reverse match from the sound that was heard.

Elements: Control buttons, audio playback button.

The basic structure of the level is demonstrated in Figure 5.17. The visual representation is shown in Figure 5.18.

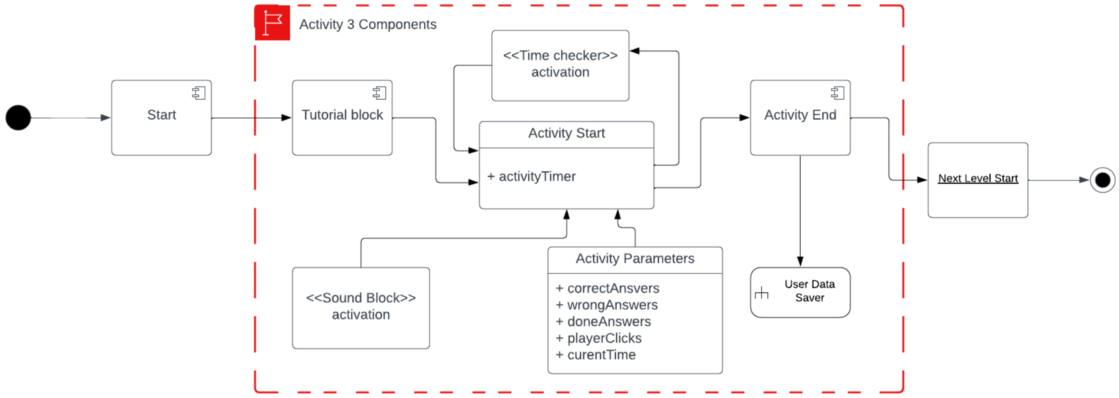


Figure 5.17. Block diagram of SoundChoose operation principle.

Figure 5.18. Visual display of SoundChoose level.

This level starts with the user hearing a sound related to a car or train after reading the introduction and prompts. If necessary, this sound can be played again by pressing the speaker button. Depending on what sound the player hears, he has to make a choice towards the opposite source. In other words, if a train sound is heard, the car button is selected and vice versa. This is practicing both attention and matching. After 15 correctly selected sounds, you move on to the next level.

d) Home Block. Activity 4

Name: FindMatches.

Task: Select pairs of objects from the proposed 4x4 grid of options.

Elements: 4x4 grid of objects, control buttons.

The basic structure of the level is demonstrated in Figure 5.19. The visual representation is shown in Figure 5.20.

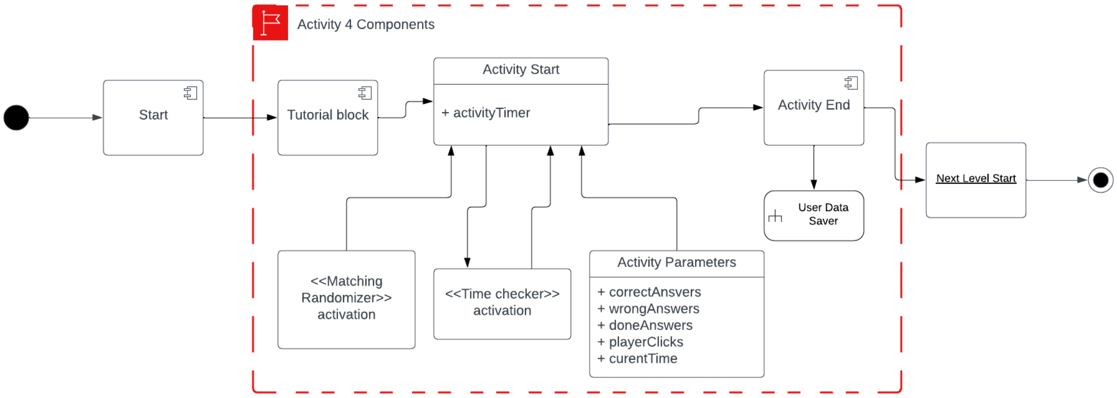


Figure 5.19. Block diagram of FindMatches operation principle.

Figure 5.20. Visual representation of FindMatches level.

This activity consists of two parts. Both of them represent a screen with a grid of 16 hidden objects, which, when you click on them, open and show an image from two categories: dessert and regular food. In the first part of the activity, it is necessary by clicking on the objects to memorize where the object stands and to find a pair from the same image.

The second part is fundamentally performed in the same way, but this time the pair of objects will be 1 picture of dessert and 1 picture of regular food. This level is designed to train short-term memory and associative thinking.

e) Home Block. Activity 5

Name: TraficLights.

Task: Depending on the signal at the traffic light, choose an object of the opposite color and meaning.

Elements: Control buttons, traffic light image.

The basic structure of the level is demonstrated in Figure 5.21. The visual representation is shown in Figure 5.22.

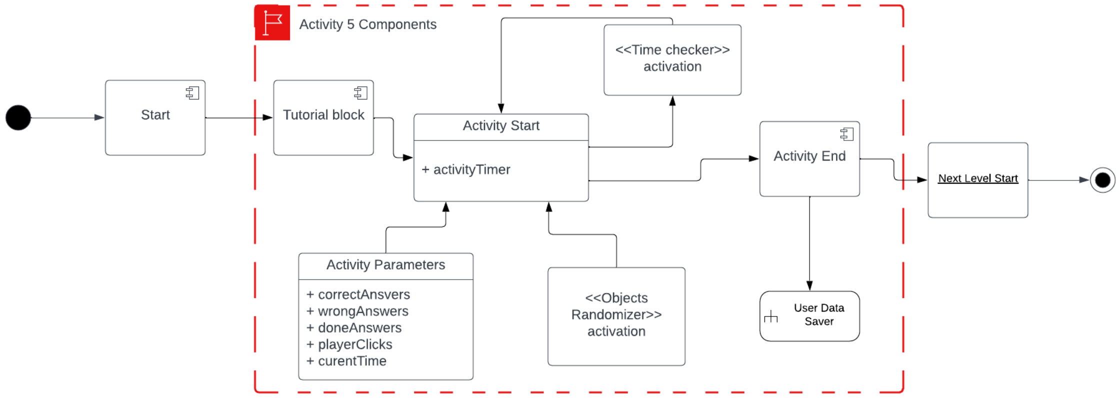


Figure 5.21. Block diagram of TraficLights working principle.

Figure 5.22. Visual display of TraficLights level.

This activity is somewhat similar to activity 3. On the screen, the user sees a traffic light whose signals light up in a random order. Also, on the screen there is a tomato, a clover leaf and a button. The essence of the level is that when seeing, for example, a green traffic light signal, the player must choose a tomato.

In the case of such confusion, if the player correctly chooses opposites, it is a training for correspondences and logical thinking. In the case of obvious non-obvious opposites, the effectiveness of such exercises increases.

f) City Block. Activity 1

Name: PackingItems2.

Task: Distribute things according to what season they are best suited for. Put winter clothes in the wardrobe and wash summer clothes.

Elements: Elements for allocation, allocation buttons, timer, list tooltip.

The basic structure of the level is demonstrated in Figure 5.23. The visual display is shown in Figure 5.24.

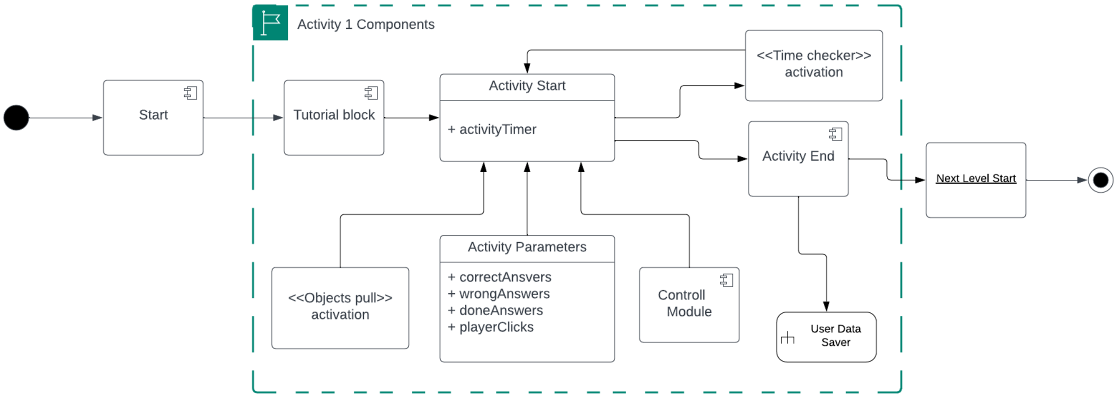


Figure 5.23. Block diagram of PackingItems2 operation principle.

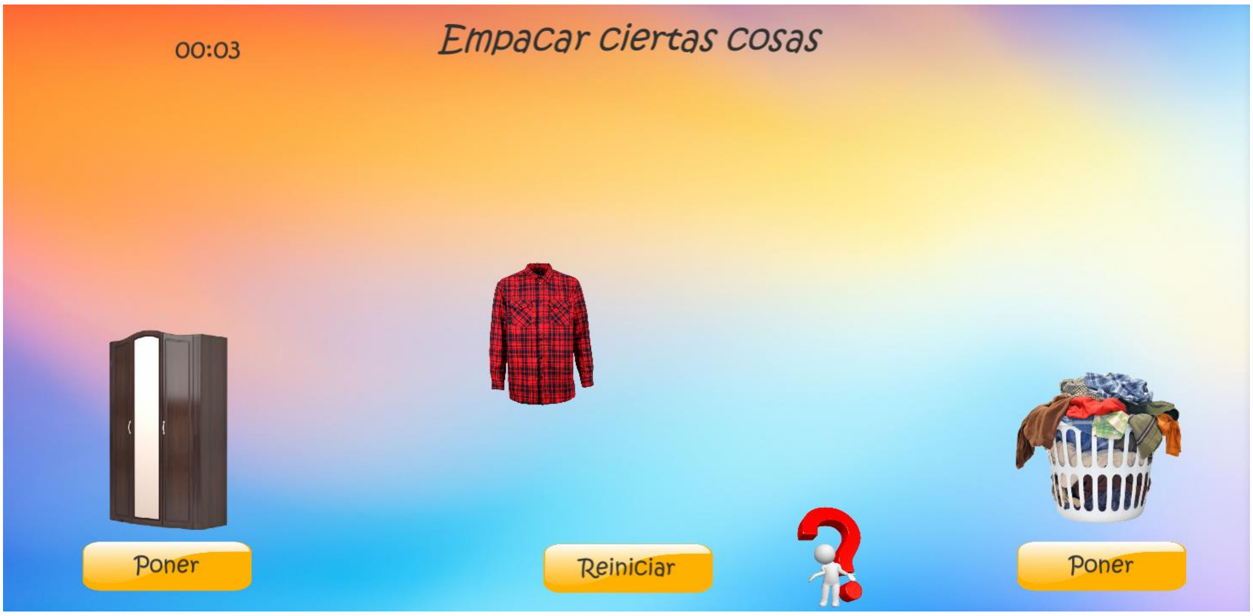


Figure 5.24. PackingItems2 visualization.

This activity is similar to the first and second activities of the first level. The difference is that this time the level has a sequential narrative. In technical terms, you now have to manually select an item that appears, move it to the image of the distribution object, and confirm your choice. This level will help to train associative thinking as well as motor skills.

g) City Block. Activity 2

Name: SortItems2.

Task: Sort through the items and select those needed for sports training.

Elements: Elements for allocation, allocation buttons, timer, list tooltip.

The basic structure of the level is demonstrated in Figure 5.25. The visual representation is shown in Figure 5.26.

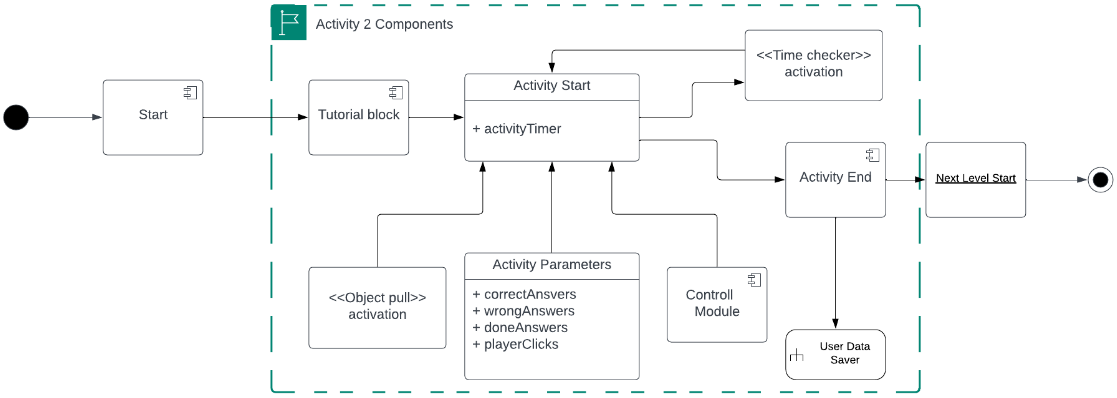


Figure 5.25. Block diagram of SortItems2 operation principle.

Figure 5.26. Visual display of SortItems2 level.

This activity is almost the same as the previous one, with the difference that now the objects to be sorted move on the screen. Here the task is more difficult, and the player needs to catch the object in time, otherwise it can fly off the screen. In this case the attempt is counted as unsuccessful.

h) City Block. Activity 3

Name: SortItems3.

Task: From a large list of items, choose the ones you need to bring in your bag.

Elements: Elements for allocation, allocation buttons, timer, list tooltip.

The basic structure of the level is demonstrated in Figure 5.27. The visual representation is shown in Figure 5.28.

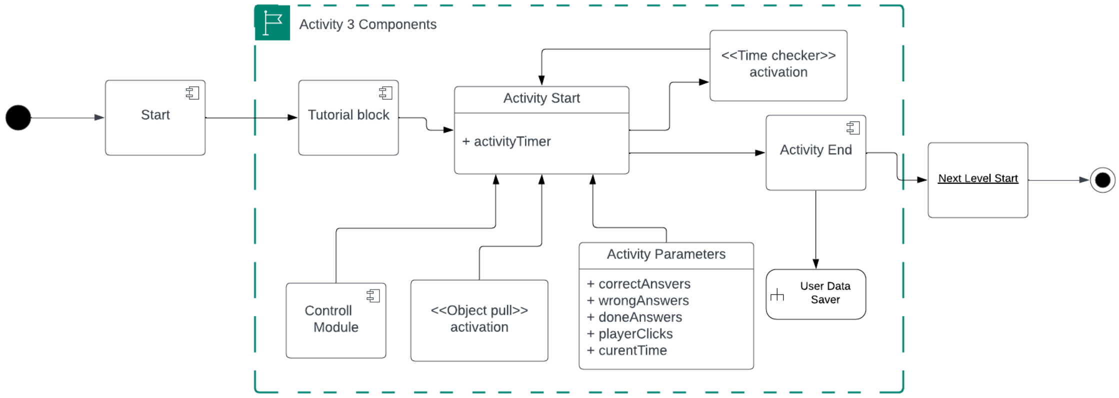


Figure 5.27. Block diagram of SortItems3 operation principle.

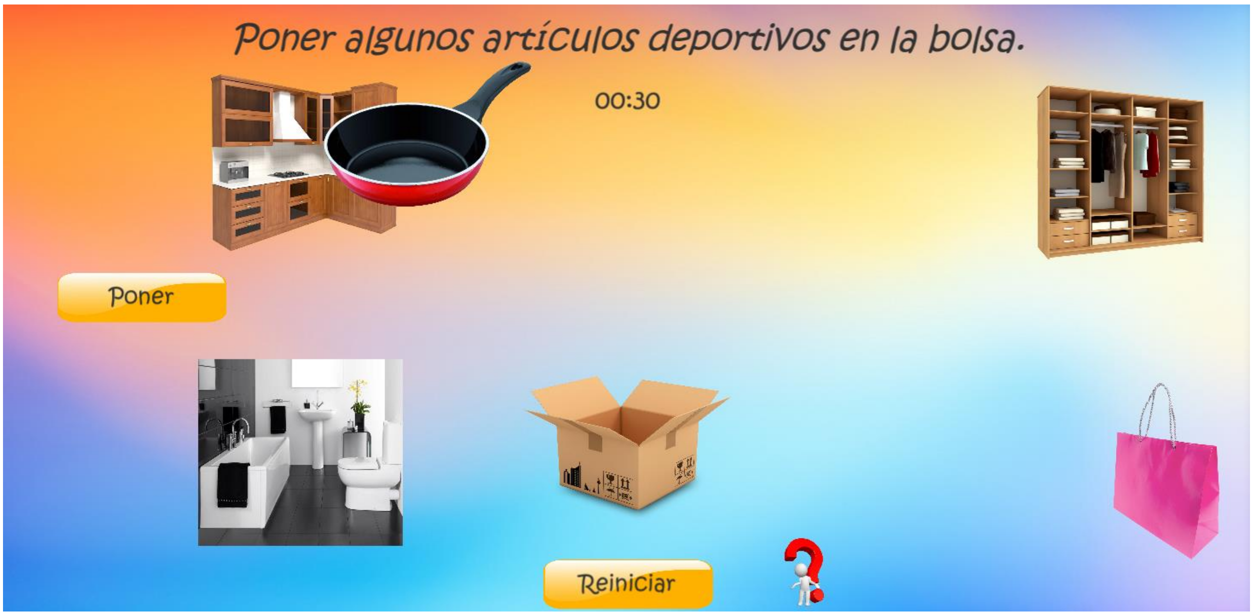


Figure 5.28. Visual display of SortItems3 level.

i) City Block. Activity 4

Name: HappyBirthdayLevel.

Task: Put in the right order the activities that need to be done when preparing for a birthday party.

Elements: Elements for allocation, allocation buttons, timer, list tooltip.

The basic structure of the level is demonstrated in Figure 5.29. The visual representation is shown in Figure 5.30.

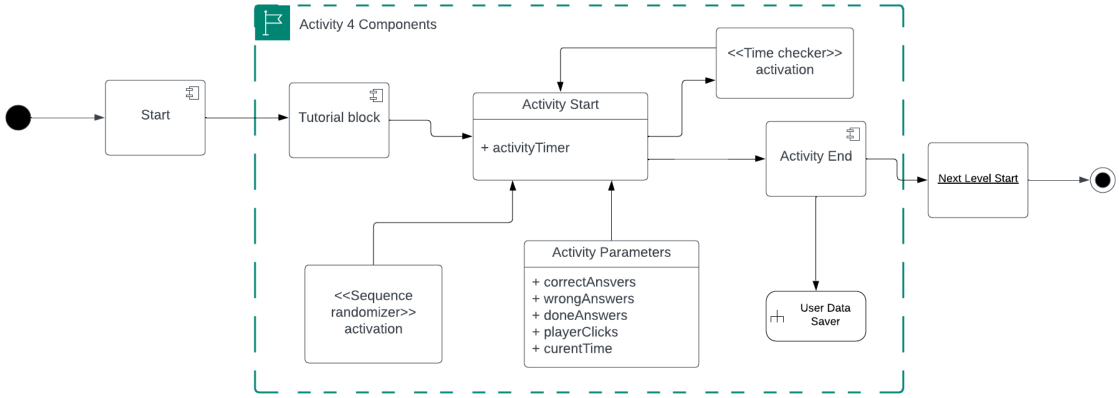


Figure 5.29. Block diagram of HappyBirthdayLevel operation principle.

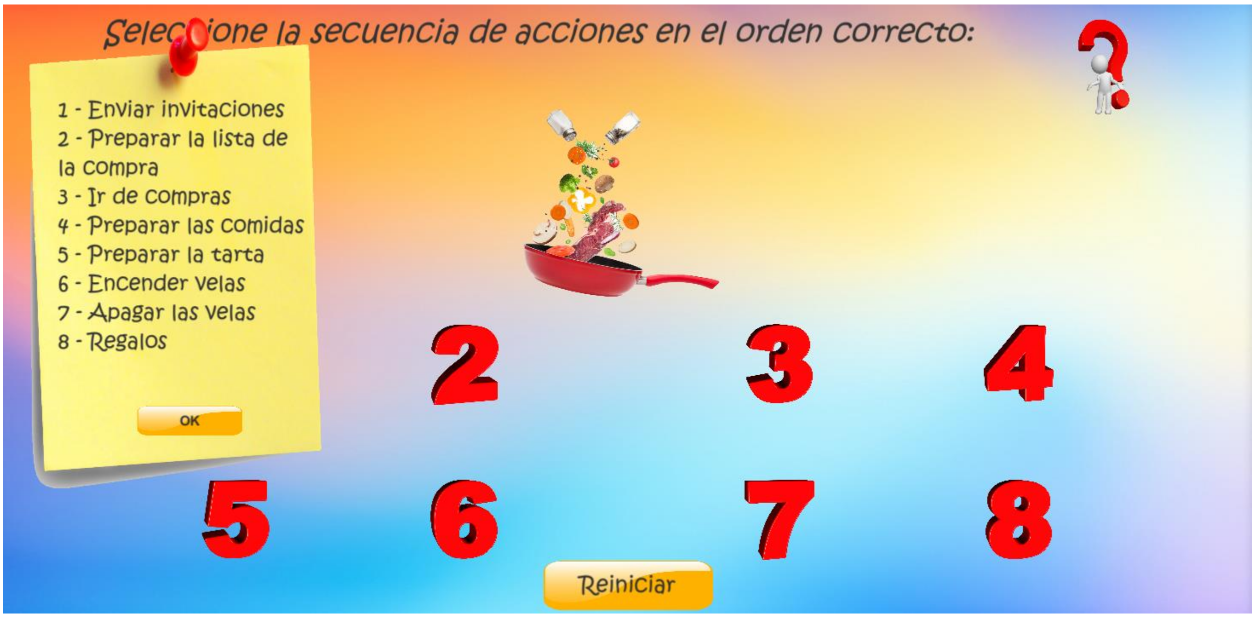


Figure 5.30. Visual display of HappyBirthdayLevel level.

In this activity, the player has to distribute the appearing images of actions in an order that corresponds to the procedure of preparing for a birthday party. An image with an activity appears on the screen and the player must click on the number corresponding to the order of the activity.

j) City Block. Activity 5

Name: ChooseDishLevel.

Task: From the list of suggested dishes, desserts and drinks, choose the one that matches the description.

Elements: Set of items to select, confirmation button, timer.

The basic structure of the level is demonstrated in Figure 5.31. The visual representation is shown in Figure 5.32.

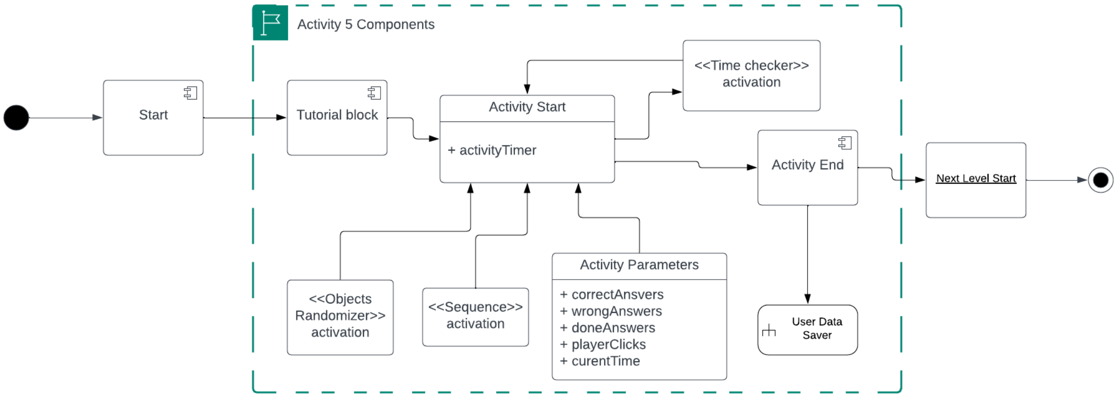


Figure 5.31. Block diagram of ChooseDishLevel operation principle.

Figure 5.32. Visual display of ChooseDishLevel level.

In this level, the player has to choose from a list of dishes the one that corresponds to the description at the top of the screen. The sequence of the description corresponds to the healthy eating order, and the correct answers will be not only the dish itself, but also what category it belongs to, namely healthy food or unhealthy food. The player can choose more than one dish, or more than one. The essence of this level will be to explain to the user the principles of good nutrition and its importance, as well as training associative thinking.

k) Level Result Example

After completing each level, the player will be presented with the results screen, which is shown in Figure 5.33. Depending on what the player's score is, this screen will display the appropriate visual design option for good, average, and poor scores.

