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LC-Neurorehab: a Mental Rotation Training tool to investigate the role of practice and strategy in cognitive improvement in people with Long Covid syndrome

Supervisors:
Luigi De Russis
Vito De Feo

Candidate:
Federica D'Ambrosio

Ai miei genitori…

Abstract

My thesis project focuses on the design and development of a desktop application called "LC-Neurorehab", dedicated to the neurorehabilitation of patients affected by Long Covid, with particular attention to issues related to anxiety which arise when they encounter concentration difficulties. This initiative originated from the results obtained through the web app "Happy Again", developed in collaboration with the University of Essex. Through the completion of tasks and questionnaires by Long Covid patients, common issues related to attention and anxiety emerged. In response to these needs, the present desktop application has been designed, representing a further step in collaboration with the University of Essex. It aims to offer a specific approach to the Long Covid neurorehabilitation. The application features two distinct tasks: Adaptive Dual N-Back and Mental Rotation Test, integrated into rehabilitation sessions and closely monitored by attending physicians.

The central aspect of the project revolves around the design and implementation of the application as a whole. Initially, the focus was on defining the main objectives and functionalities. Subsequently, an analysis of functional and non-functional requirements was conducted, crucial to ensuring an optimal user experience. The next step involved the selection of the framework and programming language, database design, and code writing.

This desktop app was developed using the Python programming language. The choice of this technology was guided by the need to include the tool in a neurofeedback loop, where an EEG is recorded. An AI (to be developed) will take advantage from the EEG analysis to establish runtime the parameters of the training, e.g., the speed of the tasks. Python is a very flexible and extensible language and it allows developers to leverage existing libraries and optimize performance when necessary.

A key aspect of the project is the in-depth exploration of the Mental Rotation Test. In this phase of the study, the focus is on analyzing the effectiveness of teaching patients specific spatial strategies during the execution of mental rotation tasks. The goal is to evaluate whether adopting such strategies can improve performance compared to the execution of isolated mental rotation exercises. This task is designed to be adaptive and targeted, constituting a distinctive element of the application. As it assesses the ability to identify similarities between pairs of images, it represents a significant contribution to the field of Long Covid neurorehabilitation.

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Introduction

The emergence of the novel coronavirus, identified as SARS-CoV-2, shook the world in 2019, unleashing the ongoing COVID-19 pandemic. This virus, recognized as the "sibling" of the one responsible for the SARS outbreak, was officially designated by the International Committee on Taxonomy of Viruses (ICTV) as SARS-CoV-2. The disease associated with this infection is named COVID-19, an acronym reflecting its origin (CO for corona, VI for virus, D for disease, and 19 for the year of manifestation).

On February 11, 2020, the Director-General of the WHO, Tedros Adhanom Ghebreyesus, officially announced the name COVID-19 during a press briefing. The initial cases were identified