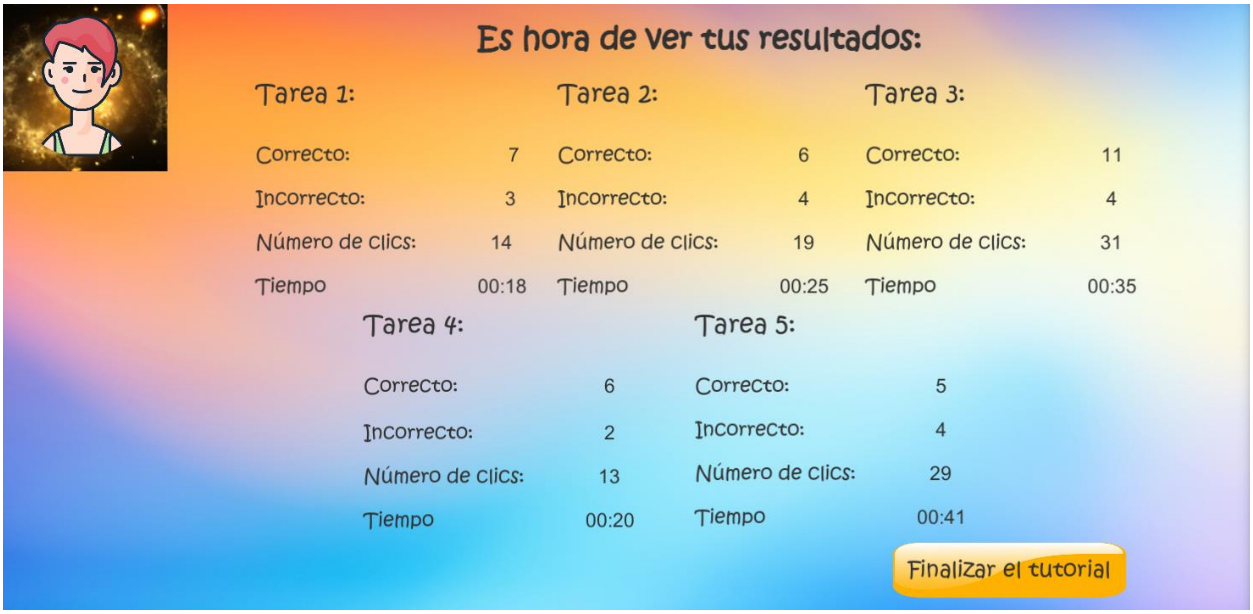


Figure 5.33. Visual display of Result level.

5.2.4 Data saving

In the presented system the algorithm of data saving for the possibility of their further processing was realized. It consists in the realization of sending and saving data on the server with the possibility of further access at any time. The principle of operation of this system is demonstrated in Figure 5.34.

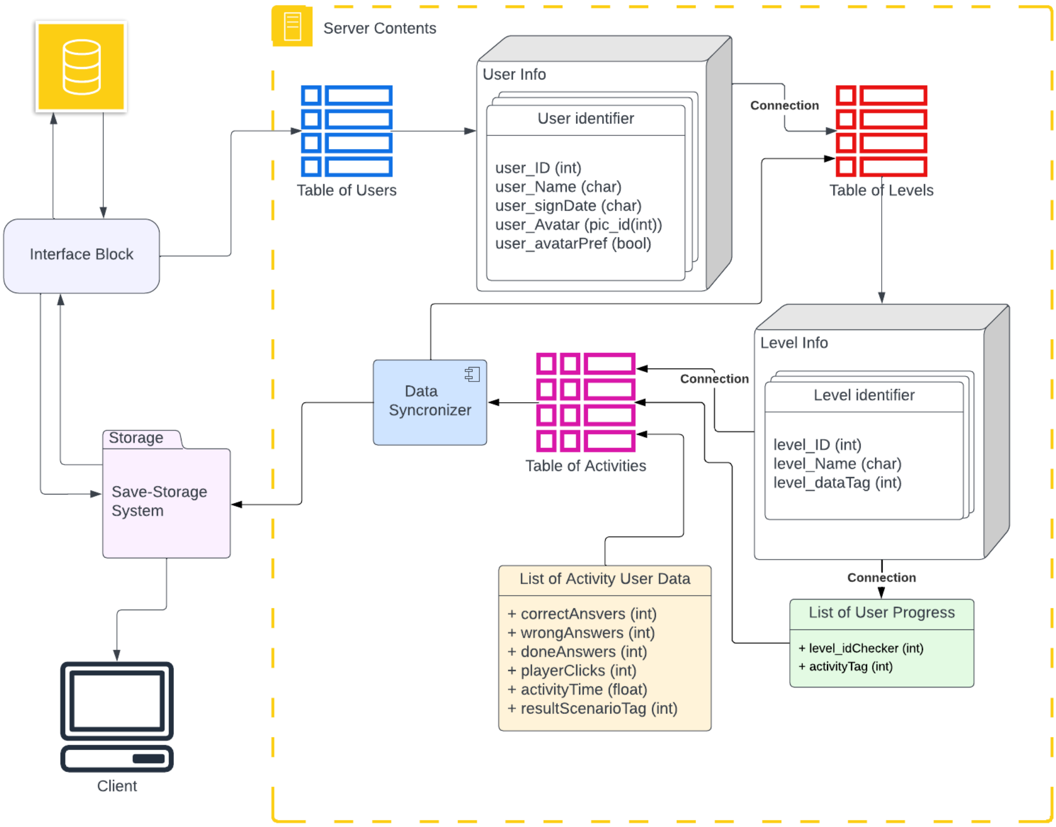


Figure 5.34. Block diagram of the principle of operation of the data saving and sending system.

In principle, the system of data exchange between the client and the server does not differ from the one presented in Section 4 in point 4.2.5. The construction and structure of tables used is practically the same, as well as the method of data reception and transmission, client-server communication and database manipulations. The peculiarity is that in the case of the Cognitive block a separate storage is created and used, which is not connected with the storage of the Physical block. This allows to achieve autonomy and independence of systems from each other, besides, in case of possible failure only a part of data can be lost, not all at once.

5.3 Results

5.3.1. Information About Testers

Considering that the goals of the cognitive block, as well as the methods of interaction and influence are different from those proposed above in the Physical block, the information parameters about users are presented in a slightly different format.

In total, 4 groups of users were selected for testing the cognitive block, one of which was a test group, and 3 target groups. All groups were recruited considering the 3 main parameters required for the results:

1) Age. Young, middle-aged and elderly people were recruited in this category.

2) Cognitive status. Presence or absence of special cognitive status.

3) Level of disability. A parameter of the percentage of disability that characterizes the degree of cognitive characteristics.

In view of the notions of ethics and preservation of personal data, all users were assigned a personal identification number (id) that corresponds to their profile in the system database. Table 5.1 presents the list of users and their parameters. It should be said that in this case all users are Spanish citizens, and their physical parameters of weight, height and mobility are not parameters necessary for the study in this case.

Table 5.1. Information about testing groups of the Cognitive Block of the system.

№	User ID	Age	Gender	Cognitive State	Disability level, %
			Test Group		
1	1	29	Male	0	10%
2	2	27	Male	0	5%
3	3	25	Female	0	10%
4	4	27	Male	0	8%
5	5	23	Female	0	5%
6	6	22	Female	0	7%
7	7	41	Male	0	9%
8	8	26	Female	0	12%
9	9	31	Male	0	15%
10	10	33	Male	0	10%
			Group A		
11	49	22	Female	1	65%
12	50	24	Female	1	68%
13	51	20	Male	1	62%
14	52	27	Female	1	65%
15	53	20	Female	1	65%
16	54	25	Female	1	68%

17	55	24	Female	1	68%
18	56	26	Male	1	62%
19	57	24	Female	1	68%
20	58	25	Female	1	60%
21	59	22	Female	1	65%
22	60	26	Female	1	78%
23	61	22	Male	1	62%
24	62	26	Female	1	60%
25	63	22	Male	1	67%
26	64	22	Male	1	62%
Group B					
27	18	51	Male	1	68%
28	19	53	Male	1	68%
29	20	45	Male	1	68%
30	21	50	Male	1	65%
31	41	37	Female	1	97%
32	42	44	Female	1	93%
33	43	42	Male	1	89%
34	44	36	Male	1	89%
35	45	35	Male	1	68%
36	46	41	Male	1	97%
37	47	41	Female	1	89%
Group C					
38	27	46	Male	0	77%
39	28	51	Male	0	72%
40	29	45	Male	1	80%
41	30	43	Female	1	75%
42	31	46	Male	0	76%
43	32	33	Female	1	65%
44	33	48	Male	0	70%
45	34	45	Female	1	81%
46	35	47	Male	1	75%
47	65	47	Female	0	65%
48	66	40	Male	0	79%
49	67	58	Female	0	92%
50	68	49	Female	0	94%
51	69	46	Female	1	70%
52	70	40	Female	0	76%
53	71	50	Female	0	67%
54	72	38	Female	1	75%

This table presents the necessary information about those players who were involved in the direct testing of the system. In addition to the above information, it should be said that all data were collected in the presence of physicians specialized in cognitive and intellectual rehabilitation. The data was collected through direct interaction with the application and recorded in an electronic database. Some users, due to various factors and peculiarities, passed levels within the system several times, so in some cases an average score was taken from the users, provided that the best and worst did not differ from each other by more than 10% in terms of time, percentage of correct answers, and overall mentor score.

If the data from Table 5.1 is evaluated visually, all 3 main parameters for each group can be interpreted and are presented in Figure 5.35, 5.36, 5.37 and 5.38.

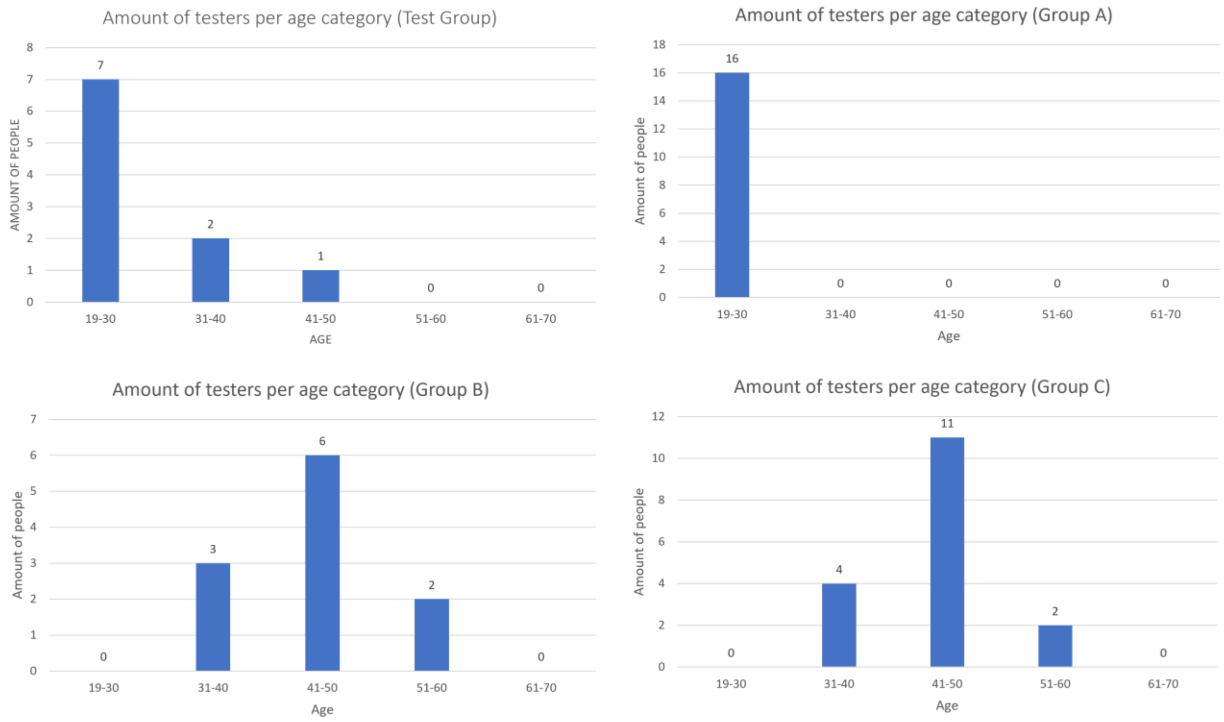


Figure 5.35. Age parameters of tester by groups.

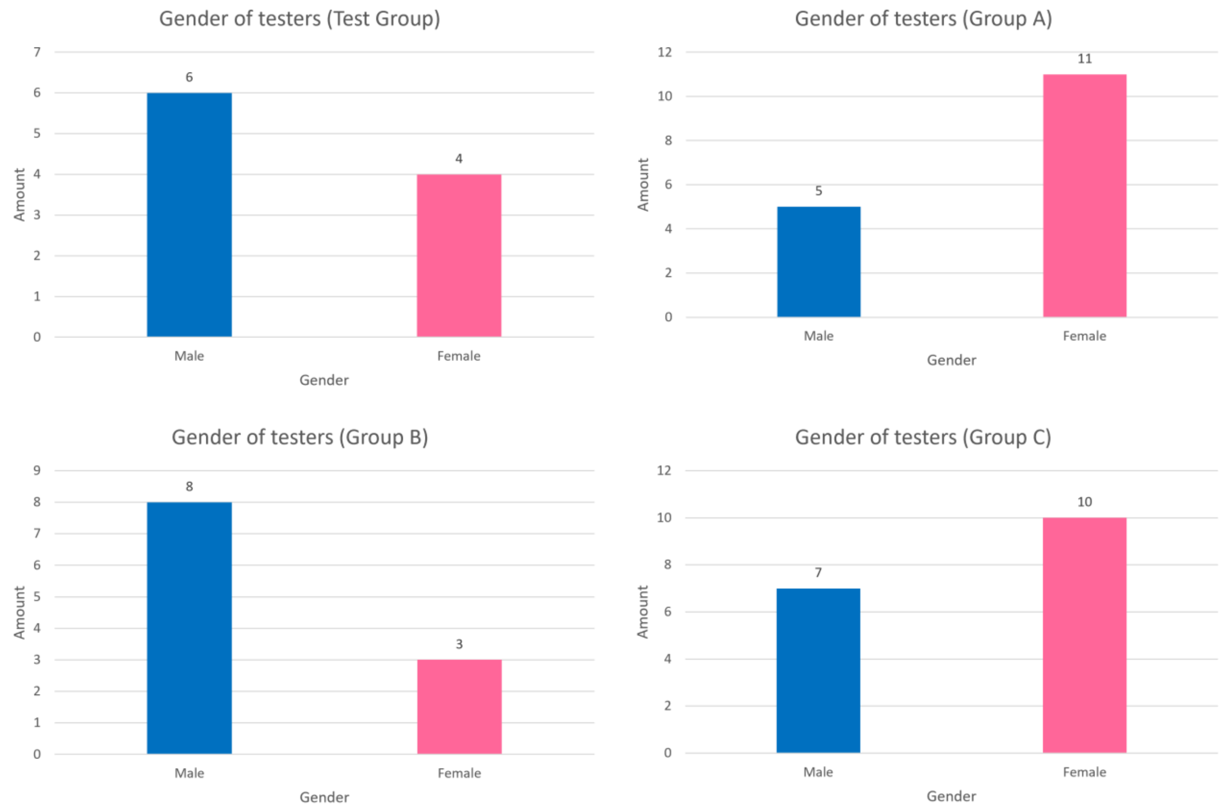


Figure 5.36. Gender parameters of tester by groups.

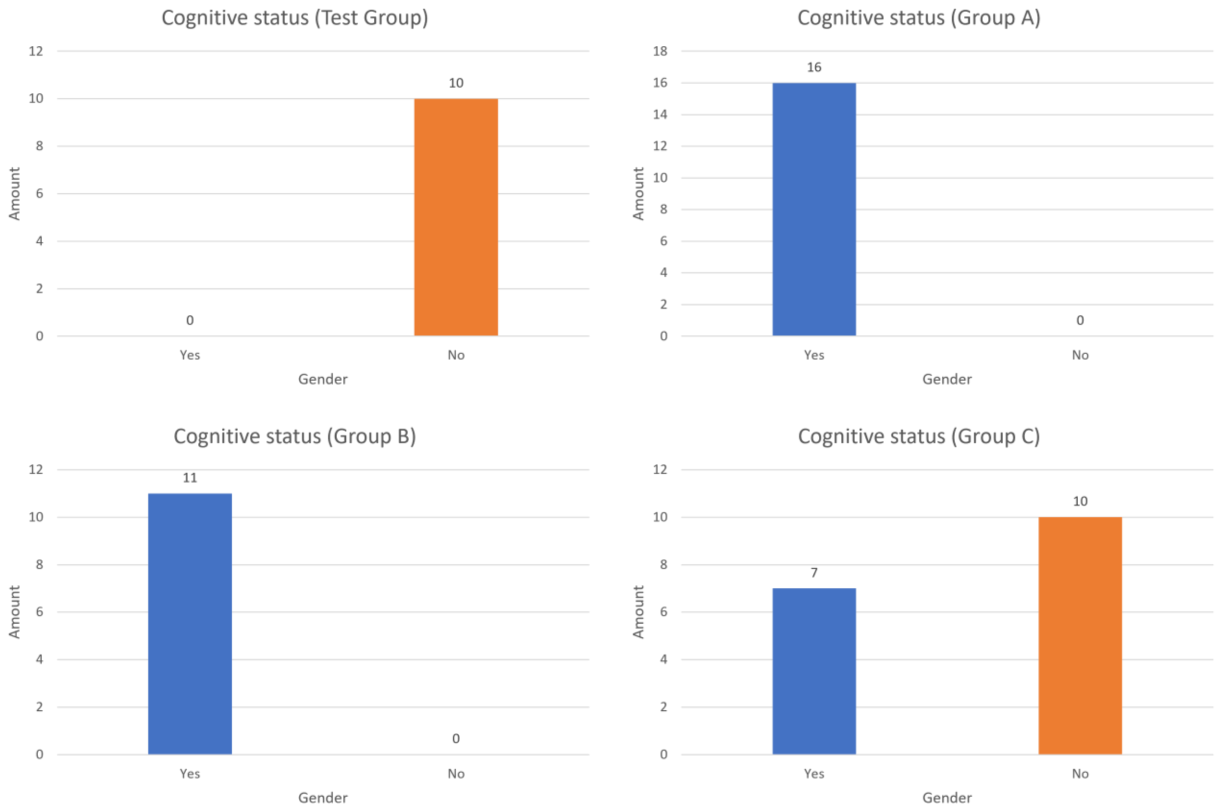


Figure 5.37. Cognitive status of tester by groups.

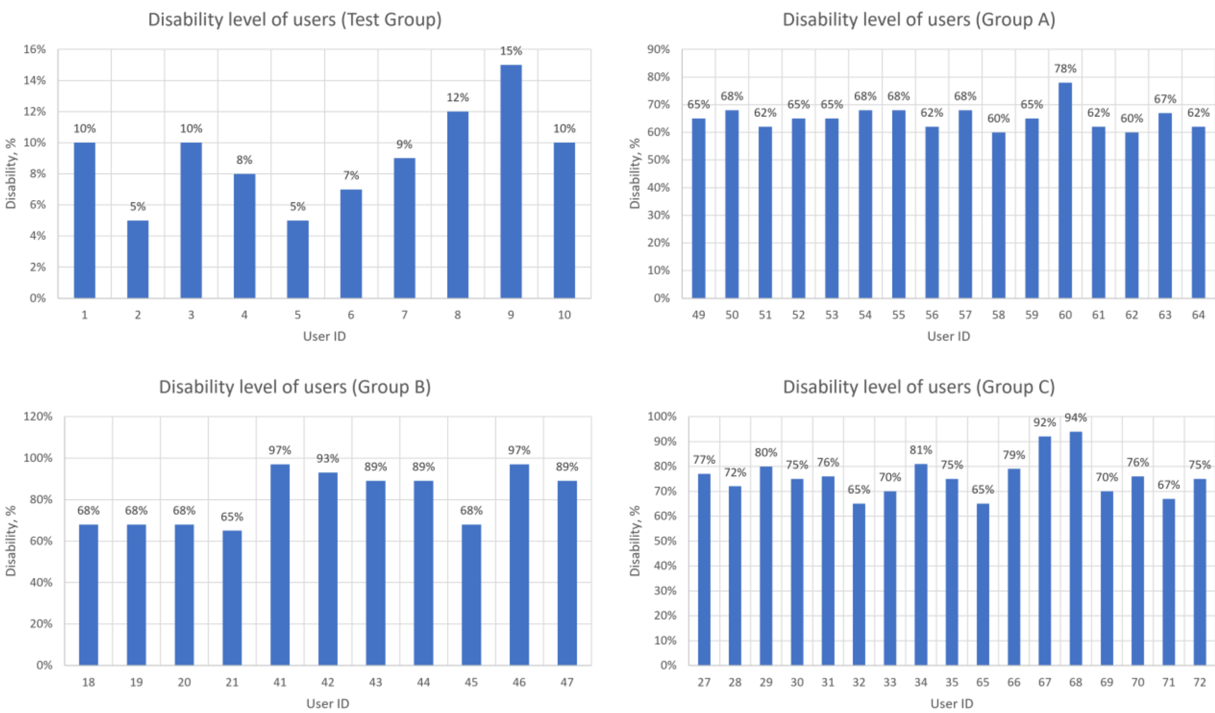


Figure 5.38. Disability level parameters of tester by groups.

The figures above show a visual interpretation of the data in Table 5.1. It is important to analyze this data, because already in this state it can characterize and, in some way, give a general idea of the result that can be obtained in the process of using the Cognitive Rehabilitation Block.

5.3.2 Data Analysis

Before directly starting the game, the user has to create a profile for himself, in which he has to select 1 avatar from 15 available avatars, and choose whether to put jewelry (scarf and glasses) on the avatar or not. The user selection in general view can be seen in Figure 5.39.

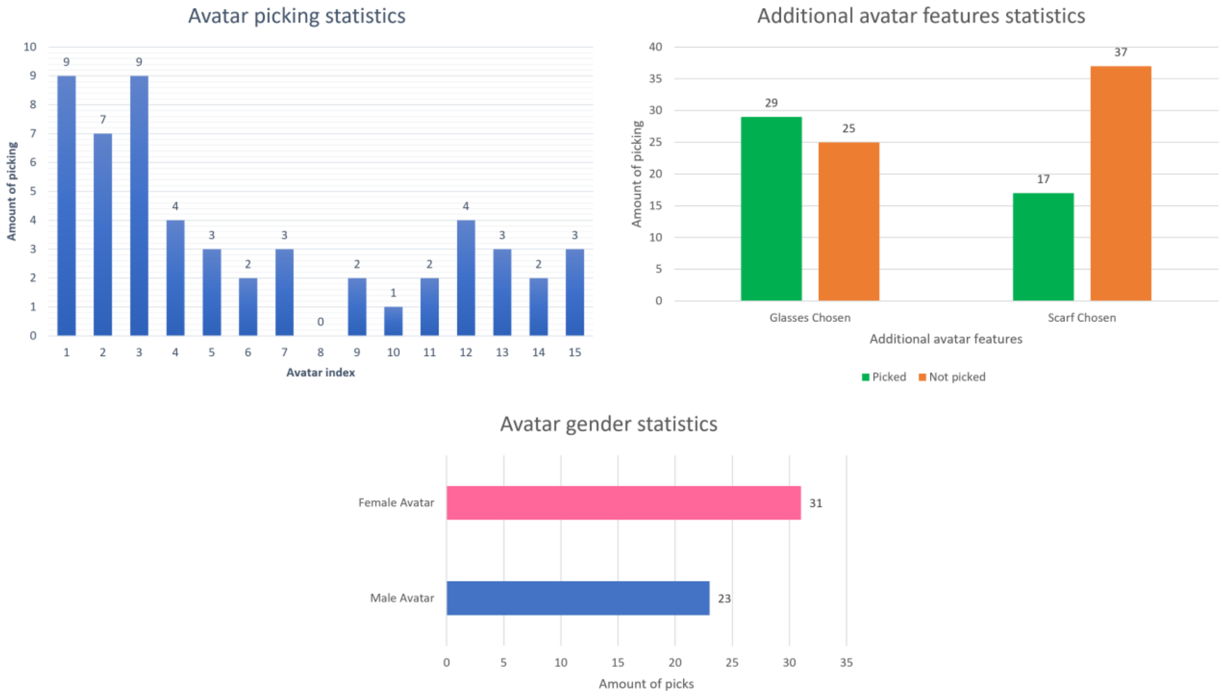


Figure 5.39: Statistics on player avatar selection and customization.

The result was quite predictable. Considering the gender distribution, (28 females and 26 males), roughly the same distribution can be observed in this case, although 3 males decided to choose female avatars, which can be written off as a margin of error.

Regarding additional accessories, 53.7% of users chose glasses, 31.4% chose a scarf, the rest either chose 2 accessories at once or not at all. Nevertheless, user surveys at the point of selecting such options elicited positive responses, indicating a high degree of initial involvement in the process.

5.3.2.1 Analyzing of the results of the levels and activities.

As previously stated in Section 5, the Cognitive Block includes 2 fully functional and customized levels, each containing 5 different activities. Appendix D presents the results of each group's task performance, and Table 5.2 demonstrates the percentage of task performance by each group as a whole.

Table 5.2. Percentage of task fulfillment of each of the tested groups.

№	**Group**	**Level 1, %**	**Level 2, %**
1	Test Group	100%	92%
2	Group A	98%	6%
3	Group B	71%	20%
4	Group C	94%	0%

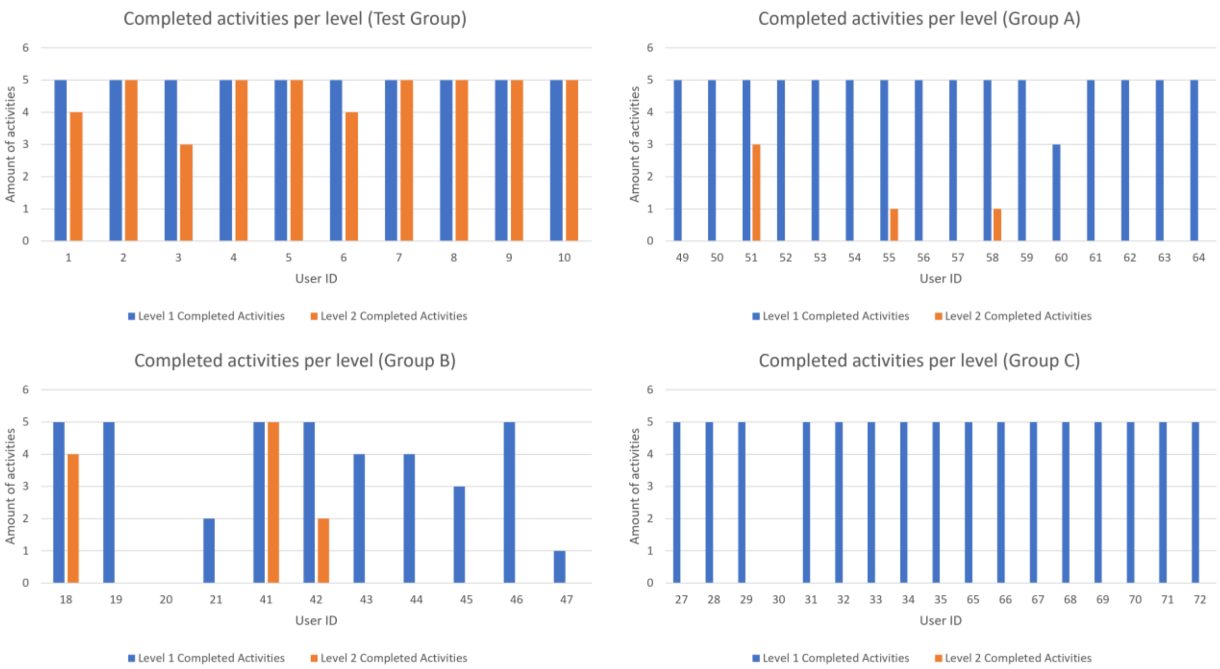


Figure 5.40: Visual interpretation of each group's task performance.

As can be seen in Table 5.2 and Figure 5.40, only the test group was able to complete the second level, while for the other groups it became either very technically difficult or incomprehensible. Taking this fact into account, further on we will show more analysis of the results of the first level and its activities.

5.3.2.2 Analyzing the results of the tested groups by activities.

First, for clarity, it is worth assessing the average values of each group for each Tier 1 activity. For this purpose, results obtained by each user, containing the key evaluation parameters, namely:

- User Id;
- Click counts;
- Number of correct answers;
- Number of incorrect answers;
- Time for level complete;
- Average time per all levels;
- Average % of correct answers in all activities;
- Average amount of clicks in all activities.

With these parameters, we can talk about the application's performance and accuracy. To begin with, Figures 5.41 and 5.42 show the overall results of all four groups on the five Tier 1 activities. Although this approach to representing the results does not give an absolute final accuracy, because the large differences between the worst and best user results give a margin of error, it does give an overall characterization of the group and the average level of each individual user.

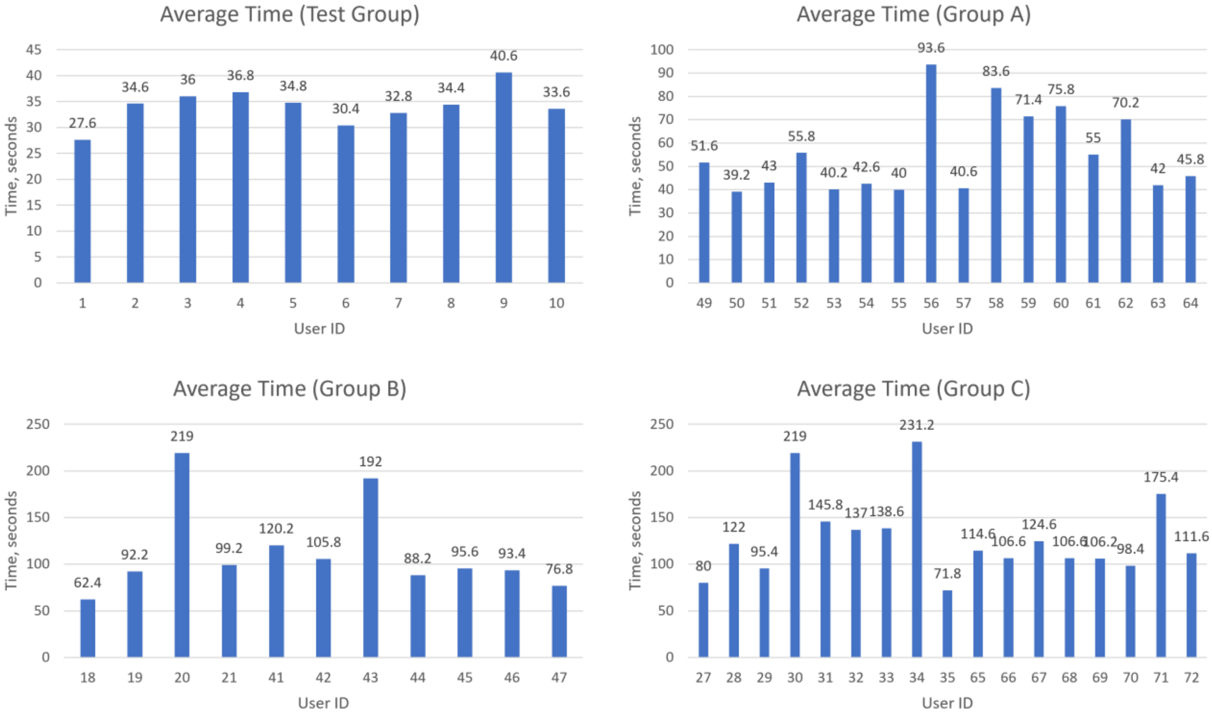


Figure 5.41: Total time spent by group.

Figure 5.42: Overall percentage of correct user responses by group.

As can be seen from the figures, depending on the task and the parameters of a particular group, the results vary in one direction or another. However, at this stage it is impossible to assess the difficulty of each task separately, which does not demonstrate an objective picture of the results.

a) Assessment of Tier 1 results Tasks 1.

If we move on to analyzing the results of specific tasks, in this case it becomes possible not only to see the efficiency of specific users, but also to get information about the efficiency of the task itself.

It should be mentioned that the first level is essentially an introductory part, the task of which is to demonstrate the basic elements and ways of managing the application. Therefore, in this case, the prediction of low activity results is normal. Nevertheless, for the primary analysis, the main indicator will be the statistics of correct and incorrect answers of each group. Such statistics are demonstrated in Figure 5.43.

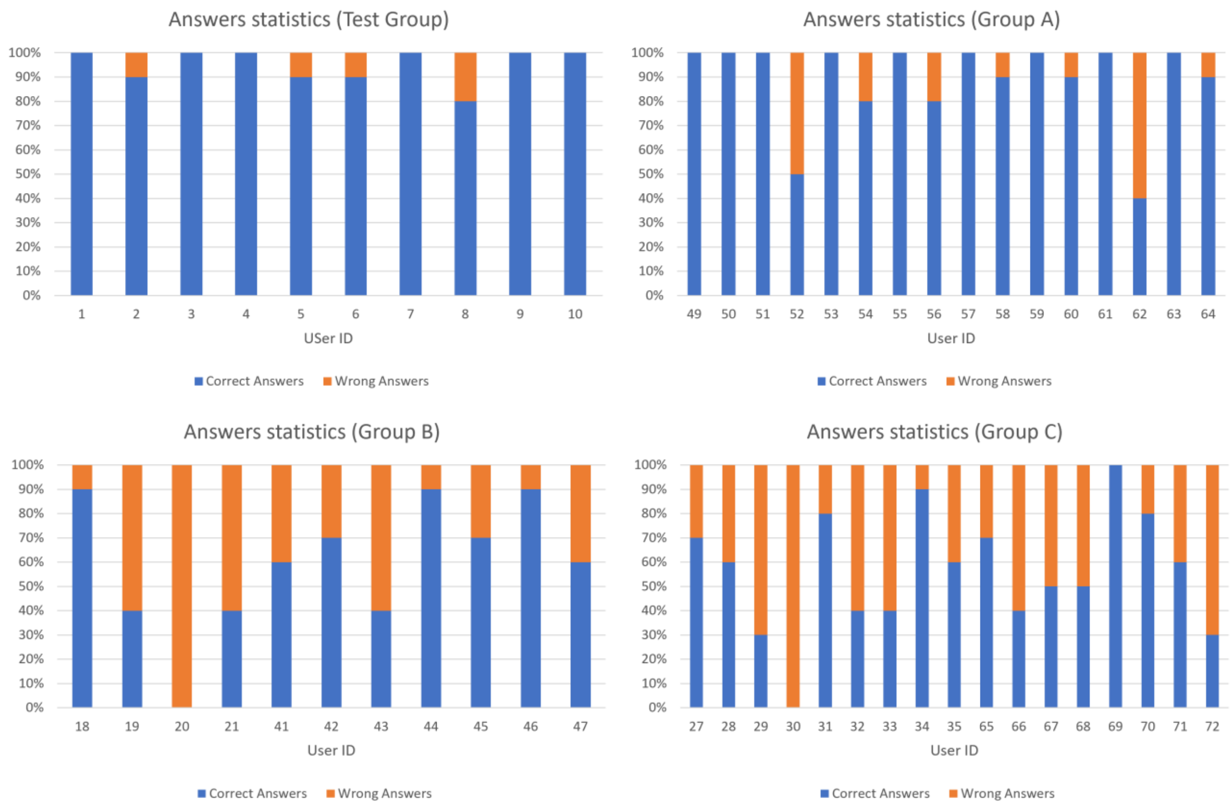


Figure 5.43. Ratio statistics of user responses for Level 1 Task 1.

In this task we can clearly see how each group coped with the first task. The best result is for the test group, the worst is for Group C. Approximately the same statistics is shown by the groups in terms of time spent on the exercise, which is shown in Figure 5.43.

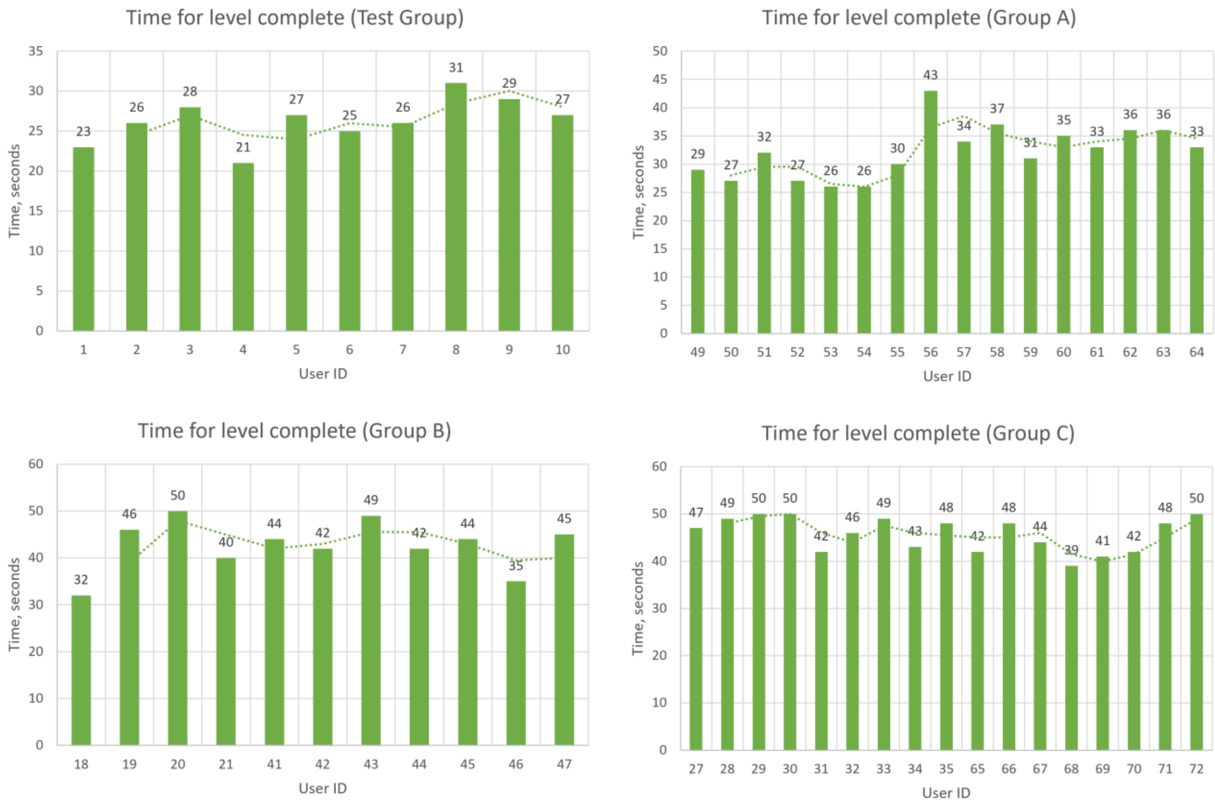


Figure 5.44. Group timeline for Tier 1 Task 1.

Figures 6.43 and 6.44 show that the indicators of these groups are regular and clearly depend on certain parameters, albeit to different degrees. The most obvious reason for these parameters is, first of all, the level of disability, the level of which is expressed in the results of all four groups. Figures 6.45 and 6.46 show the dependence of incorrect answers and time indicators, respectively, depending on this level of disability.

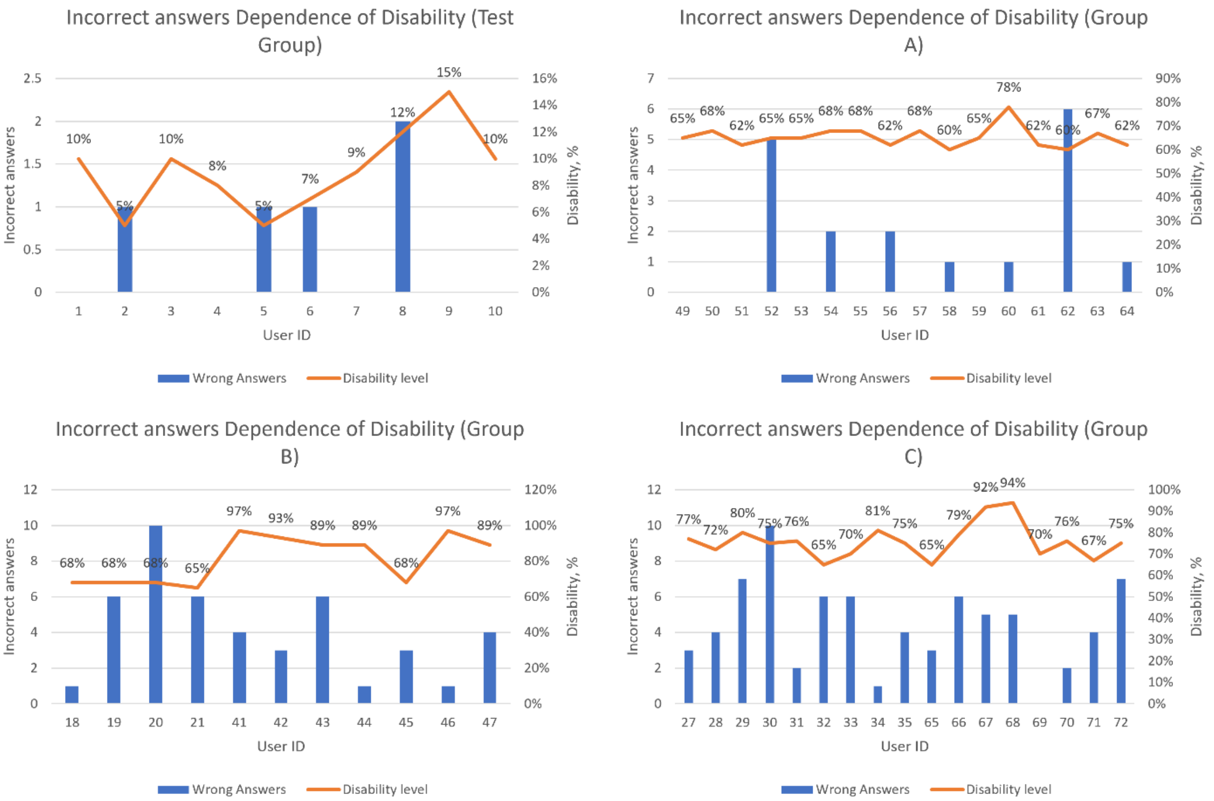


Figure 5.45. Correlation between incorrect answers and the level of disability of the groups for Task 1 of Level 1.

Figure 5.46. Time dependence index on the level of group disability for Tier 1 Task 1.

If we draw a trend line for the parameters of time and incorrect answers, we can notice that it will generally repeat the line that represents the average line of disability level by group. In some cases, implicitly, and in some cases, reaching almost 70-80% overlap. This indicates that there is a certain value of correlation between these parameters.

One more additional parameter of user activity and result can be considered as the number of clicks he/she makes during the time of solving a task. This parameter can indicate several parameters, namely how the user has solved the task, how clearly, he performs it and demonstrate his level of attention and coordination. If the attention span is low, the clicks will go anywhere but on the necessary objects. These statistics for each group are presented in Figure 5.47.

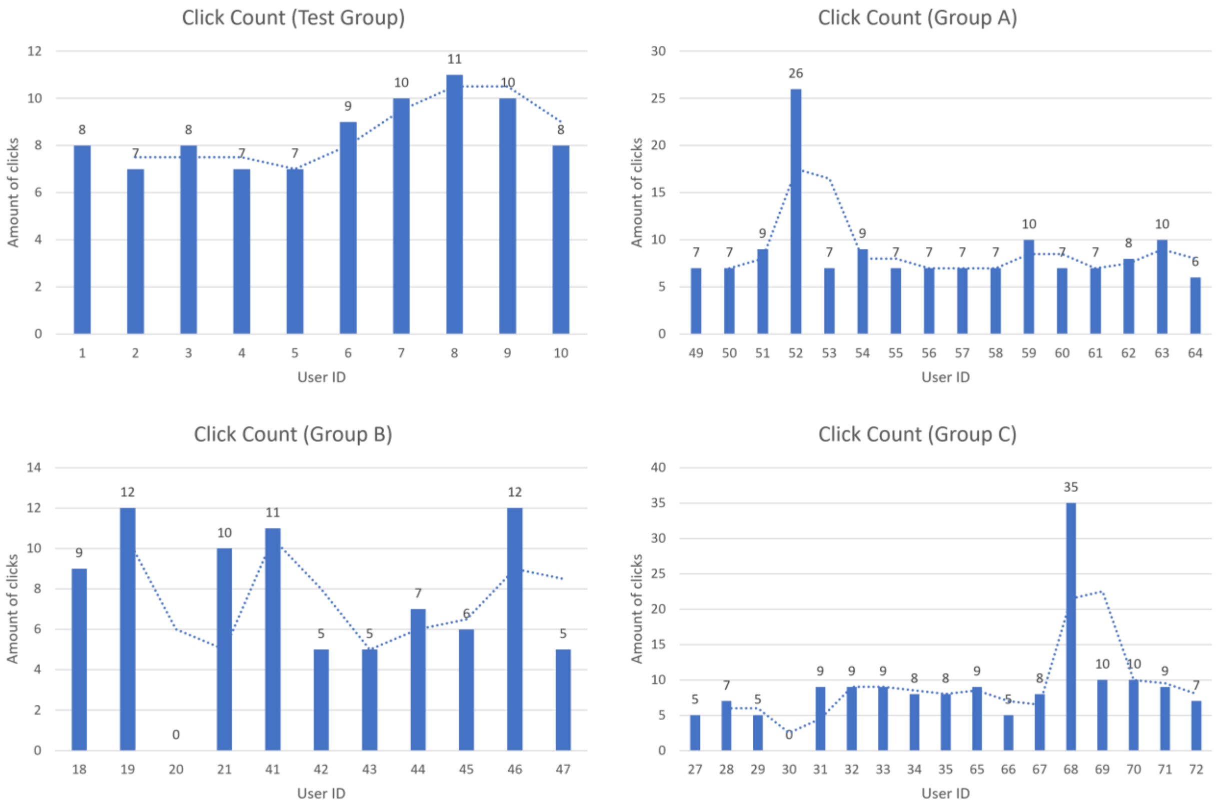


Figure 5.47. Group click-through rate for Level 1 Task 1.

An interesting point is that in this case, if we compare Figure 5.46 and Figure 5.47, we can see that for three of the four groups (except Group A), the average trend line follows the disability line to some extent. This indicates that in some cases, depending on the setting, this parameter may also be a characteristic of the user's outcome.

b) Assessment of results of Tier 1 Tasks 2.

This task is a slightly more complicated version of the previous one. The only difference is the number of correct answers that the user has to give, as well as the way of selecting them. In this case, it is assumed that the player already knows how to act and how to operate the interface of the system, so this is by and large the first task where the real indicators of the user's level will be demonstrated. The response ratio statistics are shown in Figure 5.48.

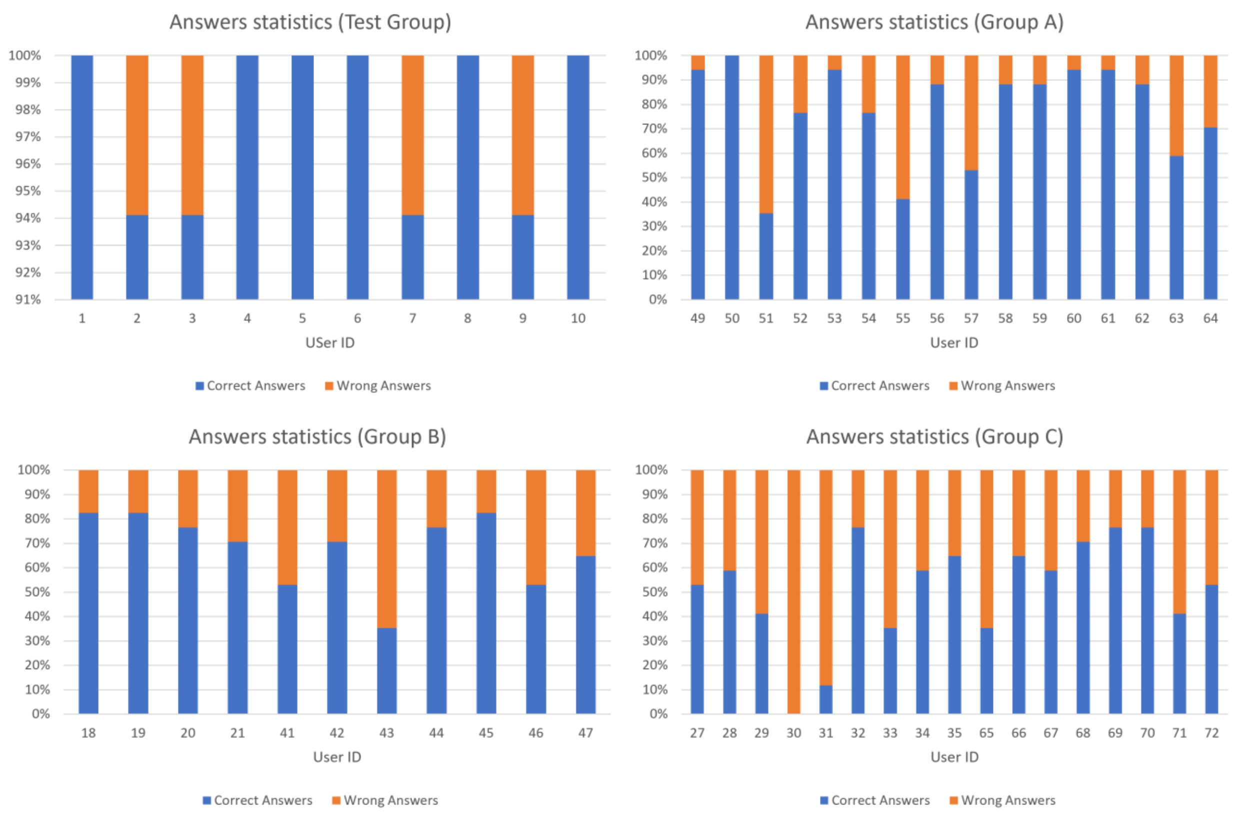


Figure 5.48. Ratio statistics of user responses for Tier 1 Task 2.

In this case, the trend of the groups' successes shows roughly the same ratios of results. The time profile, which is shown in Figure 5.49, also shows a similar pattern.

Figure 5.49. Group timeline for Tier 1 Task 2.

The above figures show the same pattern as before. However, it already differs slightly more, which is clearly seen in Figure 5.50, on the example of the number of wrong answers and Figure 5.51 on the time parameters.

Figure 5.50. Correlation between incorrect answers and the level of disability of the groups for Task 2 of Level 1.

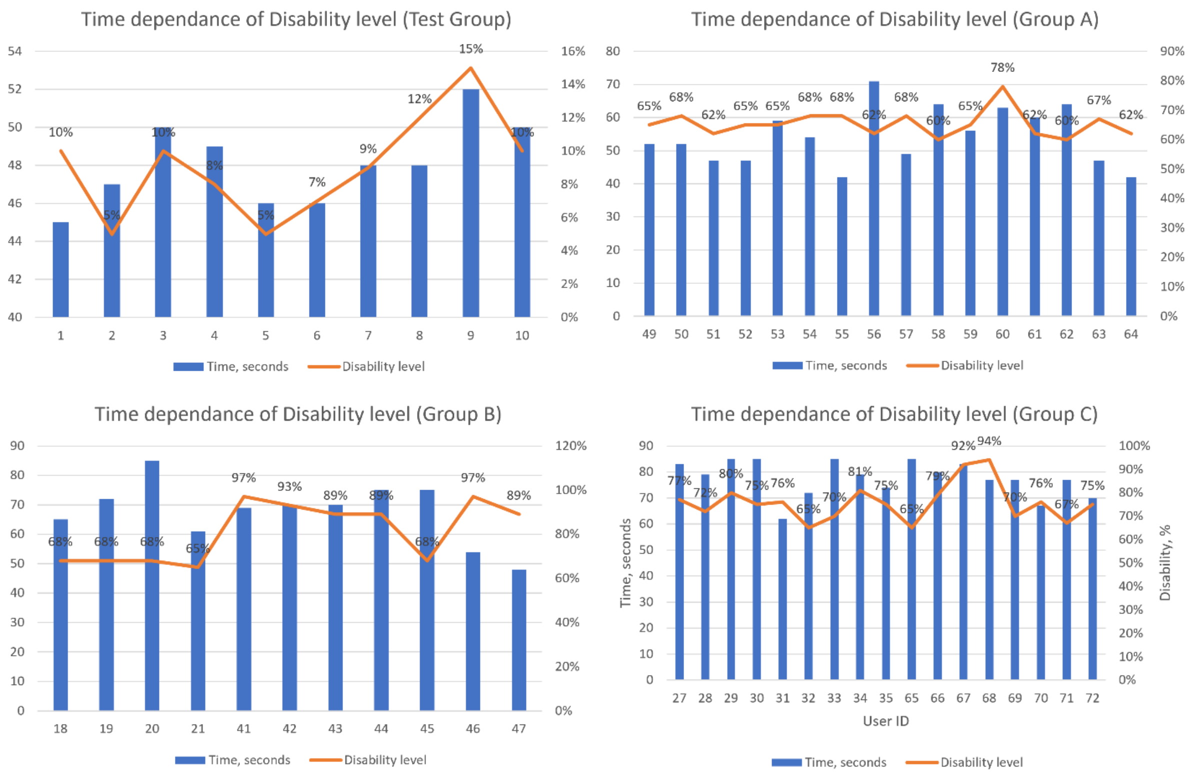


Figure 5.51. Time dependency index of the level of group disability for Tier 1 Task 2.

In this case, there is also a correlation between the parameters of time, response ratio and level of disability. Two consecutive cases can already indicate a strong correlation between these parameters. In addition, the example of Group C shows the effect of user age on the speed and quality of task completion.

However, task 2 shows that the number of clicks made by the user can only be a private and additional parameter, as Figure 5.52 shows that the average results of the Test Group and Group C are approximately equal. This figure will depend directly on the specific task at hand, and on the specific user.

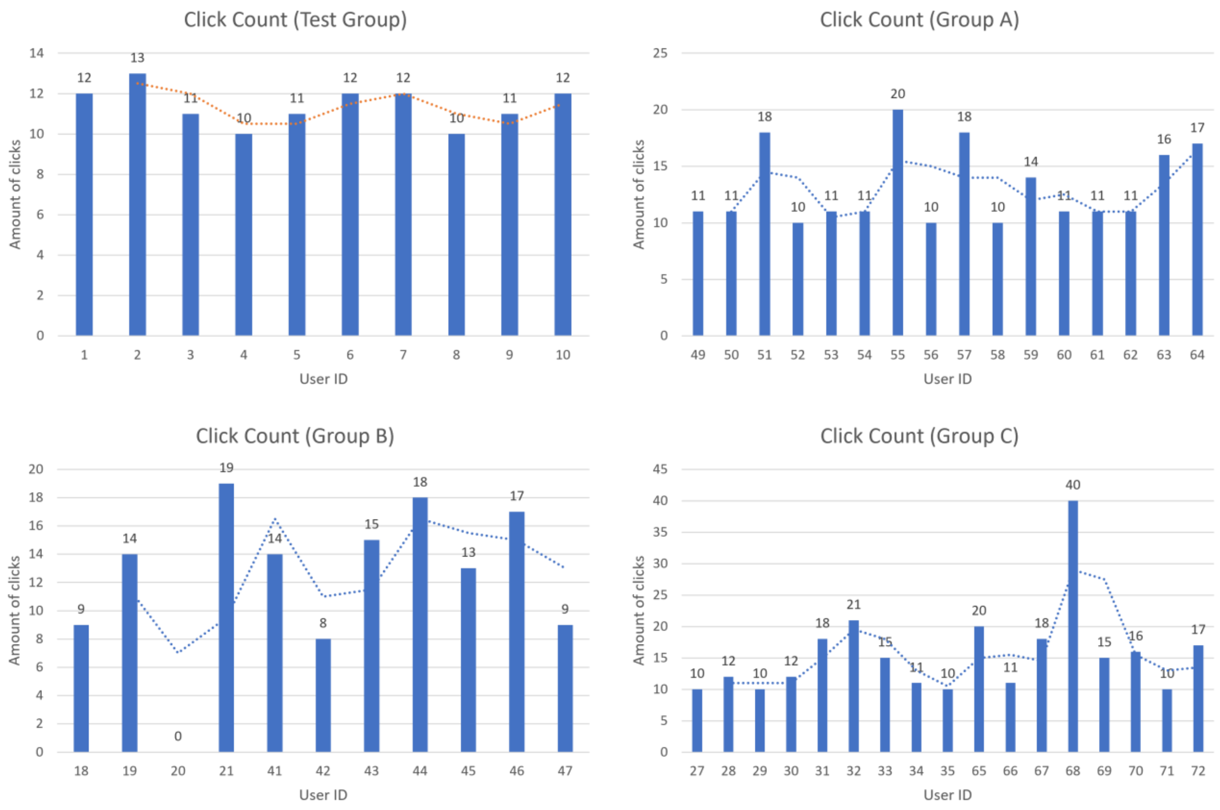


Figure 5.52. Group click-through rate for Level 1 Task 2.

c) Assessment of results of Level 1 Tasks 3.

The specifics of Level 3 involve listening to certain sounds and matching them to an opposite object. Since listening to the sounds and making a decision may require additional time, this parameter will play a major role in this task. As for the previous tasks, the analysis plan is carried out in the same sequence.

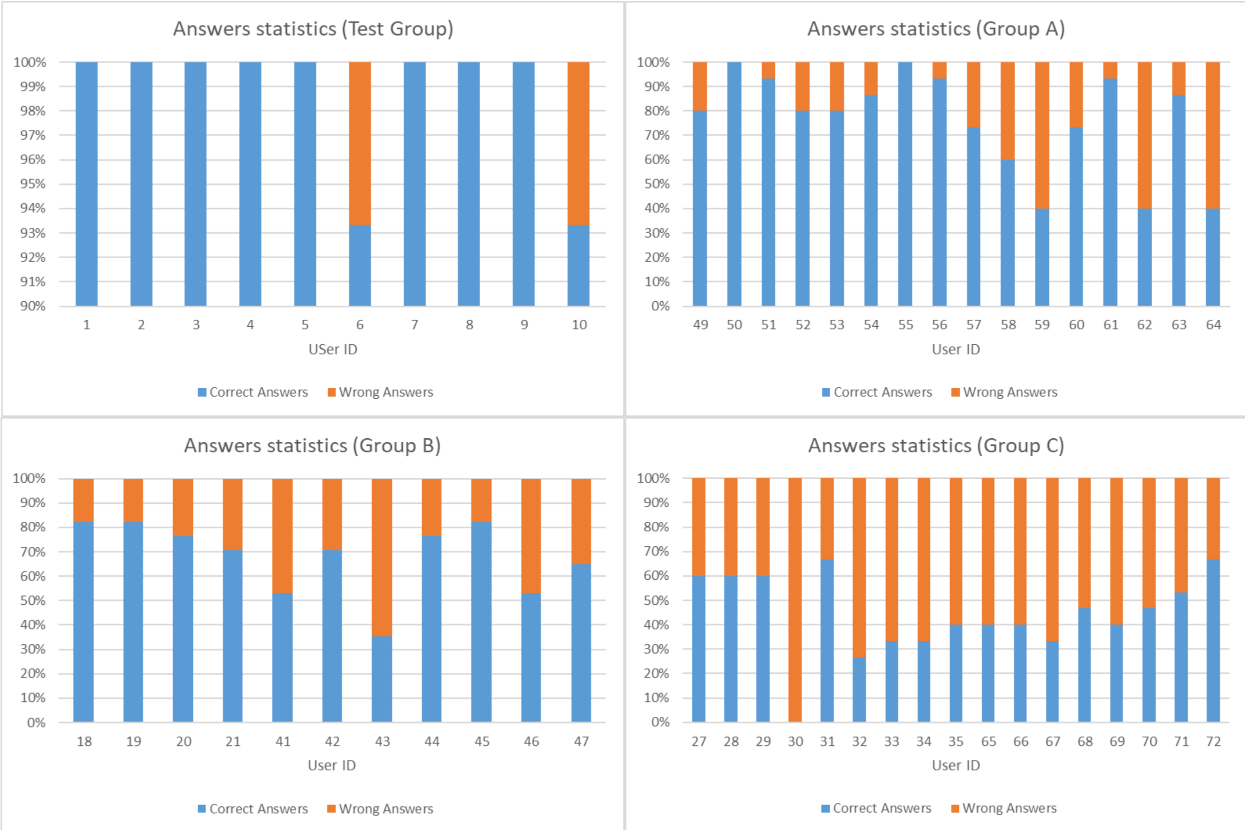


Figure 5.53. Ratio statistics of user responses for Level 1 Task 3.

Figure 5.54. Group timeline for Tier 1 Task 3.

Indeed, as mentioned earlier, Figure 5.54 demonstrates that more time is needed to make a judgment for each iteration of Task 3, especially for Groups B and C. However, the other groups also took more time on average to complete this activity. At the same time, the results of the ratio of correct to incorrect answers for each group are at approximately the same qualitative levels as in the previous task.

In this case, a pattern of results is also observed. Detailed visual statistics is presented in Figure 5.55, Figure 5.56.

Figure 5.55. Correlation between incorrect answers and level of group disability for Task 3, Level 1.

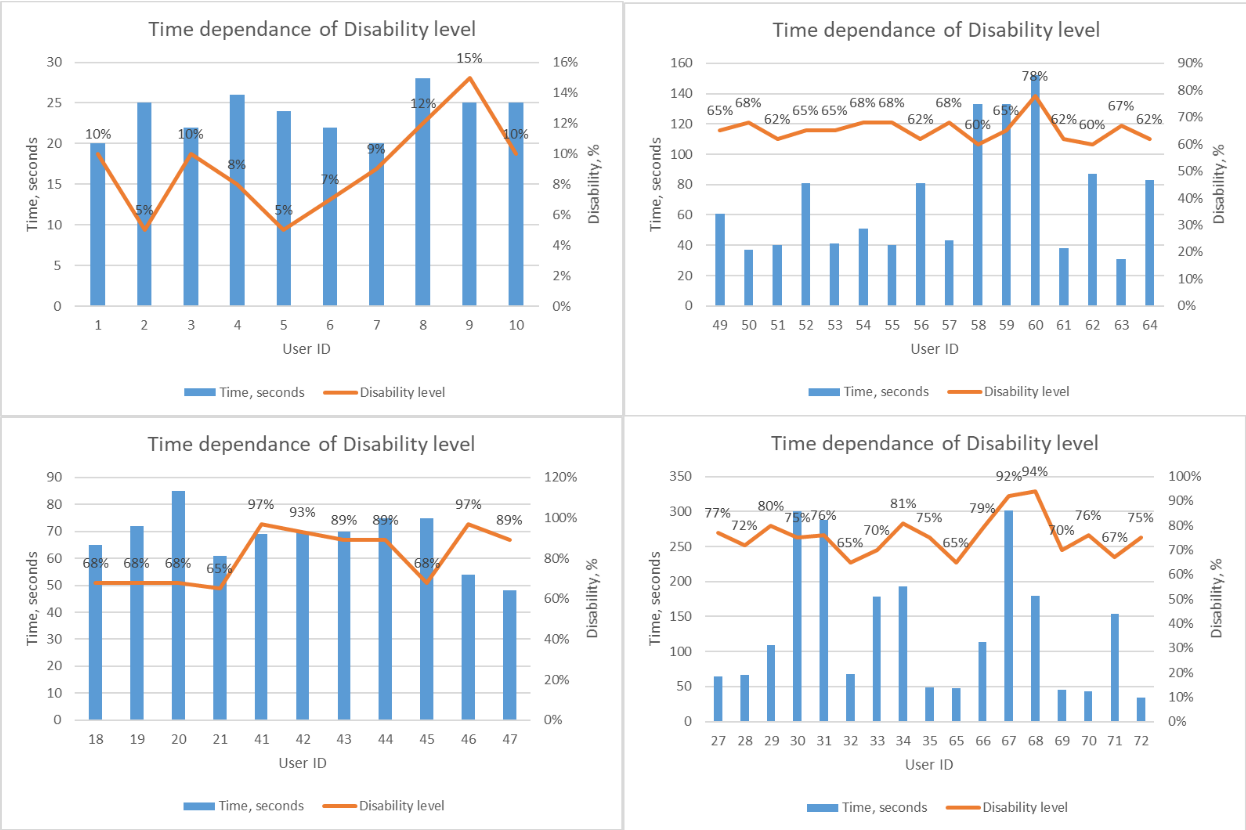


Figure 5.56. Time-dependent group disability rate for Task 3 of Level 1.

In this case, we can also see a regularity between the parameters of time, response ratio and level of disability. The example of Groups A and C shows a rather strong dependence of decision-making time on the level of disability, while Figure 6.28 shows a lesser dependence of the parameters.

But the situation with the number of clicks in all groups is very similar and stable. The majority of users in all groups coped well with the task, although Group B demonstrates a lower result, as can be seen in Figure 5.57.

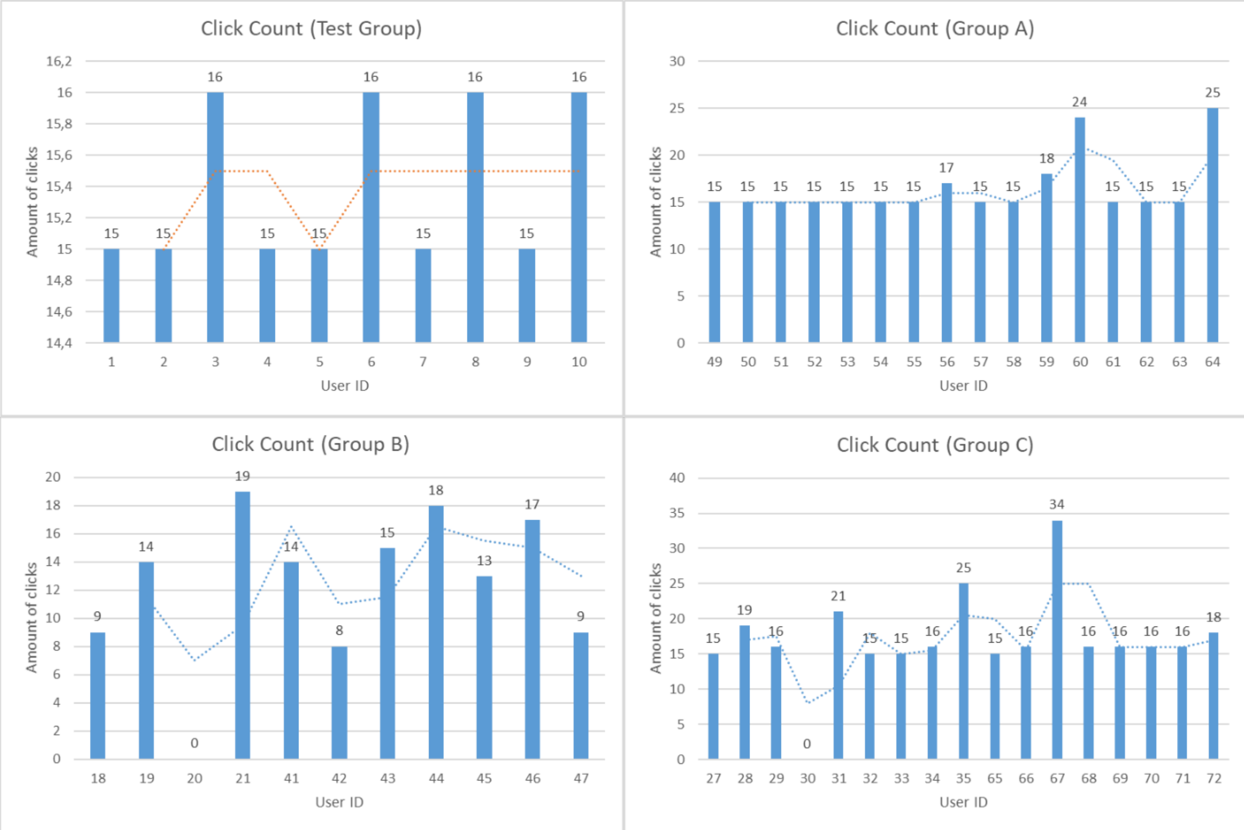


Figure 5.57. Group click-through rate for Level 1 Task 3.

d) Assessment of results of Level 1 Assignment 4.

This activity can be called the most difficult. In addition to the short-term memory factor, the number of iterations for the first and second parts of the task plays an important role in this case. Given that the first part is the most difficult, it is its result that counts, while the second part serves to consolidate the skill.

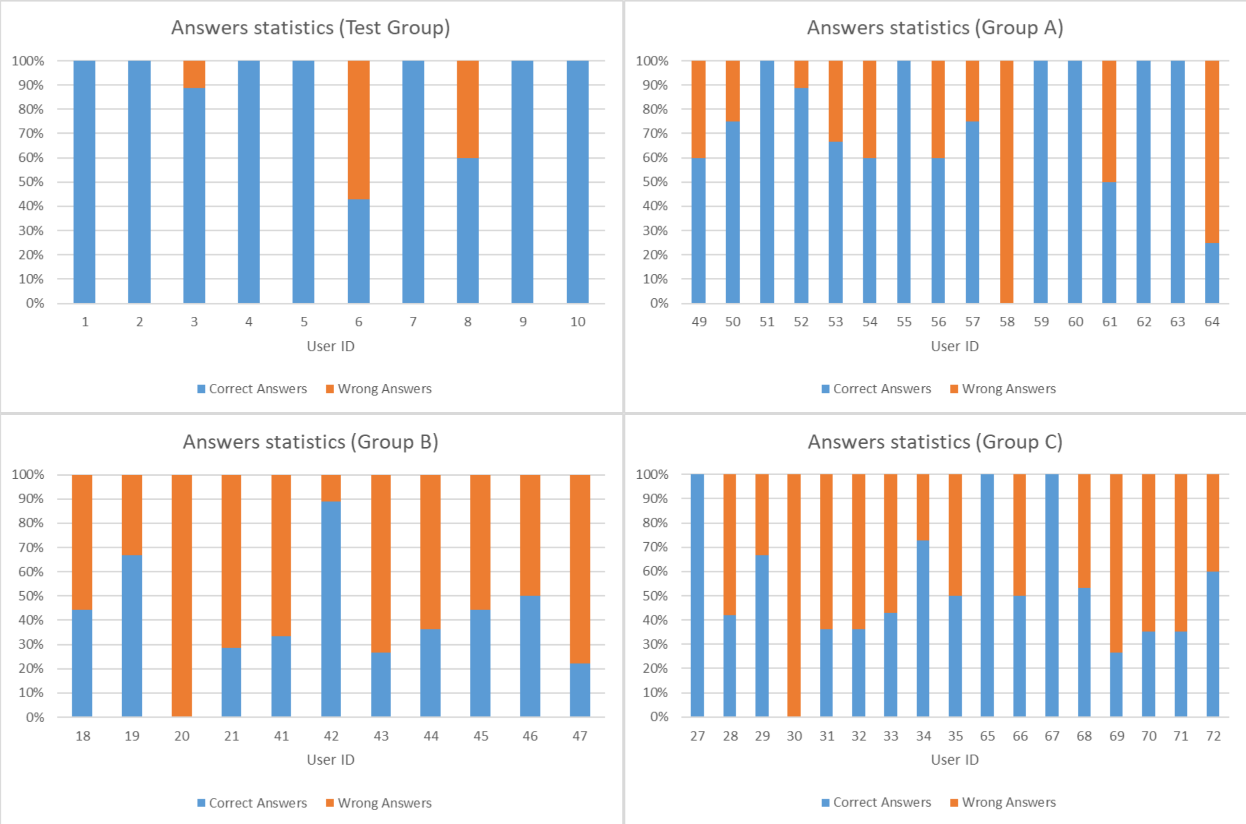


Figure 5.58. Ratio statistics of user responses for Task 4 of Level 1.

Even though there are only 8 correct answers, the number of wrong answers is a more meaningful indicator in this case.

Figure 5.59. Group timeline for Tier 1 Task 4.

In Activity 4, the temporal characteristic for all groups shows rather high values, especially when analyzing those in the test group. This is due to the fact that each time the location of the selected elements is random, and this introduces a large error in the process of task performance. It means that, for example, the first attempt can finish in 30 seconds, and the second one in 130 seconds. And this factor will not be influenced by the age, level of disability or mood of the user. Therefore, in this case the most important evaluation parameter will be the number of clicks and statistics of wrong answers.

Figure 5.60. Correlation between incorrect answers and level of group disability for Task 4, Level 1.

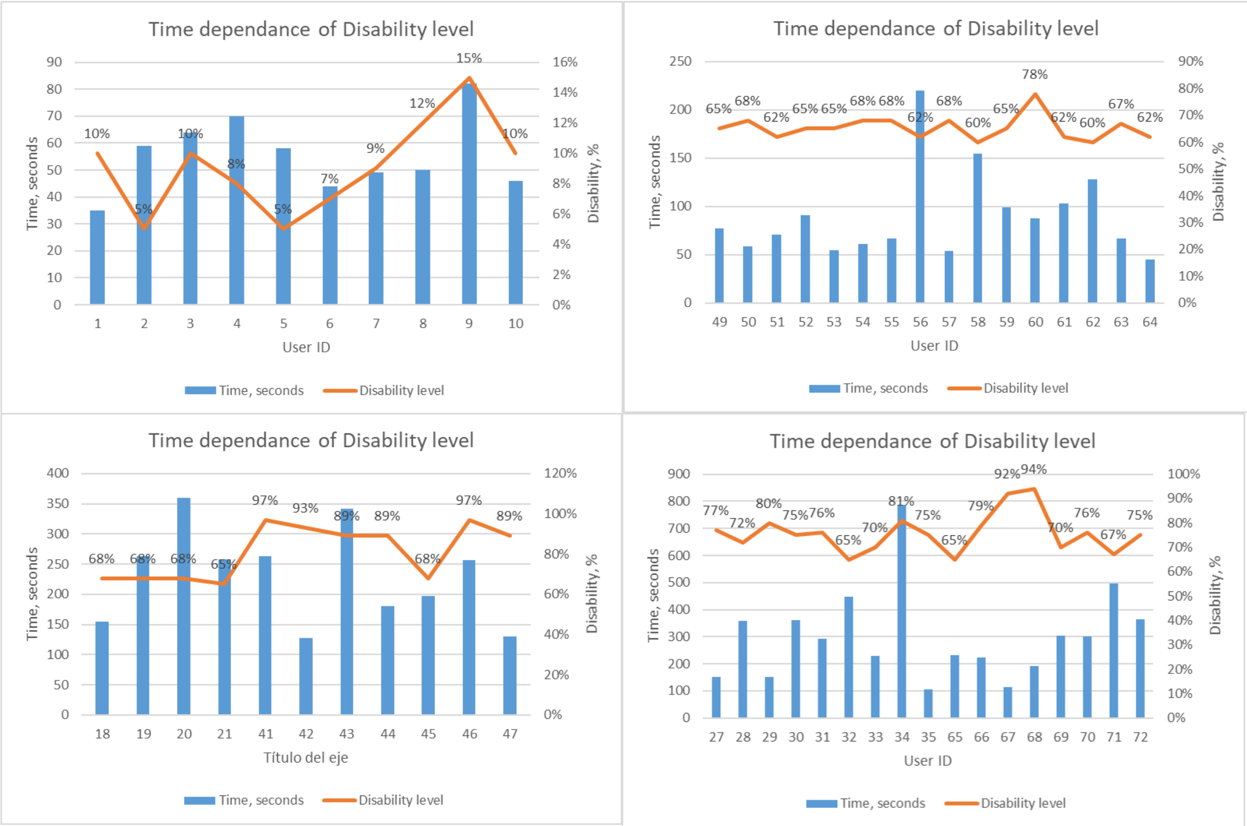


Figure 5.61. Time-dependent group disability rate for Tier 1 Task 4.

Figure 5.60 and Figure 5.61 demonstrate the relationship of response times and statistics to the level of disability. Figure 5.60 is important for understanding the level and quality of short-term memory in a particular user. But Figure 5.61, as mentioned earlier, does not provide a clear picture to evaluate and characterize the user's results, because the influence of randomness is very high.

However, the characterization of clicks made, Figure 5.62, gives an indication of how effectively users performed the task and how quickly they completed it. Overall, as can be seen in Figure 5.62, only Group C had great difficulty with this task, while the other three performed at a good level on average.

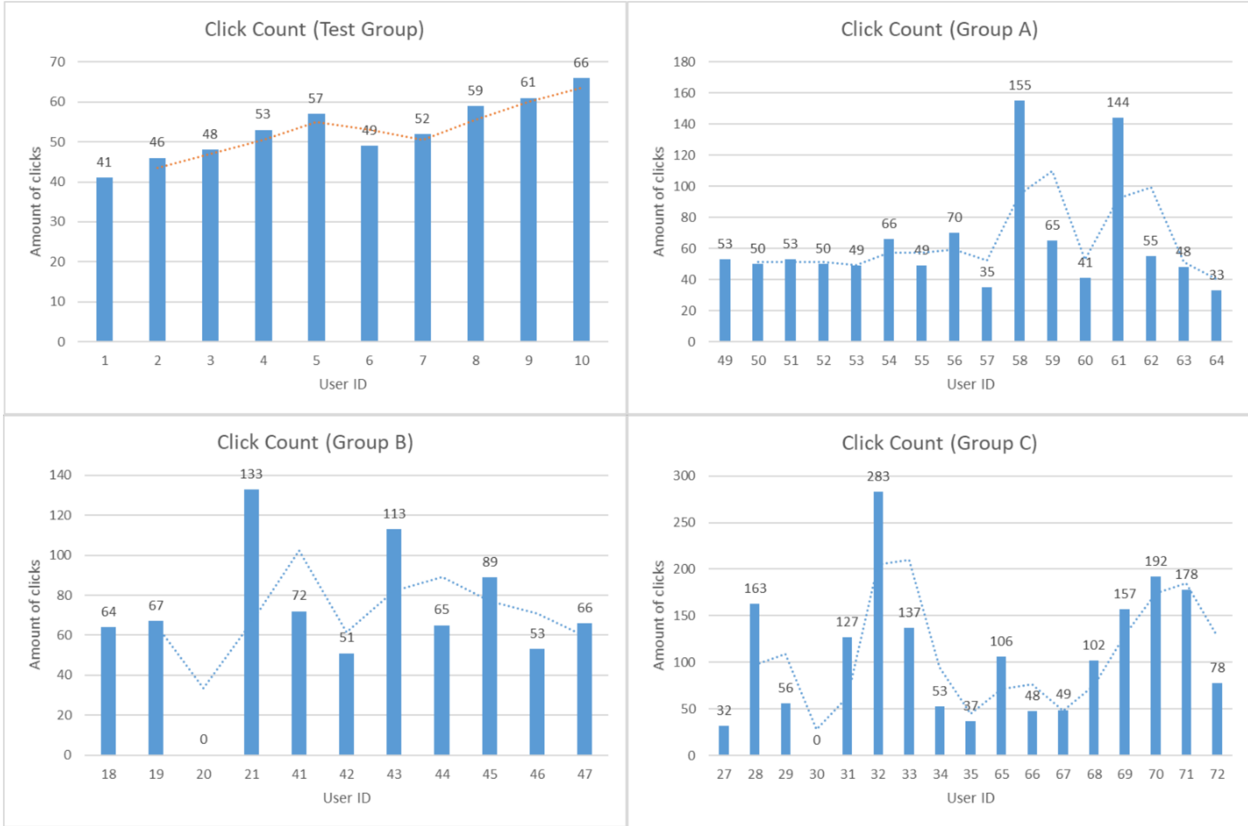


Figure 5.62. Group click-through rate for Level 1 Task 4.

e) Assessment of results of Level 1 Assignment 5.

The final Level 1 task is a simple task that is similar in its mechanics to Tasks 1 and 2, but incorporates the mechanics of Task 3, namely associative choice. It serves to reinforce and test all the skills learned in the previous tasks. In this case, the important evaluation parameters will be, first of all, the time characteristic of performance, as well as the response ratio statistic as an auxiliary value. The response ratio statistics and time statistics are shown in Figure 5.63 and Figure 5.64, respectively.

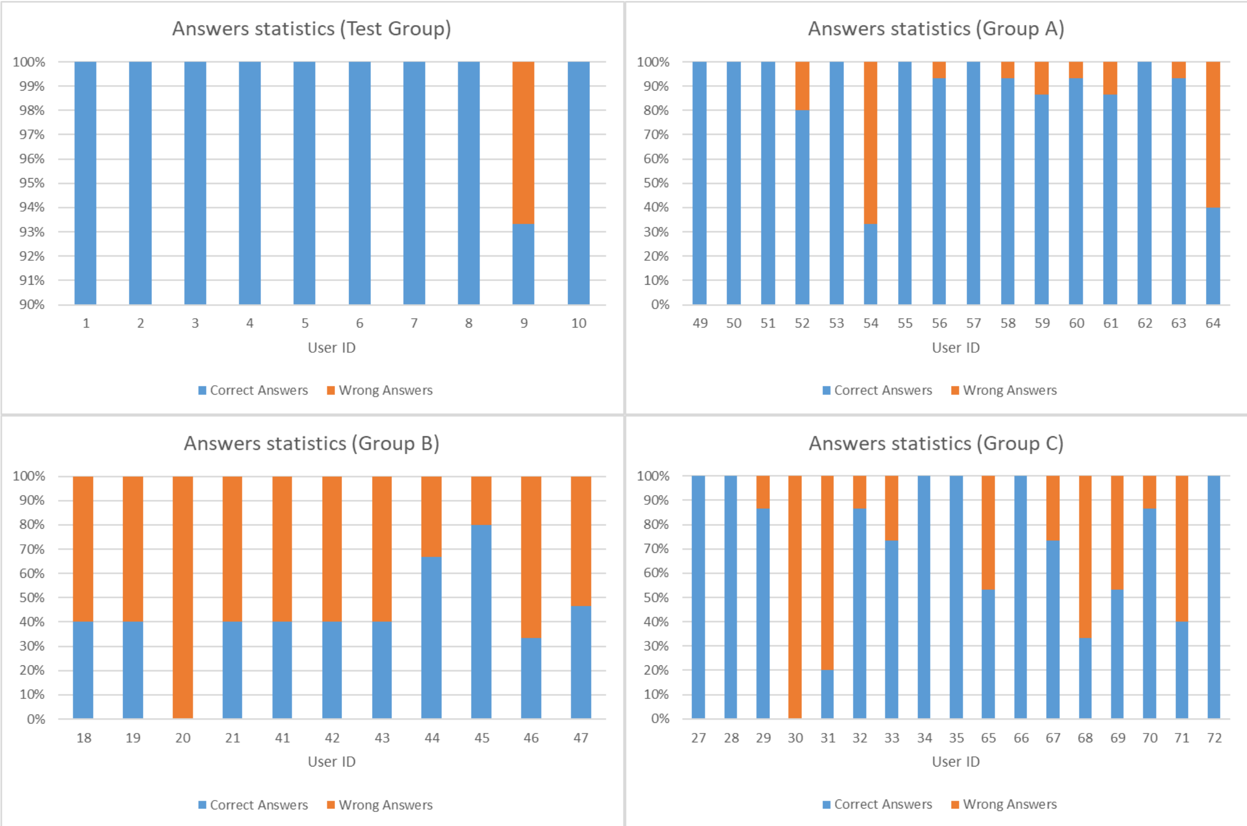


Figure 6.63. Ratio statistics of user responses for Task 5 of Level 1.

Figure 5.64. Group timeline for Tier 1 Task 5.

The data presented above allow us to speak about several lucks. First of all, based on Figure 5.63, we can say that all groups, except Group B, coped well with the task, even in comparison with previous activities. The result of Group B suggests that the associative choices task is somewhat difficult. As for the temporal characterization, the results are relatively consistent for each group. This once again demonstrates the regularities in the parameters and characteristics of each group.

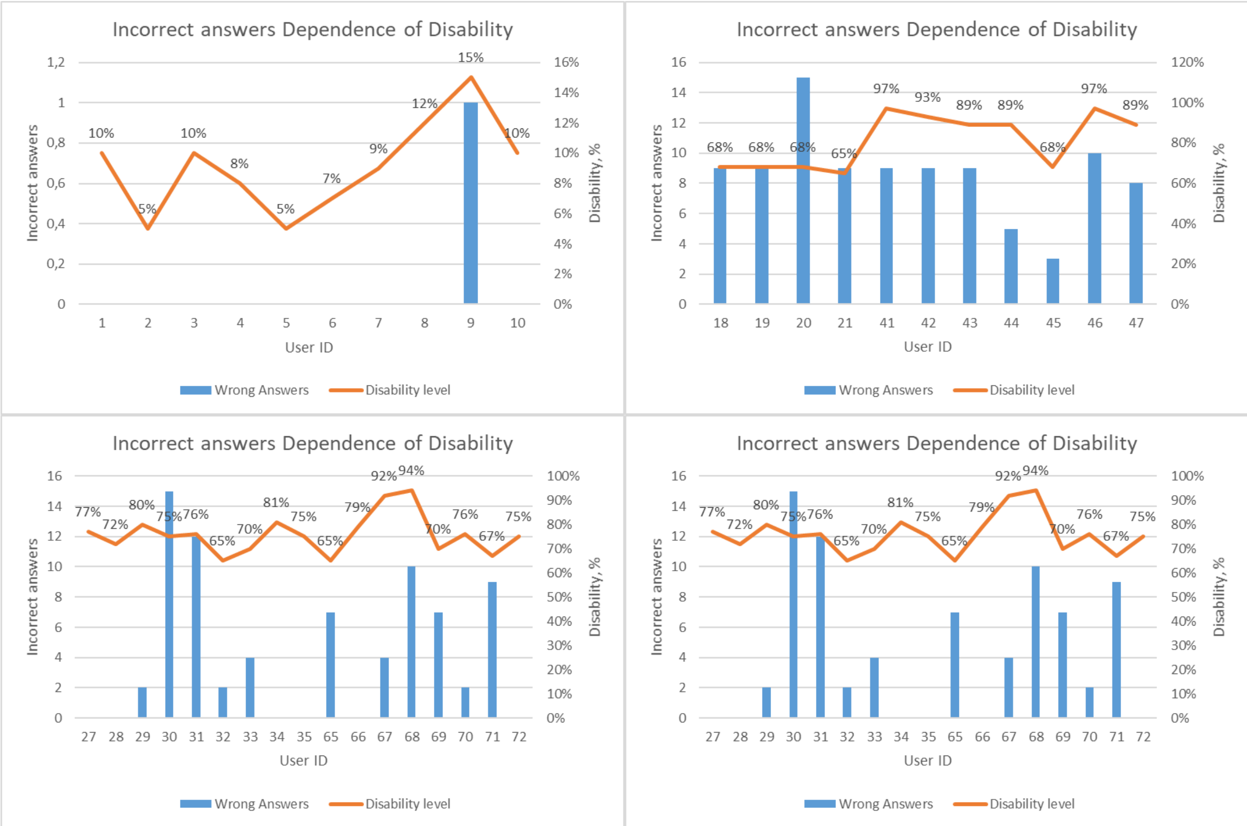


Figure 5.65. Correlation between incorrect answers and level of group disability for Task 5, Level 1.

Figure 5.66. Time dependence index on the level of group disability for Tier 1 Task 5.

Figures 5.65 and 5.66 also demonstrate the influence of individual characteristics and their relationship with the final result. In this case, the temporal characteristic of the number of incorrect answers to some extent corresponds and repeats the trend line of the level of disability. The same pattern can be seen in Figure 5.67, although it is less pronounced in the characteristic of clicks than other results.

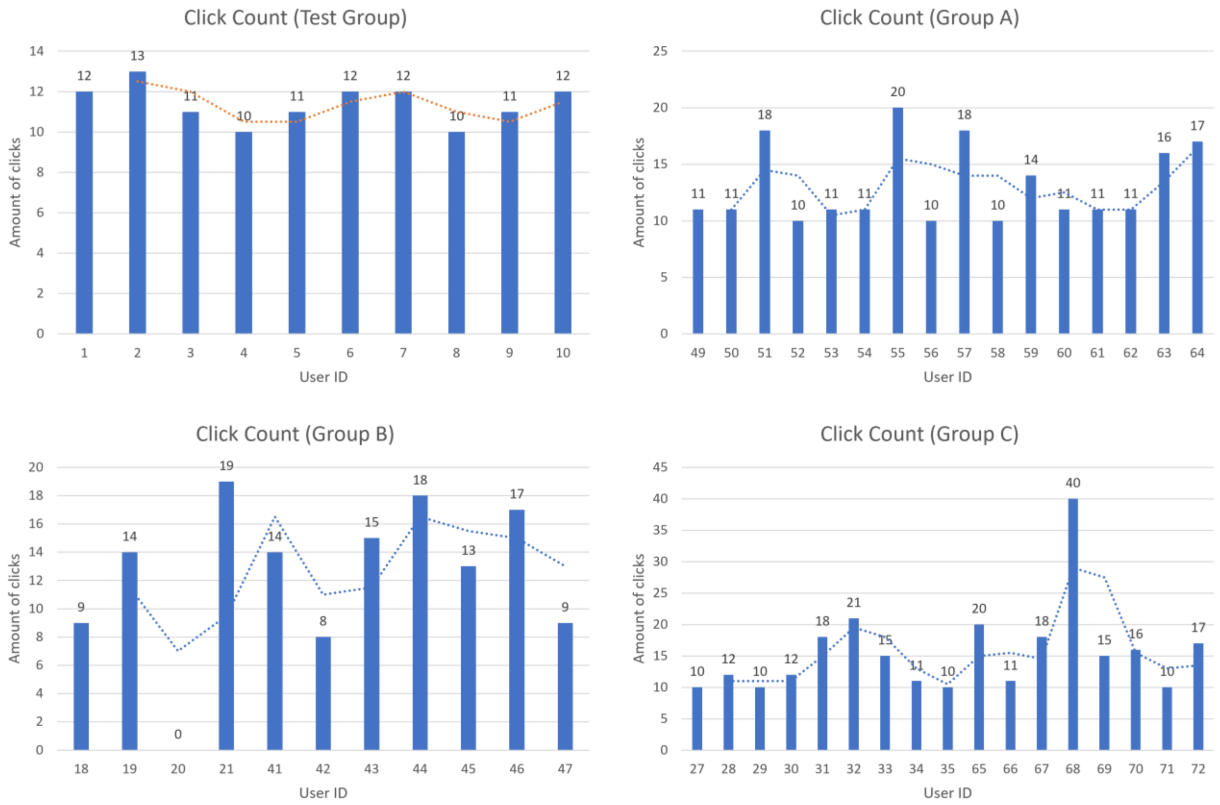


Figure 5.67. Group click-through rate for Level 1 Task 5.

5.3.2.3. Correlation matrix

Considering the results obtained above and the proof that correlation dependence is present in all these data, it makes sense to construct and study a matrix demonstrating this dependence.

The input data for such a matrix will be 6 parameters, which will be taken from a specially compiled Appendix D table. It contains 6 parameters for each user: age, gender, level of disability, number of correct answers, time and number of clicks. This produces the 6x6 matrix shown in Figure 5.68, which is a correlation matrix with the addition of a temperature map showing the dependencies of each of the parameters

The matrix itself was constructed using code written in Python. Also, the SeaBorn library and the Python 3.5 environment were used as the main library in the construction process. Also, as an additional analysis, data clustering was done. For this purpose, the K-means library was used, which systematized the results into clusters. After several variants of such partitioning, it was determined that the appropriate number of such partitions is 4 groups.

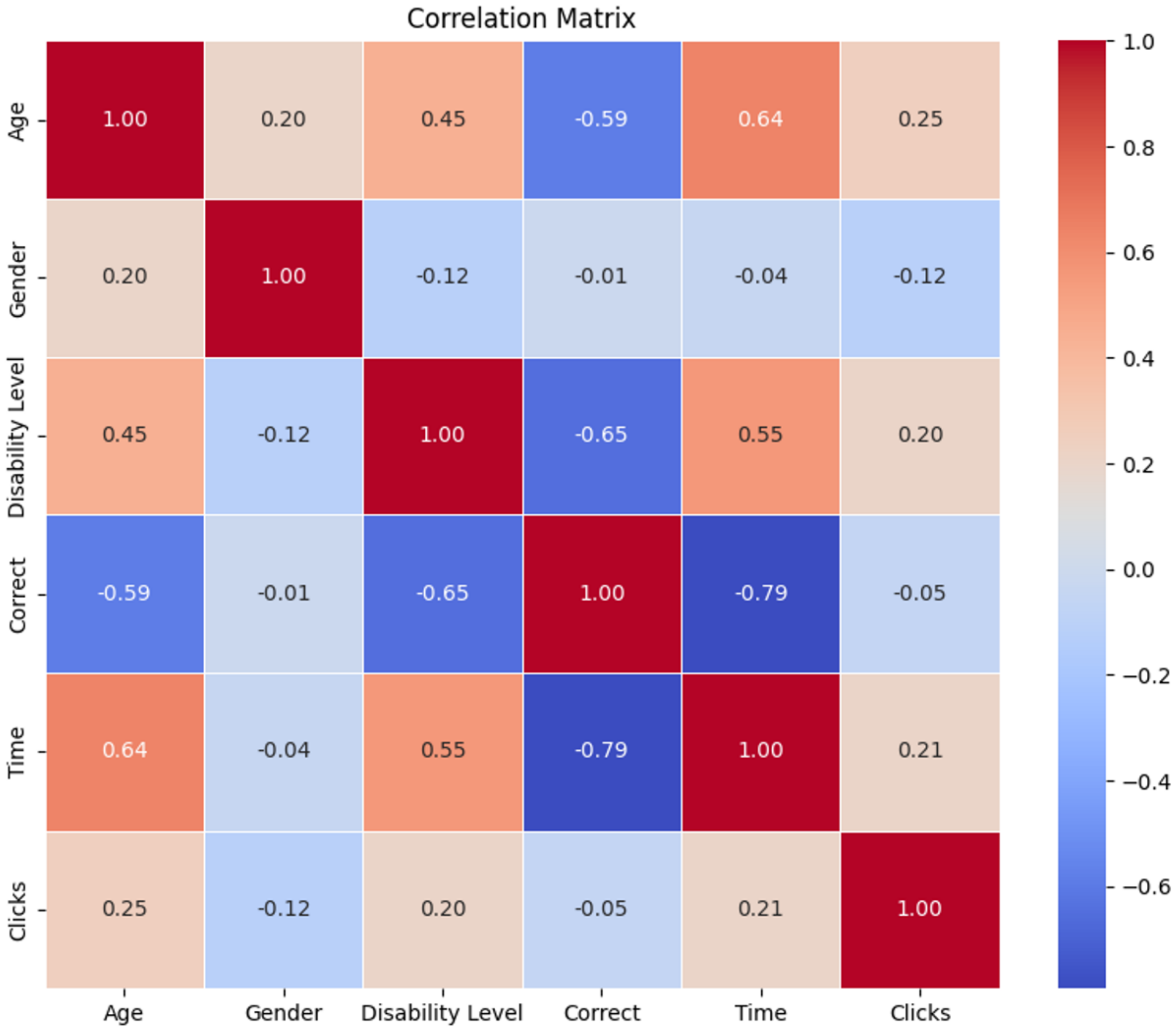


Figure 5.68. Correlation matrix of results with added temperature map.

As can be seen from Figure 5.68, the strongest dependence of parameters is observed in the dependence of time and age, time and level of disability, number of correct answers on level of disability and age. In addition, the dependence of time and correct answers is interesting. Further, each specific case of these dependencies will be analyzed.

1) Correlation of parameters Age - Number of correct answers.

This relationship is a weak inverse correlation, the graph of which is shown in Figure 5.69.

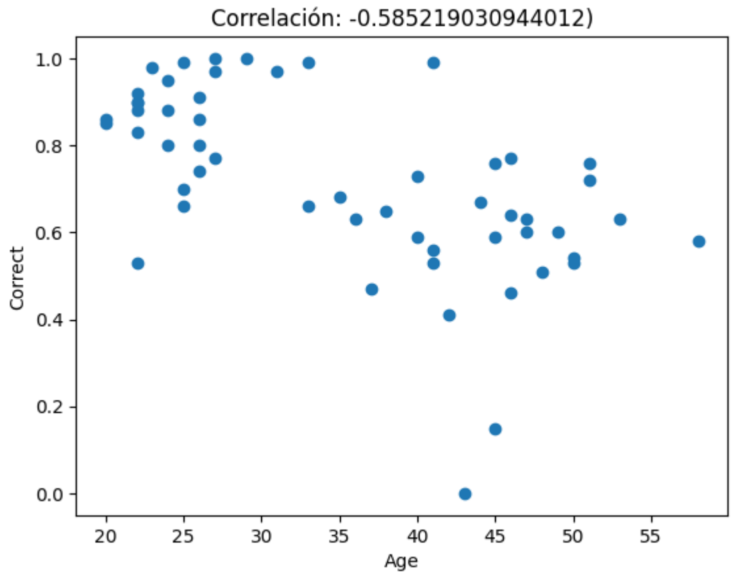


Figure 5.69. Correlation of the Correct Answers Quantity parameter with Age.

This relationship demonstrates that the age parameter is a strong influence on the result of the ratio of correct to incorrect answers given by the user, but due to the presence of additional influencing factors, it is not overwhelming or key.

2) Correlation of parameters Age - Time characteristic.

This dependence is already a direct, but also weak correlation, shown in Figure 5.70.

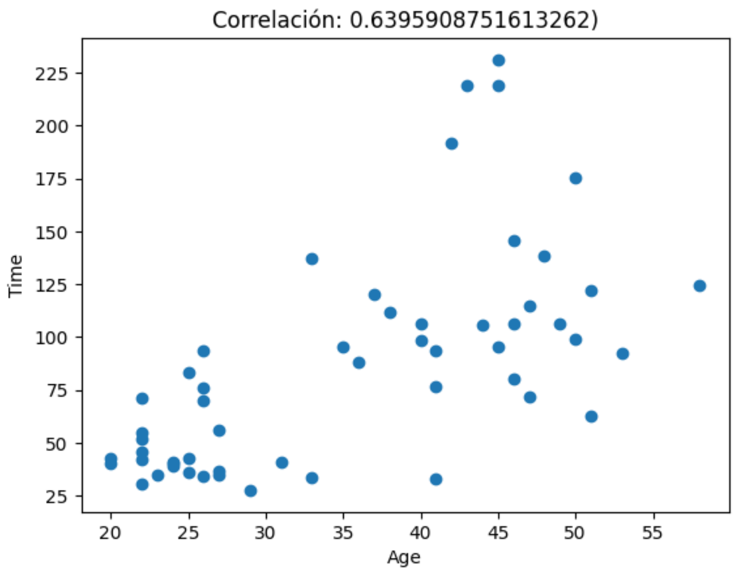


Figure 5.70. Correlation dependence of the Time parameter on the Age parameter.

In this case, age shows a much greater dependence on the result, in terms of time spent on the task. This is explained by rather obvious age-related reasons (speed of movements and reactions, attitude to technological innovations).

3) Correlation of parameters Level of disability - Number of correct answers.

In this case, the correlation is also a weak inverse relationship, but has a relatively high impact on the result. The correlation is shown in Figure 5.71.

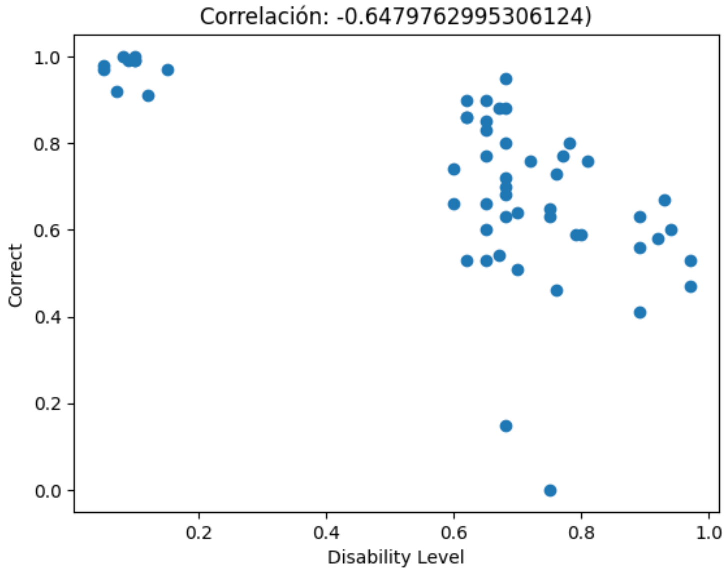


Figure 5.71. Correlation between Number of correct answers and Level of Disability.

Obviously, the degree of cognitive features a particular user has will influence the correctness of answer selection. The previous results clearly demonstrate this dependence, so its influence is quite large on the overall result of users.

4) Correlation of parameters Level of disability - Time.

The last of the main characteristics is a weak direct dependence of time on the level of disability. The relationship is presented in Figure 5.72.

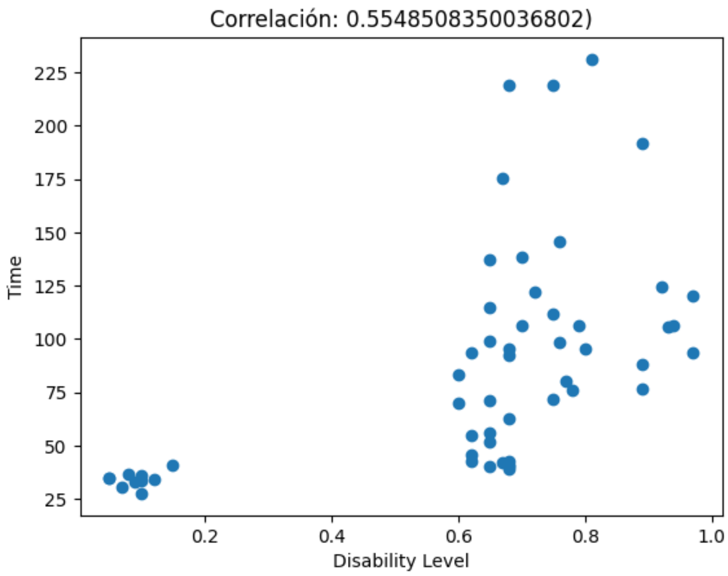


Figure 5.72. Correlation dependence of the Time parameter on the Level of Disability.

This dependence is also quite obvious. The higher the percentage of cognitive features, the more time a user may need to solve a task. We cannot say that this pattern is 100% correct, but it is quite pronounced.

5) Correlation of parameters Time - Number of correct answers.

This is a rather interesting pattern, because both of these parameters are outcomes, not factors affecting this very outcome. In addition to being direct, the correlations still weak.

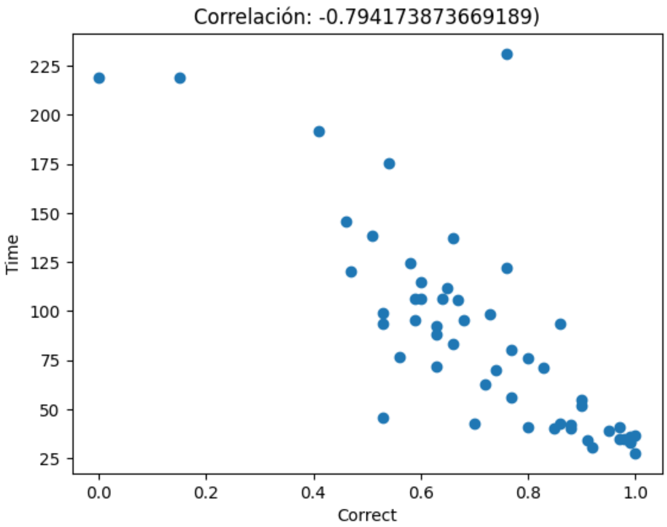


Figure 5.73. Correlation dependence of the Time parameter on the Correct Answers Quantity.

Besides, if we analyze the results of the five activities, there is no direct correlation between the different groups with the way the time characteristic depends on the number of correct answers and the number of possible variants. The only variant of such a correlation is explained by too large variation of the total values of the time parameter, as well as the average value of correct answers. While the total time value is quite low, the average number of correct answers is quite high, because it is taken as a percentage, not as a numerical parameter. Therefore, this correlation parameter can be neglected as an error.

If we talk about the general characterization of the correlation component, this result is explained quite simply. Due to the fact that all the presented parameters, namely age and level of disability, are influencing factors, they simultaneously and almost equally affect the final result of the task. In this connection, their weak correlation component is expressed. Because the influence factor is distributed depending on the task.

If we take all the data obtained, the result of the relationship between the different parameters is demonstrated in Figure 5.74.

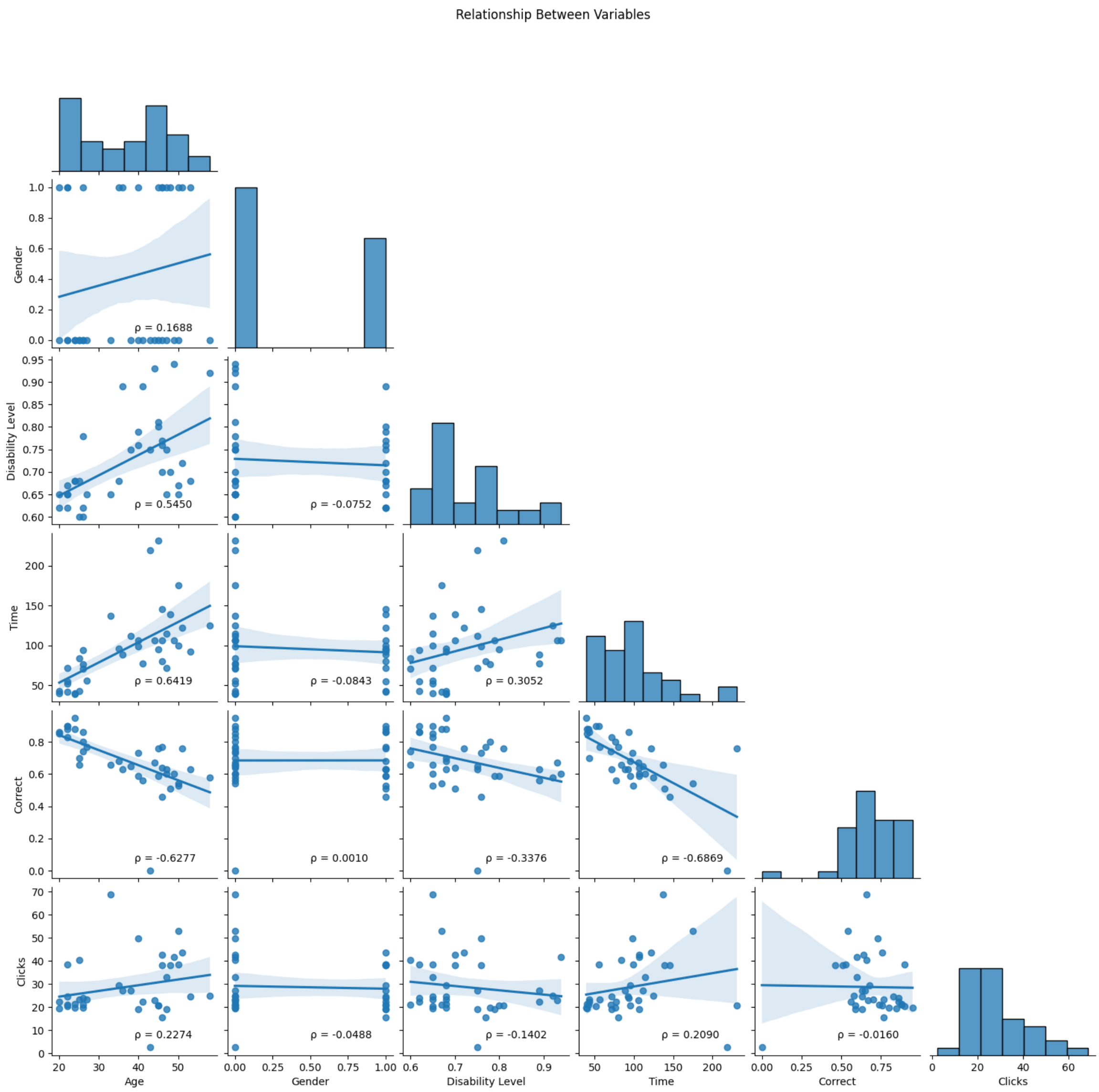


Figure 5.74. Correlations between all the data obtained.

5.3.2.4. Clustering

Data clustering is also necessary to understand which groups of data and which combinations of data are the most significant and influential on the results of using the platform. This process has been broken down into several steps, which are described below.

Figure 5.75 shows a mapping of the characterization of the features of the non-normalized data that were obtained during testing. This display is necessary in order to understand the general characterization of the dependencies between the data, and to preliminarily evaluate their group characteristics. It is also worth mentioning that in further calculations the column "Gender" will be removed due to its extremely low impact on the result.

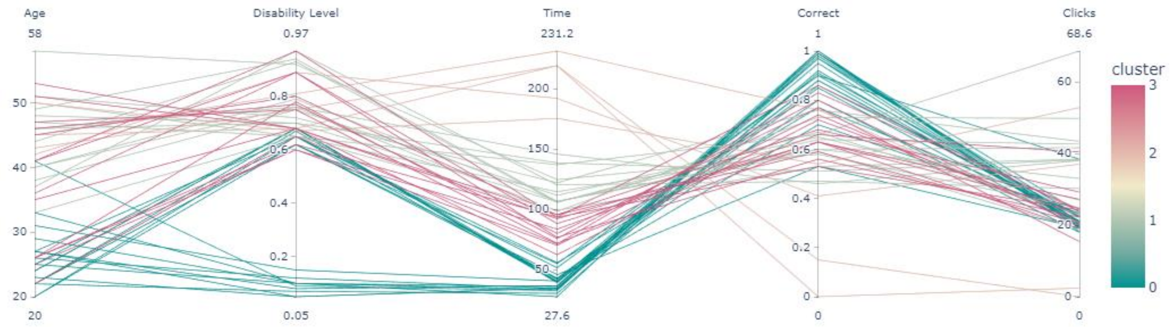


Figure 5.75. Functional display of the acquired data.

The first task in investigating the partitioning of data into clusters is to determine the optimal number of these very groups of data. One of the simplest and most accurate methods of determination is the "elbow method". It runs clustering on a data set for a range of k values. In this case, the standard range of 1 to 10 was taken due to the small amount of original data under study. Then for each value of k, it calculates the average score for all clusters. By default, the distortion score is calculated as the sum of squares of distances from each point to its center. This calculation results in the characterization shown in Figure 5.76.

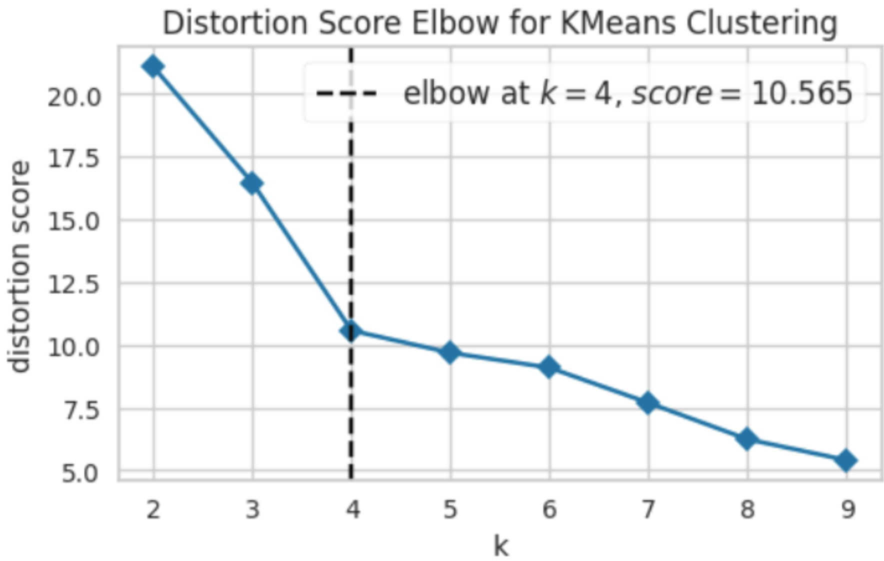


Figure 5.76. Result of determining the optimal cluster number.

As can be seen, the optimal number of cluster groups according to Figure 5.76 is 4 clusters. Next, we need to understand how similar the data points are to each other within one cluster (cohesion) compared to other clusters (separation). To do this, we need to calculate the silhouette parameter, which is demonstrated in Figure 5.77.

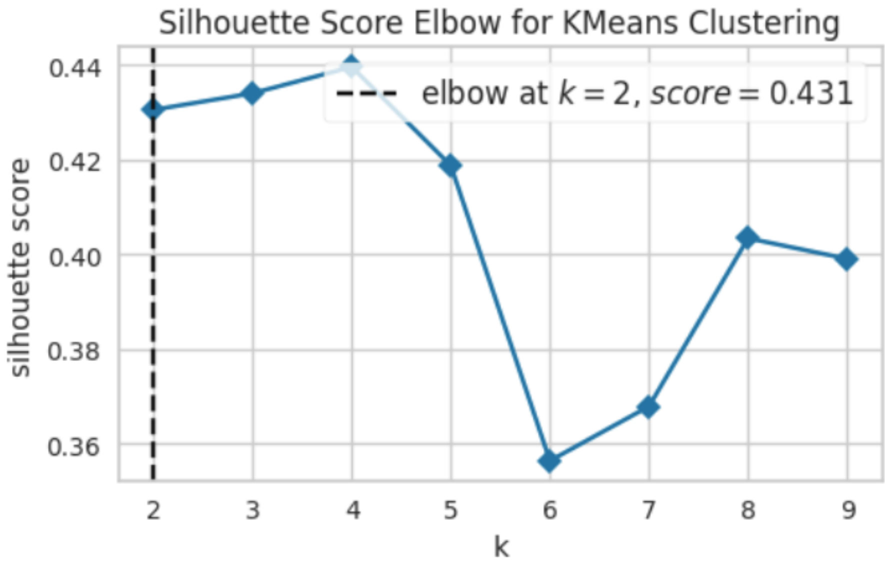


Figure 5.77. Result of determining the silhouette value of cluster groups.

The obtained value of 0.431 is an indication of the identity of the values in each cluster. According to the definition of the silhouette value, namely:

- The value of the silhouette coefficient is between [-1, 1].
- A score of 1 denotes the best, meaning that the data point is very compact within the cluster to which it belongs and far away from the other clusters.
- The worst value is -1. Values near 0 denote overlapping clusters.

The obtained value means the average degree of heaviness of points in different clusters.

Then, using the silhouette characteristic it is possible to estimate the real value of the optimal number of clusters and their weighting characteristics. The result of this operation is demonstrated in Figure 5.78.

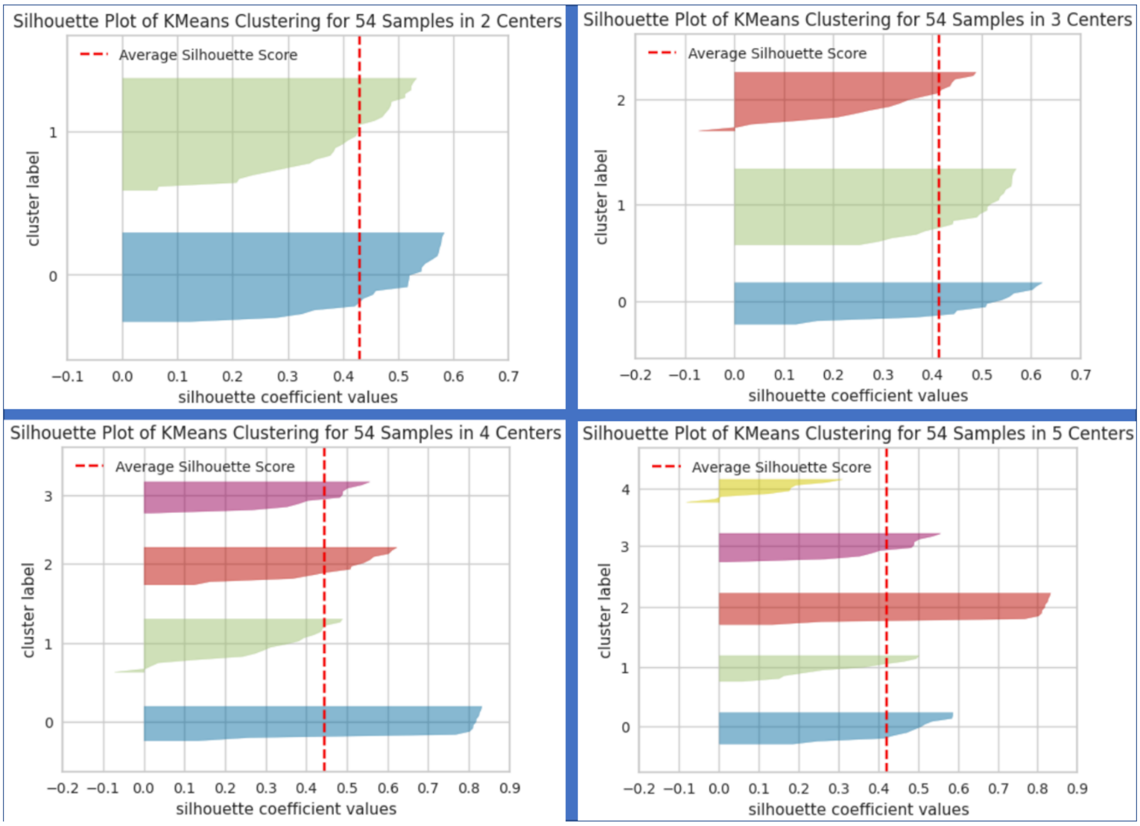


Figure 5.78. Examples of data distribution in different number of clusters.

As can be seen from Figure 5.78, the most optimal number of clusters is four. In addition, the importance of the data and key parameters included in the clusters and affecting the quality of the result is also an important parameter. The resulting matrix of these values with the temperature map is presented in Figure 5.79.

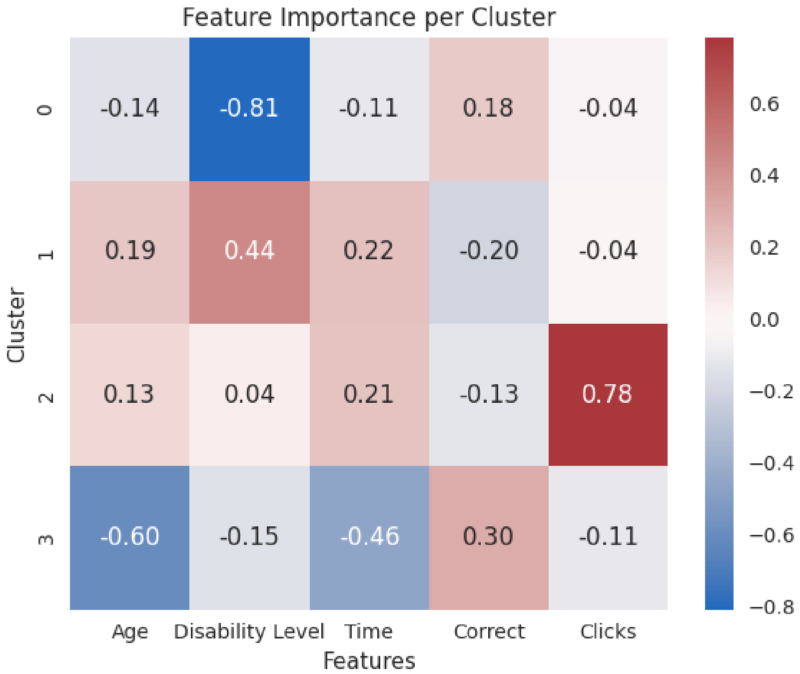


Figure 5.80. Matrix of parameter importance distribution on the result of the Cognitive Training Block performance.

As you can see from the figure, there are a total of 4 main parameters, confirmed in earlier data analysis, that affect user results: age, disability level, time and number of clicks.

5.3.2.5. Features Evaluation and Classification

In addition to the basic analysis, the previously obtained data also require a systematic test of the relationship between each other and the impact on the overall result. For this purpose, the obtained data set was analyzed by various statistical methods, including: Pearson correlation coefficient evaluation method, ordinary least squares (OLS), random forest method, support vector machine model.

During the validation, it was decided to exclude the parameter "Disability Level" from the initial parameters. This is explained as follows: if we imagine that in the initial data of the user there is no information about his/her disability state or parameter, then is it possible having the rest set of parameters to estimate their influence on the result. The magnitude of this impact, the quality and combinations of parameters that are key factors.

Therefore, by running the available results through the above evaluation models, the result demonstrated in Figure 5.81 was obtained.

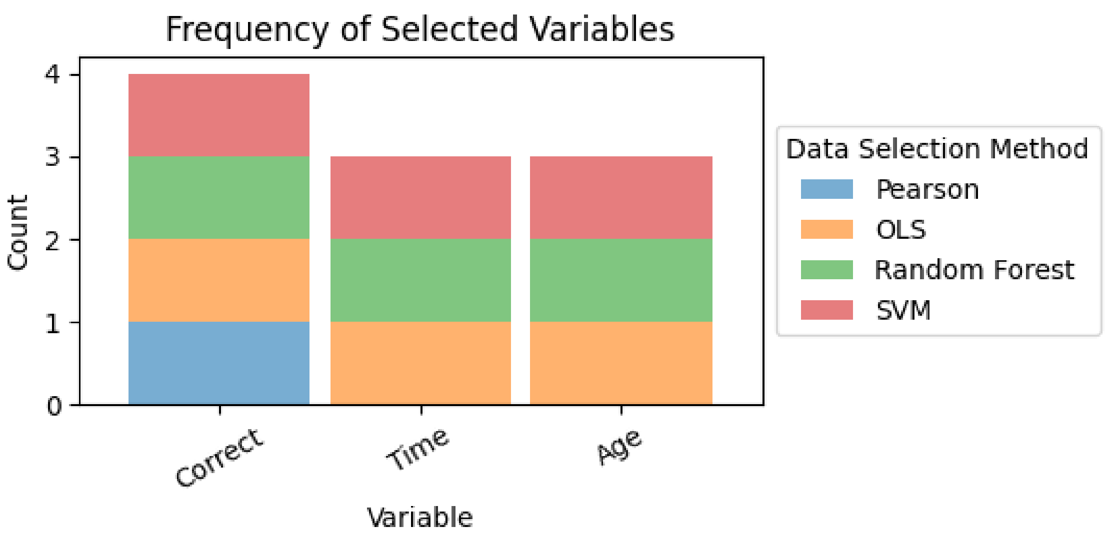


Figure 5.81. Graph of distribution of key values depending on sampling by proposed estimation algorithms.

During the course of the evaluation algorithms, those weighting values for each parameter were obtained, showing the impact on the overall state of the data and its sample. These are demonstrated in Table 5.3.

Table 5.3. Weighting coefficients of the influence of different parameters on the data sample.

	Pearson	**OLS**	**Random forest**	**SVM**
Age	5	3	3	2
Gender	5	5	5	5
Time	5	1	1	3
Correct	1	2	2	1
Clicks	5	5	5	5

According to the results obtained, it can be said that the parameter of Clicks and Gender can be neglected and their influence on the overall result can be considered to be extremely small. Nevertheless, for convenience, Figure 5.82 and Table 5.4 below show the Weighting Coefficients as well as the overall weighting of the parameters.

Table 5.4. Weighting coefficients of influence of key parameters on the data sample.

	Pearson	**OLS**	**Random forest**	**SVM**	**Rans Sum**	**Rank**
Correct	1	2	2	1	6	0.166667
Time	5	1	1	3	10	0.100000
Age	5	3	3	2	13	0.076923

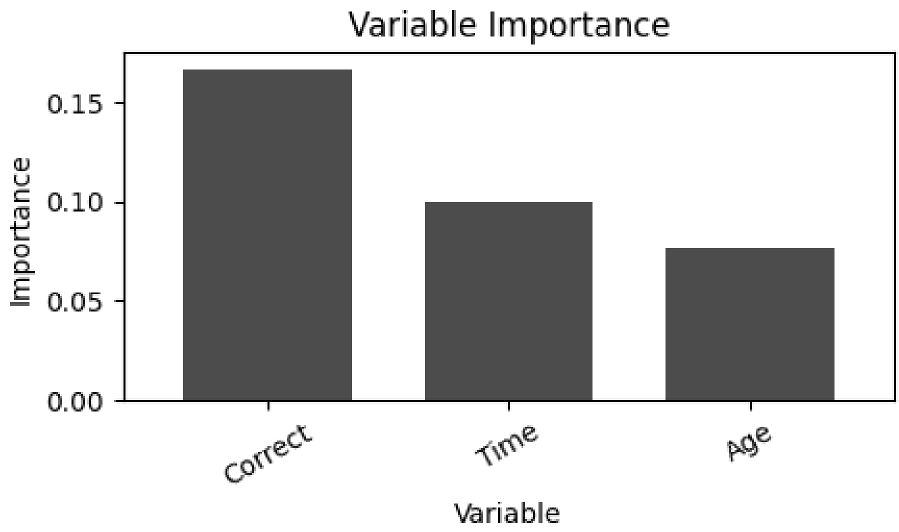


Figure 5.82. Graph of distribution of key parameters for the sample.

In addition, in order to fully observe how the parameters affect the outcome, it was decided to analyze the estimation of the models on different variants of the initial parameter combinations, the results of which are shown in Figure 5.83 and 5.84.

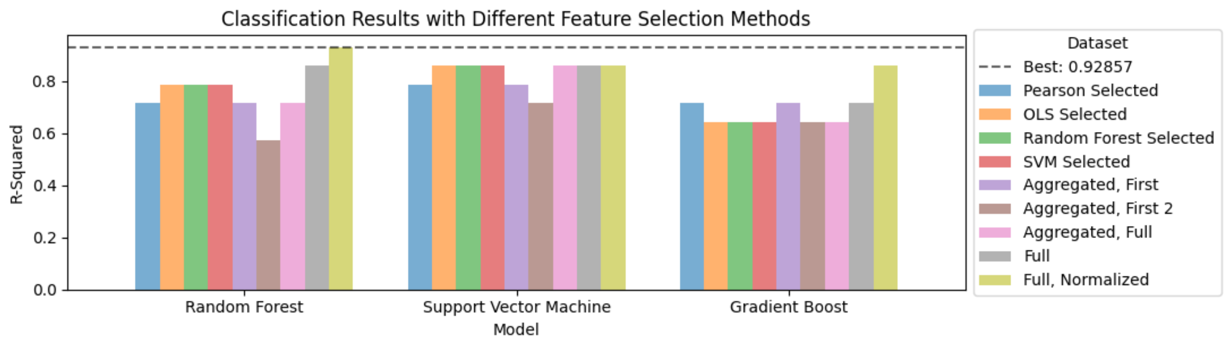


Figure 5.83. Graph of estimation of different combinations of data sampling.

Dataset	Random Forest Classifier	Support Vector Machine	Gradient Boost
Pearson Selected	0.714290	0.785710	0.714290
OLS Selected	0.785710	0.857140	0.642860
Random Forest Selected	0.785710	0.857140	0.642860
SVM Selected	0.785710	0.857140	0.642860
Aggregated, First	0.714290	0.785710	0.714290
Aggregated, First 2	0.571430	0.714290	0.642860
Aggregated, Full	0.714290	0.857140	0.642860
Full	0.857140	0.857140	0.714290
Full, Normalized	0.928570	0.857140	0.857140

Figure 5.84. Representation of the value of the impact parameters of a sample of different data combinations.

For this operation, the raw data were taken and normalized. Figure 6.54 and Figure 6.55 show that the highest average result is shown by the full combination of all parameters, which indicates the complexity and interrelation of all the parameters under study, albeit to different degrees.

5.3.2.6. Subjective User feedback

In order to better evaluate the results of the presented Cognitive Block, all users were asked for their opinions and suggestions regarding their interaction with the system. Appendix C presents an example of a questionnaire that was given to each player after completing the activities. The method of questioning the users was in the form of evaluating different parameters of the game, specifically 7:

- I found the application easy to use
- I found the application complex and I need help from another person.
- I found it fun and entertaining.
- I think it is heavy or boring
- The examples in the game helped me to know how to play.
- I liked the pictures and images
- The audio sound helped me to understand the game.

In addition to this, there were 2 questions to be answered in a detailed form (as much as possible). The questions were of the following nature:

1) Comments (games that you liked the most, the easiest or most difficult games, the most fun or other things that you want to comment).
2) Other observations: would you add anything else to the application or games.

The answer to the first 7 is a list of 4 variants: Strongly Agree, Agree, Disagree and Strongly Disagree.

After evaluating all the questionnaires, users are mostly satisfied with the app presented to them, in particular the possibility to choose avatars, the structure of the levels and the pleasant visual design of the Cognitive Block. Of the improvements, users mostly talk about more music, more color variations and a simpler hint system.

5.3.2.6 Study perspectives according to results

After results evaluation obtained, it is important to consider the prospects and options for the use of systems such as the one presented in this study. The perspective study allows to answer several questions at once, among them the feasibility of the research, the possibilities for future applications and development, and will also help to evaluate the main features of this kind of applications. In the following, the different areas and aspects of helper applications will be discussed, examples of their use, and the strengths and weaknesses of such systems will be presented.

1) Attraction and Motivation:

Perspective: Serious games provide a fun and interactive environment that can improve patient motivation.

One of the main problems of any rehabilitation or training application is its basic essence, namely, repetitiveness. Depending on the intensity, nature and duration of rehabilitation or training, sooner or later a situation arises where the subject of these activities becomes less and less willing to repeat the prescribed actions. This happens for various reasons, mainly due to the monotony and simplicity of the actions. Because of this, different people experience different degrees of decreased motivation and, consequently, different effectiveness of rehabilitation or training activities.

In order to circumvent this problem, it is advisable to use assistant applications that make routine, for example, physical exercises meaningful and responsive to the tasks assigned to the user. As an example, the use of Virtual Reality (VR) or Augmented Reality (AR) technologies or the principles of specialized computer game applications can make rehabilitation activities more interesting, encouraging patients to participate more actively in therapy sessions. In essence, these platforms allow for some sort of disguise of common exercises or tasks so that the user does not realize they are performing any medical or educational activity.

In the process of development and testing of the developed system, it was discovered that users are much more willing to use those methods of rehabilitation or educational activities that are presented in the form of a computer game. Subsequent surveys and questionnaires confirmed that such methods are much more interesting to users, and they are more motivated and willing to perform the prescribed procedures for longer periods of time. In addition to this, users had a higher morale, which indicates that the use of modern technological approaches in medicine and education has a good perspective.

2) Individualization and Personalization:

Perspective: Serious games allow for customization of rehabilitation and training programs according to the individual needs of the user.

The use of various tools for creating computer applications allows for different levels of task customization, thereby increasing user engagement in the gaming process. There can be many levels and methods of customization of a particular task for the user and all of them will be very different from each other depending on the task.

For example, in terms of the complexity of execution of both individual levels and the system as a whole, there are various models of algorithm construction, schematically demonstrated in Figure 5.85, and representing the conditional execution of the functional logic of a task.

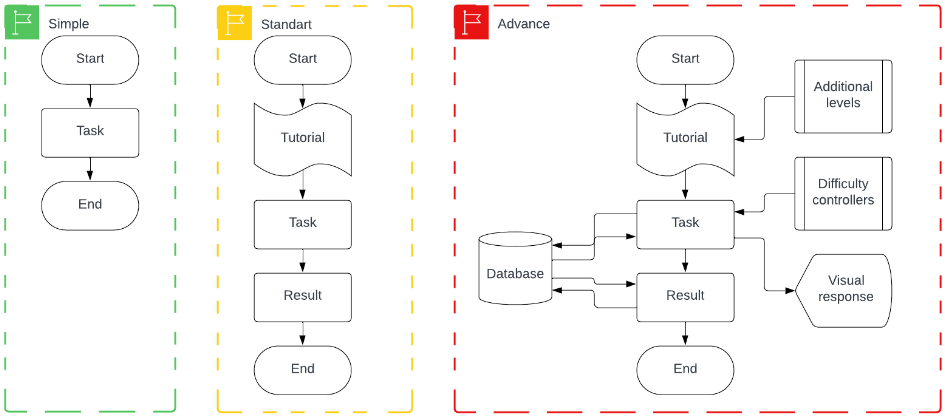


Figure 5.85. An example of the complexity of the component arrangement of functional tasks in rehabilitation or training applications.

As can be seen from Figure 5.85, the same task, depending on various factors, can be performed in different variants with different levels of functional complexity. It may include only minimally necessary components or a whole set of various components that are often not visible to the user.

The second option of adapting the application to the user are built-in algorithms that allow to directly adjust the parameters of the task set for the user. There are 2 main mechanisms for this: direct and indirect influence. In the first case, the parameters are adjusted directly during the game, in the second case - before or after the end of the activity.

The third way of adaptation is through visual and audible adjustments. Depending on the progress and process of the task, the app responds to the progress in different ways, letting the user know whether he or she is performing the task correctly or not.

All three of these options are often used in combination, to increase the quality of response and feedback between the app and the user. In the long run, even using visual personalization and indication methods alone can provide a good level of increase in user results. This will not only have a positive impact on training results, but will also motivate users to return to the app repeatedly.

3) Training of Functional and Cognitive Tasks:

Perspective: Serious games can simulate real-life scenarios, providing training in functional skills.

Simulations of everyday activities, such as cooking, for example, help patients train specific movements necessary for daily life. At the heart of such applications is the principle of recreating different kinds of everyday, or specialized, activities that the user must repeat. The closer the player's actions match the necessary ones, the better the results will be.

This method is useful primarily because it directly affects coordination as well as the user's ability to memorize complex sequences of actions. This is particularly relevant to support cases of cognitive problems responsible for memory. In such cases, constant practice can either maintain a particular level of cognitive state of the user or slow down the deterioration of that state through constant repetition. Such methods are fully practiced in the treatment of age-related dementia, the effects of strokes, and other similar cognitive problems.

The prospect of applications based on this method will make it possible to control the speed and quality of a particular user's progress within the limits required in a given situation. In addition, the meaningfulness of tasks, as well as maximizing their approximation to real actions in the perspective increases the motivation to perform them repeatedly and higher moral satisfaction from the process.

4) Remote Rehabilitation:

Perspective: Serious Games facilitates remote access to rehabilitation by providing the opportunity to engage in therapy outside of traditional clinical settings.

It is often the case that a user is unable to be directly physically present at a medical facility, for example, due to various reasons: age, current health status, unforeseen circumstances, and so on. Nevertheless, in today's reality, this problem can be easily solved thanks to remote access technologies. Mobile gaming exercises allow users to continue rehabilitation at home, ensuring continuity of care.

Advances in data exchange technologies allow tutors and doctors to literally monitor the results of any user in real time and correct their actions directly during the performance of tasks by means of audio or video communication, as well as direct prompts within the application.

The prospects of this approach also lie in the fact that it is not uncommon for users to be extremely uncomfortable in medical or training facilities. At the same time, in a familiar home environment the motivation to perform the prescribed actions is much higher, as well as the end result itself. Therefore, this approach of remote training is quite effective in some cases.

5) Data Collection and Monitoring:

Perspective: Serious games provide the opportunity to collect and analyze patient performance data.

One of the most important parts of any training or rehabilitation endeavor is the collection of relevant and accurate data about the user's actions. In addition to visual assessment by experts, it is important to clearly understand the degree of progress and quality of task performance. There are several techniques and methods for this purpose.

The first main way is to use sensors embedded in gaming devices that can track movements and provide objective data to assess progress and adjust training and rehabilitation plans. This can be both physical data of movements, the work of certain organs (heartbeat, respiration, blood pressure), and physiological data, up to the composition and quality of blood, hormones and so on. This method is quite complicated in terms of setting up all the necessary sensor systems, besides, it requires the constant presence of specialists. In addition, it is inconvenient for the user in terms of both physical convenience and the need to use additional devices, but it allows you to get the widest range of information. This method is mainly used in some specific or severe cases, when the user needs a special support program.

The second method, which is simpler and less costly, is used in general cases where it is sufficient to track only basic parameters, such as time to complete a task, in order to understand the picture of rehabilitation processes. It is based on tracking those parameters that can be obtained by software methods, such as various counters, built-in data analysis algorithms, or more advanced neural networks and artificial intelligence. With a minimum of input data, they are able to calculate in real time the basic parameters of movements, times, results, and so on.

The prospect of using systems based on neural networks and artificial intelligence has recently justified itself more and more strongly. Taking into account the features of such algorithms, they are already demonstrating the ability to replace some types of sensors, which 10-15 years ago were necessary to analyze physical parameters

5.4 Summary

In the course of this research phase, the basic structural and conceptual design of the Cognitive Block of the system was developed. In addition, an algorithm for analyzing results and adapting the game to the realities and progress of the user was developed and tested.

This section demonstrates the structural and conceptual view of the Cognitive Block of the system presented in the thesis. Examples of visual and structural execution of each level are provided. A total of 2 full levels with 5 tasks in each level are activated in the shown version of the application. In addition, the structure of recording and data exchange between the system and the server storage is demonstrated.

6

Conclusion

This section presents the most relevant conclusions that follow from the work done and the analysis of its results.

This thesis presents a system developed from scratch that is able to act as an assistant application for users suffering from various musculoskeletal problems as well as cognitive features. The work has developed such a platform consisting of two blocks, Physical and Cognitive, which are designed to support and train the relevant aspects suffered by different populations, namely the elderly and people requiring special care.

In addition, the study was conducted to investigate the feasibility and effectiveness of using additional computer technologies such as neural networks, artificial intelligence and other similar algorithms in the physical and cognitive rehabilitation of patients. Using various tools for integrating such systems into the computer game development environment, it was possible to fully reproduce, test and analyze the effectiveness of such systems belonging to the family of medical Serious Games.

Also based on the hypotheses that were defined in Section 1, it follows that:

The introduction of modern information technology in the medical field increases the effectiveness of treatment and support.

Rehabilitation methods using complementary software and hardware may be more effective than traditional methods.

The use of additional high-level software systems (Neural Networks) increases the effectiveness and simplifies the process of rehabilitation measures.

From the results obtained in the previous sections, it can be said that in modern rehabilitation practice, various assistant systems using additional embedded neural network and artificial intelligence algorithms demonstrate quite high efficiency and help to improve the results of long-term rehabilitation measures. In addition, such systems are convenient for simplifying the measures themselves from the material aspect, as well as simplifying the systematization of results for further processing by doctors/mentors.

6.1 Discussion

Thanks to the results obtained during the research and their analysis, it is possible to have an informed discussion about the perspectives and possibilities that the developed platform is able to provide. Since, as in the past, both parts of the system, namely the Physical and Cognitive blocks were presented separately, in this case the discussion of the possible perspectives of both blocks will be presented together in most cases.

Generally speaking, thanks to the variety of technical and program solutions, it is possible to find an activity for almost any type of rehabilitation procedure. This applies, for example, to help with problems in the upper limbs [129, 133, 134], lower limbs [132, 135] or the whole body [127, 128, 136]. The same applies to cognitive rehabilitation [137 - 140]. The variability in the methods used in these studies also allows the rehabilitation process to be adapted as efficiently as possible. These include the use of special tracking tools such as the Kinect system or virtual reality interfaces [127, 129, 131, 134, 135] and neural networks to avoid the need for additional sensors [128, 136]. Separate cases of such embedded systems are also the use of hidden fuzzy logic algorithms and limited artificial intelligence [141 - 142].

Since the system presented in this study also has its own features, it is possible to compare it with the above-mentioned solutions. This should be done in terms of several aspects that touch on different sides of the platforms.

Technical side. Includes additional peripherals or technical devices. If we turn to this case, it is worth comparing what additional tools and sensors were used in different approaches and what was the rationale behind this decision. At the very beginning of the study, one of the key objectives was set at the goal-setting stage - to create a system that is as convenient and simple as possible, without requiring any additional manipulation on the part of the physician or users. Such a technical solution already offers certain advantages, in contrast to variants where a virtual reality system [127, 133], Kinect or Wii platform [131, 134], additional camera systems and additional hardware [127, 135] were used. Avoiding additional sensors offers an advantage in terms of affordability as well as the long-term relevance of the platform. For example, Microsoft Kinect and Nintendo Wii have been discontinued and unsupported since 2017 and 2013, respectively.

The same applies to the Cognitive Unit, which as in the example from [143] should have the highest possible mobility and usability. The platform presented in the study does not require any additional peripherals except for a webcam, which is a very common and cheap device, and in the case of mobile platforms is already part of the device. This makes the system not only as financially affordable as possible, but also easy to install and use.

Visual side. Undoubtedly, the visual part of the platform fulfills a very important function, namely to attract the player and motivate him to return to the game. In the case of the developed platform, it was decided to make the player a part of some small story, in which he is directly involved. Unlike other solutions [129, 133-135], where the player simply performs tasks and exercises related to only one general style or has no thematic activities at all [128, 136], our platform offers a small adventure, which makes the system more interesting. However, this only applies to the Physical block.

The cognitive block also has a history and a certain form of user involvement, but the visual aspect, due to the specificity and direction [145] the visual part should be as simple and clear as possible, but at the same time functional and attractive [144].

In addition, this form of exercise presentation, having a beginning and an end goal, is designed to help the player psychologically. The theme of traveling, in the case of both blocks of the system is chosen precisely because of the possible limited mobility of the players, taking into account the age category and general level of ability in addition to the peculiarities of the location, and thus helps to try themselves in an activity that is not normally available to humans, albeit not to the fullest extent. And this, in turn, has a positive effect on their mental state.

Algorithm used. The motion recognition algorithm built into the Physical Unit is based on a neural network, and this solution has both pros and cons. Unlike Kinect technologies [131, 134], where a 3D image is constructed using a depth camera system, or virtual reality systems [127, 133], where operation is based on continuously reading the position of sensors inside the helmet and controllers in addition to constructing a volumetric image using a camera system, neural network-based solutions are quite dependent on external parameters. These include the quality of illumination, the positioning of the player in front of the camera, and the quality of the processed image. Because of this, and in order to obtain the most correct data, additional rules for working with neural network-based systems need to be introduced and observed [128, 136].

The cognitive block also has an algorithm of limited artificial intelligence, which, unlike neural networks, is less dependent on conditions and influences of external factors. However, most of the presented solutions, such as [146 - 148], are based only on standard program algorithms. The presented study, on the other hand, utilizes a system that adapts itself to the specific situation and user, which improves the response.

Such solutions not only simplify the use of the platform itself, but also allow the end user or mentor/physician not to waste time on additional sampling and processing of results. This kind of system achieves the principle of "Install - Run - Use".

Medical focus and value to physicians. This item is mainly characteristic of the Physical Unit only. The proposed system is designed to support and rehabilitate mainly elderly people, although it can also be used for patients with minor musculoskeletal problems. The choice of exercises and their focus is based on the principle of "a little bit of everything", in contrast to systems that target a specific part of the body, such as the upper [129, 131, 133] or lower [127, 135, 136] limbs.

In terms of the value of the system to the medical staff, the platform acts as a tool for systematizing information, allowing the clinician to more accurately and better track the patient's recovery progress and overall activity scores. The main feature is that, unlike some similar systems [128, 133, 135], direct involvement of the treating physician in the gameplay process is not required. All the obtained data can be viewed and studied at any time, thanks to the cloud interface, where this information is duplicated, as, for example, in the solution [128].

Cognitive focus and effect. As stated earlier in Section 2, both units can be used in tandem or as two independent applications. However, both have a definite impact on the cognitive component.

The physical block does so to a much lesser extent than the cognitive block, but the impact is still there. For example, on a number of solutions [129, 131, 136], in addition to physical parameters and general motor skills, the exercises also improve the connection between motor skills and the task to be performed. For example, in the first level, where it is necessary to describe a movement in the form of an infinity sign, this movement is associated with the inverted number 8, the movement should be performed from left to right, 10 times, then do the same with the other hand and in the other direction. The same with other levels, but including their peculiarities. Such chains generate sequences in the memory and associative thinking of the user, which positively affects his condition and increases the level of subsequent results.

Regarding the Cognitive Block, in this case each exercise and each activity is aimed at training one or a complex of cognitive and executive functions [145].

Results and effectiveness. Given the specifics of the presented study, it is difficult to compare it with the results obtained with similar solutions. Despite the fact that the effectiveness of the gaming platform increases the patient outcome from 30 to 50% depending on the level and activity, the value in this case does not show the specific rehabilitation potential of the system. There are several reasons for this.

First, whereas in studies like ours, it was the rehabilitation performance that was the main parameters for evaluating the effectiveness of the system, and it was the result of the rehabilitation activities that were compared and evaluated, in our case the signals into which the system transforms the player's performance are investigated. Therefore, in this case it is the indicators of the received signals, such as amplitude-frequency characteristics, time indicators, ratios of responses (for the Cognitive Block) and the number of movements, and so on, that are important for the presented study. It is this comparison that is the basis for the work of the presented platform.

Secondly, due to the situation related to the COVID-19 pandemic, it was not possible to conduct tests with the target population in the Physical Block. Considering that the study involved young people (21 to 42 years old), the results obtained from them are not entirely accurate, but at the same time extremely useful for further research. Even though later, another group of 5 people of the required age segment was selected, this number of subjects is not sufficient for a clear assessment.

Third, which follows from the first point, based on the results obtained, it proved to be an inappropriate decision to study indicators such as Activities of Daily Living (ADLs), Cognitive Function Scale (CFS), Nottingham Health Profile (NHP) [136]. This is because it is incorrect to compare the performance of healthy young people with that of older people. This is also true to some extent for the cognitive aspect. The results show that even in the presence of cognitive features, the age of the users also had a significant influence on the final result.

However, the platform presented in this study is already showing quite a bit of promise for use in physical and cognitive rehabilitation and support for users.

Emotional component. During platform testing, most players indicated that performing physical and cognitive activities in the form of a computer game was a more interesting experience for them than conventional interpretations of these activities. In this study, the emotional state of the participants after playing the game was only investigated upon completion of the Cognitive Block, since in the case of the Physical Block, the emotional background is a side effect of using the system and not a direct parameter investigated. Nevertheless, the feedback from the users was 90% positive, with only a few wishes. Also, all users showed an increased desire to return to the platform offered to them and to perform the necessary tasks with great enthusiasm.

6.2. Achievements

This dissertation work has made some contribution to the analysis and systematization of the development techniques of the Serious Games family of systems for rehabilitation and support. By analyzing the development techniques, basic mechanics and options for the use and integration of neural networks, it was possible to create the most suitable system in terms of structure and functionality for use in the investigated area.

In terms of the two parts (blocks) of the platform, the following work was done:

- For the Physical Block the following was performed: The task of developing and training a neural network model for processing and recognizing a human figure on a webcam screenshot, its optimization and implementation in the Unity development environment. After that, based on a set of exercises developed by physiotherapists (Cruces Hospital), a computer game of the Serious Games type was created. In the process of testing 10 people of the control group and 5 people of the target group were involved, who in several stages tested the game for a certain period of time. The result was a ready and customized training and support system for elderly people with musculoskeletal problems. This platform became part of the AAL European project titled "frAAgiLe" platform for detecting and preventing frailty and falls.

- For the cognitive unit: In collaboration with a team of researchers in cognitive analysis and rehabilitation from Barcelona's Ramon Llull Universitat, a specific methodology was developed to design and train patients with cognitive disabilities, which was further adapted to the form of Serious Games. Comprising 2 levels with five activities in each, this platform was developed, customized and tested with the help of a total of 54 users with different levels of cognitive impairment. This system was also part of the ACM project called "eMotivaMente".

6.3. Scientific contribution

In the process of research and development of the system presented in this thesis, certain research investigations were carried out, which in the process of research were formed into separate articles and published in scientific publications. Conditionally, all publications can be divided into two types: the first one is publications in scientific journals with impact factor Q1-Q2; the second one is publications at scientific conferences. All these activities were published during the PhD activity at the Universidad de Deusto. All these contributions are summarized below.

6.3.1. Articles in international journals with impact factor

The first paper demonstrated in Table 6.1 is the technical description and results of the Physical Unit of the developed system.

Table 6.1. Publication details.

Title	Biofeedback Applied to Interactive Serious Games to Monitor Frailty in an Elderly Population.		
Authors	Shapoval, S., García Zapirain, B., Mendez Zorrilla, A., & Mugueta-Aguinaga, I.		
Journal	Applied Sciences, MDPI		
Date	14.04.2021		
Impact Factor	3.674 (2021)	Quartile	Q2
DOI	https://doi.org/10.3390/app11083502		

The second article presented in Table 6.2 is a systematic review on the Serious Games family of solutions in the support and rehabilitation of people with cognitive disabilities.

Table 6.2. Publication details.

Title	Serious Games for Executive Functions Training for Adults with Intellectual Disability: Overview		
Authors	Shapoval, S., Gimeno-Santos, M., Mendez Zorrilla, A., Garcia-Zapirain, B., Guerra-Balic, M., Signo-Miguel, S., & Bruna-Rabassa, O.		
Journal	International Journal of Environmental Research and Public Health		
Date	09.09.2022		
Impact Factor	4.614 (2022)	Quartile	Q1
DOI	https://doi.org/10.3390/ijerph191811369		

The third publication is a Scoping review article, and is published as a chapter in the book Health research: current challenges and future perspectives 3, published by Atena Editora em. At the time of this description, this article has been approved and is awaiting publication and the book itself. The tentative release date is June 2024. Basic information is described in Table 6.3.

Table 6.3. Publication details.

Title	Solutions to support and rehabilitate older adults: Scoping Review		
Authors	Shapoval, S., Mendez Zorrilla, A., Garcia-Zapirain, B.		
Book	Health research: current challenges and future perspectives 3		
Date	20.05.2024 (Accepted for publication)		
Impact Factor		Quartile	
DOI			

6.3.2. Communications in international conferences

Additionally, as an initial interpretation and demonstration of the first results of the Physical Block of the system, a paper was published at an international scientific conference, presented in Table 6.4.

Table 6.4. Publication details.

Title	eSail: a body tracking interactive game for elderly and patients with locomotor system problems
Authors	Shapoval S., Garcia-Zapirain B., A. Mendez-Zorilla, I. Mugueta-Aguinaga
Journal	IEEE International Symposium on Signal Processing and Information Technology (ISSPIT) 2020
Date	09.12.2020
DOI	10.1109/ISSPIT51521.2020.9408980

In collaboration with Zabit Hameed, another paper was published at a scientific conference, the essence of which was to create an algorithm for sorting and interpreting information. In subsequent work, the developments of this algorithm formed the basis of the Cognitive Block systems. The work is summarized in Table 6.5.

Table 6.5. Publication details.

Title	Sentiment Analysis Using an Ensemble Approach of BiGRU Model: A Case Study of AMIS Tweets
Authors	Hameed Z., Shapoval S., Garcia-Zapirain B., A. Mendez-Zorilla
Journal	IEEE International Symposium on Signal Processing and Information Technology (ISSPIT) 2020
Date	09.12.2020

DOI	10.1109/ISSPIT51521.2020.9408866

It is also worth mentioning that at the time of writing this section, the authors have been accepted for presentation at the British Society of Gerontology 53rd Annual Conference, which will be held in July 2024.

Table 6.6. Publication details.

Title	Serious Games based platform for training and support Cognitive and Executive function for Elderly
Authors	Shapoval, S., Gimeno-Santos, M., Mendez Zorrilla, A., Garcia-Zapirain, B., Guerra-Balic, M., Signo-Miguel, S., & Bruna-Rabassa, O.
Journal	British Society of Gerontology 53rd Annual Conference
Date	July 2024
DOI	

6.4. Limitations

Unfortunately, there were certain difficulties and failures during the research and development of the system, which are also worth mentioning in the thesis. For example, during the development of the Physical Training Block, testing of the model and neural network operation had to be postponed and redone several times. This was due to several factors: firstly, the peak of development fell on the world pandemic COVID-19, which caused difficulties in development (impossibility to use the necessary equipment, as an example) and testing due to isolation. Secondly, given the target audience, testing with a control group was postponed several times and redesigned many times, again due to the characteristics of the audience itself. In addition, it was not possible to recruit enough users of the target audience at the time of working on the block. In addition, it can be said that it would have been more effective to use the model for a longer time than it was used.

As for the Cognitive Training Block, the main problem in this case was the correct setting of the difficulty control algorithm, as well as the general initial parameters of the system. In addition to this, there were problems with the target audience itself, in the sense that it was necessary to find a sufficient number of players and organize the testing processes. Despite the fact that in the end it was possible to recruit 54 people for the tests, it was still not enough to get a complete picture of the block's operation.

6.5. Recommendations for future research

This thesis proposes a variant of an assistant system that is designed for training and rehabilitation of elderly people with musculoskeletal problems as well as for people with different levels of cognitive disability. Although it is already fully functional and ready to use, there are certain aspects that will help to improve the developed platform more.

First of all, in order to choose the initial parameters of the system more precisely, more extensive tests should be carried out. Considering that 15 and 54 people were recruited for the two Blocks, this number is not enough. If the number of users is increased by a factor of 2-4, it becomes possible to conduct a much more comprehensive analysis of the data. Sampling and classifying a larger amount of data would allow for a more accurate selection of exercise and task parameters and better tailoring of the system to the specific capabilities of the users.

In addition to this, it will be extremely useful to conduct tests in a long-term mode. In the course of development, we have been able to conduct tests with the minimum required duration. However, rehabilitation and training activities often last for a long period of time. Therefore, using the system, for example, for a month will allow us to better understand the specifics of the work and the real increase in the results of users.

Also, in the course of the research, quite specific groups of people were chosen as target audiences, selected according to clearly defined criteria. For the first preliminary stages, this is quite acceptable, but it is also interesting when users go beyond the parameters according to different criteria (physical or cognitive). In this case it is interesting how the system will behave in a situation different from the original criteria, and what qualitative result it will show in this case.

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Appendix A

№	Reference	Title of selected dtudy	Results Description
1	*Avola 2019* *[149]*	An interactive and low-cost full body rehabilitation framework based on 3D immersive serious games	Increase in rehabilitation rates by an average 15%
2	*González-González 2019* *[150]*	Serious games for rehabilitation: Gestural interaction in personalized gamified exercises through a recommender system	Gestural exercises yielded higher percentages of task completion (> 83%) and task effectiveness (> 63%).Eye fatigue(x = 3.15; SD = 0.37). Accurate point is above average (x = 2.57; SD = 0.60)
3	*Amengual Alcover 2018* *[151]*	PROGame: A process framework for serious game development for motor rehabilitation therapy	Usage of interaction objects related to patient interests; patients performed the rehabilitation activity 13.5% faster than when the objects did not represent such interests
4	*Meijer 2018* *[152]*	Systematic review on the effects of serious games and wearable technology used in rehabilitation of patients with traumatic bone and soft tissue injuries	Serious games seem a safe alternative or addition to conventional physiotherapy following traumatic bone and soft tissue injuries.
5	*Morando 2018* *[153]*	Definition of motion and biophysical indicators for home-based rehabilitation through serious games	Most games whithin this system are nearly useless for supervised analysis.
6	*Tăut 2017* *[154]*	Play seriously: Effectiveness of serious games and their features in motor rehabilitation. A meta-analysis.	Overall moderate effect of SGs on motor indices, d = 0.59, [95% CI, 0.48, 0.71], p < 0.001
7	*Sánchez-Herrera-Baeza 2020* *[155]*	The Impact of a Novel Immersive Virtual Reality Technology Associated with Serious Games in Parkinson's Disease Patients on Upper Limb Rehabilitation: A Mixed Methods Intervention Study	Good result in strength improvements, coordination and dexterity, and speed of participants. No side effects.
8	*Postolache 2019* *[156]*	Serious Games Based on Kinect and Leap Motion Controller for Upper Limbs Physical Rehabilitation	A study of the feasibility and effectiveness of supplementary remedies on the results of rehabilitation of upper limb problems. Verification of further effectiveness.
9	*Ling 2017* *[157]*	Usability test of exercise games designed for rehabilitation of elderly	The results showed that s, 75% to 100% of the patients experienced high levels of

		patients after hip replacement surgery: Pilot study	enjoyment in all the games except the squats game
10	*Palestra 2019* *[158]*	Evaluation of a rehabilitation system for the elderly in a day care center	Performance of the postural response is improved by an average of 80%
11	*Wu 2018* *[159]*	Understanding Older Users' Acceptance of Wearable Interfaces for Sensor-based Fall Risk Assessment	System implemented in this study achieved high user acceptance (Hypothesis H1), and participants consider the fall risk estimation useful and the accessibility is appreciated.
12	*Graf 2020* *[160]*	Playing in Virtual Nature: Improving Mood of Elderly People Using VR Technology	Significant reduction of the elderly people's anxiety regarding the VR technology
13	*Shahmoradi 2022* *[161]*	A Systematic Review on Serious Games in Attention Rehabilitation and Their Effects	A systematic review of solutions aimed at training and development of different program solutions in different settings and for different rehabilitation problems of the elderly.
14	*Kondragunta 2019* *[162]*	Estimation of Gait Parameters from 3D Pose for Elderly Care	The necessary key joint for gait parameter estimation are selected and the projection of those key joints into a 3D environment is done. Some gait parameters that are useful to analyze the gait of a person are estimated
15	*Brauner 2020* *[163]*	Serious Motion-Based Exercise Games for Older Adults: Evaluation of Usability, Performance, and Pain Mitigation	Study shows two games, that were evaluated as easy to use and fun to play. Both game interventions had a strong pain-mitigating effect in older adults
16	*Gonzalez-Bernal 2021* *[164]*	Influence of the Use of Wii Games on Physical Frailty Components in Institutionalized Older Adults	A Wii Fit® console intervention for 8 weeks improved walking speed, static balance, and reduced falling risk and frailty levels in institutionalized older adults
17	*Kwan 2021* *[165]*	Feasibility and Effects of Virtual Reality Motor-Cognitive Training in Community-Dwelling Older People With Cognitive Frailty: Pilot Randomized Controlled Trial	VR simultaneous motor-cognitive training is effective at enhancing the cognitive function of older people with cognitive frailty
18	*Yu 2021* *[166]*	Randomized Controlled Trial on the Effects of a Combined Intervention of Computerized Cognitive Training Preceded by Physical Exercise for	Improves frailty status and cognitive function of community-dwelling older adults,

		Improving Frailty Status and Cognitive Function in Older Adults	
19	*Afyouni 2020* *[167]*	Adaptive Rehabilitation Bots in Serious Games	Feasibility and user experience measures were collected, and the results of experiments show that patients found our game-based adaptive solution engaging and effective, and most of them could achieve high accuracy in performing the personalized prescribed therapies.
20	*Parke 2018* *[168]*	Age-related physical and psychological vulnerability as pathways to problem gambling in older adults	Study provides a significant novel contribution to understanding pathways that account for the development and maintenance of problem gambling in older adult pop
21	*Chu 2021* *[169]*	Exergaming Platform for Older Adults Residing in Long-Term Care Homes: User-Centered Design, Development, and Usability Study	Study demonstrated that an exergaming platform could be co created with LTC home residents with multiple cognitive and physical impairments, who are a challenging group to engage in research
22	*Oliviera 2021* *[170]*	Feasibility, safety, acceptability, and functional outcomes of playing Nintendo Wii Fit Plus™ for frail elderly: study protocol for a feasibility trial	The current study is designed to evaluate the feasibility, safety, acceptability, and functional outcomes of playing NWFP for frail older adults
23	*Lunardini 2020* *[171]*	2D Virtual Reality-Based Exercise Improves Spatial Navigation in Institutionalized Non-robust Older Persons: A Preliminary Data Report of a Single-Blind, Randomized, and Controlled Study	Virtual reality-based exercise improves the spatial navigation of institutionalized non-robust older persons.
24	*Tuena 2020* *[172]*	Validity and usability of a smart ball–driven serious game to monitor grip strength in independent elderlies	Game specifically designed to measure age-related muscle weakness while engaging elder users in a compelling activity.
25	*Mugueta-Aguinaga 2019* *[173]*	Usability Issues of Clinical and Research Applications of Virtual Reality in Older People: A Systematic Review	-
26	*Lin 2020* *[174]*	Development and Evaluation of a Computer Game Combining Physical and Cognitive Activities for the Elderly	This system simultaneously combines musical rhythm games with exercises for cognitive training, while the exercises are designed to correlatively combine

			movements with the concept of acupressure points.
27	*Cuesta-Gómez 2020* *[175]*	Effects of virtual reality associated with serious games for upper limb rehabilitation inpatients with multiple sclerosis: randomized controlled trial	An experimental protocol using an LMC based Serious Games designed for UL rehabilitation showed improvements for unilateral gross manual dexterity, fine manual dexterity, and coordination in MS patients with high satisfaction and excellent compliance
28	*Shimada 2019* *[176]*	Prevalence of Psychological Frailty in Japan: NCGG-SGS as a Japanese National Cohort Study	Defined psychological frailty as the co-presence of physical frailty and depressive mood
29	*Zacharaki 2020* *[177]*	FrailSafe: An ICT Platform for Unobtrusive Sensing of Multi-Domain Frailty for Personalized Interventions	The system consists of an integrated platform that aims to early detect frailty in the older people through the use of ICT technologies equipped with artificial intelligence tools
20	*Yu 2020* *[178]*	Older adults' perspective towards participation in a multicomponent frailty prevention program: a qualitative study	These findings highlighted several important factors for consideration in future design of frailty interventions regarding the needs of pre-frail and frail older adults, which could help to motivate and sustain their participation in community-based frailty prevention programs
31	*Linn 2021* *[178]*	Digital Health Interventions among People Living with Frailty: A Scoping Review	-
32	*Tegou 2018* *[180]*	A Low-Cost Indoor Activity Monitoring System for Detecting Frailty in Older Adults	The system is based on Bluetooth RSSI fingerprints using beacons
33	*Randriambelonoro 2023* *[181]*	Gamified Physical Rehabilitation for Older Adults With Musculoskeletal Issues: Pilot Noninferiority Randomized Clinical Trial	A noninferiority related to the primary outcome (SPPB) was identified during the hospital stay, and no significant differences were found between the control and intervention groups for any of the secondary outcomes (IHGS, FIM, or steps), which demonstrates the potential of the serious game-based intervention to be as effective as the standard physical rehabilitation at the hospital.

34	*Ruiz 2018* *[182]*	Validation of an automatically generated screening score for frailty: the care assessment need (CAN) score	Tool for detection of frailty and warrants further investigation regarding its applicability in primary care setting
35	*Lau 2021* *[183]*	A framework and immersive serious game for mild cognitive impairment	A range of cognitive rehabilitation games have been proposed to supplement or replace traditional rehabilitative training by offering benefits such as improved engagement
36	*Rahemi 2018* *[184]*	Toward Smart Footwear to Track Frailty Phenotypes—Using Propulsion Performance to Determine Frailty	This study demonstrates that a foot-worn sensor-derived gait measures during the propulsive phase of walking can be sensitive metrics in assessing frailty
37	*Alhasan 2021* *[185]*	Application of Interactive Video Games as Rehabilitation Tools to Improve Postural Control and Risk of Falls in Prefrail Older Adults	In this study, objective postural control assessments were made using static posturography via traditional postural sway measurements
38	*Han 2021* *[186]*	Mobile Augmented Reality Serious Game for Improving Old Adults' Working Memory	A mobile-based augmented reality system for regular cognitive function training is proposed to minimize declines in cognitive function among the elderly. Using the characteristics of markerless augmented reality technology that can support physical activities, the foregoing system was developed in the form of a serious game based on an understanding of physical aging
39	*Pereira 2021* *[187]*	A Virtual Reality Serious Game for Hand Rehabilitation Therapy	The system was assessed by seven able-bodied participants using a semistructured interview targeting three evaluation categories: hardware usability, software usability and suggestions for improvement
40	*Madureira 2020* *[188]*	My-AHA: Software Platform to Promote Active and Healthy Ageing	Software platform that comprises a software ecosystem designed to seamlessly integrate different health and active ageing solutions, targeting senior well-being
41	*Gorregidor-Sanchez 2020* *[189]*	Effectiveness of Virtual Reality Systems to Improve the Activities of Daily Life in Older People	Use of VRSs is an innovative and feasible technique to support and improve the functional autonomy of community-dwelling older adults

42	*Kosterink 2019 [190]*	GOAL: An eHealth Application for Rewarding Healthy Behaviour. The First Experiences of Older Adults	Developed technology and assistive tools for the target population of less-technologically skilled older adults and those less motivated in achieving a healthy lifestyle, this is not necessarily the main target
43	*Shapoval 2021 [191]*	Biofeedback Applied to Interactive Serious Games to Monitor Frailty in an Elderly Population	The effectiveness of the gaming platform increases the patient's outcome from 30% to 50% depending on the level and activity, the value in this case does not show the specific rehabilitative potential of the system
44	*Eun 2022* *[192]*	Artificial intelligence-based personalized serious game for enhancing the physical and cognitive abilities of the elderly	Study designed the exercise serious game Farming with Artificial Intelligence-(AI-) based personalized systems of difficulty level adjustment and relative scoring to motivate the user to keep playing the game with pleasure while applying a set of gratification and motivation technique.
45	*Beltran-Alacreu 2022* *[193]*	A Serious Game for Performing Task-Oriented Cervical Exercises Among Older Adult Patients With Chronic Neck Pain: Development, Suitability, and Crossover Pilot Study	The serious game developed in this study showed good suitability for use in adults over 70 years of age with chronic neck pain. The game was a safe method for performing task-oriented cervical exercises, and patients reported very high levels of satisfaction and acceptance after the use of this technology
46	*Liu 2023* *[194]*	Application of Immersive Virtual-Reality-Based Puzzle Games in Elderly Patients with Post-Stroke Cognitive Impairment: A Pilot Study	This pilot study suggests that IVR-based puzzle games are a promising approach to improve post-stroke cognitive function, especially executive cognitive function, and visual–spatial attention in older adults
47	*Fu 2022* *[195]*	Conceptual Design of an Extended Reality Exercise Game for the Elderly	This research first analyzed the relevant literature and existing VR exercise games for the elderly to find characteristics and their particular needs
48	*Rorato Souza 2022* *[196]*	A Serious Games and Game Elements Based Approach for Patient Telerehabilitation Contexts	Was developed to assist in conducting telerehabilitation sessions that involve a cycle ergometer as a device – a bedside bicycle used in rehabilitation sessions for patients with motor disorders

Appendix B

№	Reference	Title of selected dtudy	Results Description
1	*McMahon et al. 2015* *[197]*	Effects of Digital Navigation Aids on Adults With Intellectual Disabilities: Comparison of Paper Map, Google Maps, and Augmented Reality	Augmented reality navigation application was functionally the most effective condition, in the context of supporting people with intellectual disorder by teaching navigation skills.
2	*Peñaloza-Salazar et al. 2016* *[198]*	Cognitive mechanisms underlying Armoni: A computer-assisted cognitive training programme for individuals with intellectual disabilitie	Naming ability, visual memory, comprehension and vasoconstriction contributed the most to the predictive models regarding performance on the Armoni activities
3	*Cano 2018* *[199]*	Using game learning analytics for validating the design of a learning game for adults with intellectual disabilities	Tendency for users to use the same character in all the sessions, we did not observed differences in the play patterns between the players that customized the character and those who did not
4	*Cano. 2019* *[200]*	Game Analytics Evidence-Based Evaluation of a Learning Game for Intellectual Disabled Users	The article presents a version of a game system to teach people the basics of social aspects, namely the use of public transportation.
5	*Derks et al. 2019* *[201]*	Effectiveness of the serious game 'You & I' in changing mentalizing abilities of adults with mild to borderline intellectual disabilities: a parallel superiority randomized controlled trial	The serious game 'You & I' aims to improve mentalizing abilities in adults with mild to borderline intellectual disabilities
6	*Lara et al. 2019* *[202]*	A Serious Videogame to Support Emotional Awareness of people with Down Syndrome	The Emotion4Down video game, a serious videogame that supports the emotional awareness of people with Down syndrome
7	*Benda et al. 2019* *[203]*	Practical Education Of Adults With Intellectual Disabilities Using A Web Course	The presented research examined whether a web course could be effective educational technology for people with intellectual disabilities focusing on repetition of knowledge
8	*Bridges et al. 2020* *[204]*	Augmented Reality: Teaching Daily Living Skills to Adults With Intellectual Disabilities	Results indicate the intervention was effective for increasing independence among all participants

9	*Michalsen et al. 2020* *[205]*	Physical Activity With Tailored mHealth Support for Individuals With Intellectual Disabilities: Protocol for a Randomized Controlled Trial	The results of the study will determine the effectiveness and sustainability of a tailored mHealth support intervention to increase PA in youth and adults with IDs.
10	*Gibson et al. 2020* *[206]*	Designing Clinical AAC Tablet Applications with Adults who have Mild Intellectual Disabilities	Have the potential to assist people with mild ID throughout all aspects of life

Appendix C

Encuesta de valoración sobre la aplicación eMotivaMente

Edad:

Sexo:

Nivel discapacidad:

A continuación, te agradeceríamos que contestaras a las siguientes preguntas sobre la aplicación eMotivaMente que nos ayudarán a mejorar el diseño de las actividades del juego.

Tu respuesta es muy importante para nosotros.

¡Gracias por tu colaboración!

Marca con una cruz una de las opciones de cada enunciado:

1. La aplicación me ha sido fácil de usar

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

2. La aplicación me ha resultado compleja y necesito ayuda de otra persona

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

3. Me ha parecido entretenida y divertida

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

4. Creo que es pesada o aburrida

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

5. Los ejemplos del juego me han ayudado a saber cómo jugar

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

6. Me han gustado los dibujos y las imágenes

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

7. El sonido del audio me ha ayudado a entender el juego

Muy de acuerdo	De acuerdo	Desacuerdo	Muy en desacuerdo

Comentarios (juegos que más te han gustado, los juegos más fáciles o más difíciles, los más divertidos u otras cosas que quieras comentar):

Otras observaciones ¿añadirías alguna otra cosa a la aplicación o a los juegos?:

Appendix D

№	User ID	Gafas	Bufanda	Avatar	L1Compl	L2Compl	Age	Gender	Cognitive status	Disability Level
					Control Group					
1	1	1	0	3	5	4	29	Male	0	10%
2	2	1	0	4	5	5	27	Male	0	5%
3	3	0	1	5	5	3	25	Female	0	10%
4	4	0	0	4	5	5	27	Male	0	8%
5	5	0	0	4	5	5	23	Female	0	5%
6	6	1	1	1	5	4	22	Female	0	7%
7	7	1	1	7	5	5	41	Male	0	9%
8	8	0	0	11	5	5	26	Female	0	12%
9	9	0	0	4	5	5	31	Male	0	15%
10	10	1	1	2	5	5	33	Male	0	10%
					Group A					
31	49	1	0	3	5	0	22	Female	1	65%
32	50	0	0	15	5	0	24	Female	1	68%
33	51	1	0	15	5	3	20	Male	1	62%
34	52	1	0	14	5	0	27	Female	1	65%
35	53	0	0	3	5	0	20	Female	1	65%
36	54	1	0	3	5	0	25	Female	1	68%
37	55	0	0	3	5	1	24	Female	1	68%
38	56	0	0	1	5	0	26	Male	1	62%
39	57	0	0	1	5	0	24	Female	1	68%
40	58	0	0	14	5	1	25	Female	1	60%
41	59	0	0	6	5	0	22	Female	1	65%
42	60	1	0	13	3	0	26	Female	1	78%
43	61	0	0	12	5	0	22	Male	1	62%
44	62	1	0	1	5	0	26	Female	1	60%
					Group B					
45	63	0	0	12	5	0	22	Male	1	67%
46	64	1	0	5	5	0	22	Male	1	62%
11	18	1	0	9	5	4	51	Male	1	68%
12	19	0	0	1	5	0	53	Male	1	68%

13	20	0	0	5	0	0	45	Male	1	68%
14	21	0	0	1	2	0	50	Male	1	65%
24	41	0	0	13	5	5	37	Female	1	97%
25	42	1	0	12	5	2	44	Female	1	93%
26	43	0	0	13	4	0	42	Male	1	89%
27	44	0	0	7	4	0	36	Male	1	89%
28	45	1	1	9	3	0	35	Male	1	68%
29	46	0	0	2	5	0	41	Male	1	97%
30	47	1	0	1	1	0	41	Female	1	89%
Group C										
15	27	1	1	2	5	0	46	Male	0	77%
16	28	0	1	10	5	0	51	Male	0	72%
17	29	1	0	15	5	0	45	Male	1	80%
18	30	1	1	2	0	0	43	Female	1	75%
19	31	1	0	2	5	0	46	Male	0	76%
20	32	1	0	3	5	0	33	Female	1	65%
21	33	1	1	3	5	0	48	Male	0	70%
22	34	1	1	3	5	0	45	Female	1	81%
23	35	1	1	2	5	0	47	Male	1	75%
47	65	0	1	11	5	0	47	Female	0	65%
48	66	1	1	1	5	0	40	Male	0	79%
49	67	0	0	12	5	0	58	Female	0	92%
50	68	1	1	1	5	0	49	Female	0	94%
51	69	0	0	2	5	0	46	Female	1	70%
52	70	1	1	6	5	0	40	Female	0	76%
53	71	1	1	7	5	0	50	Female	0	67%
54	72	1	1	3	5	0	38	Female	1	75%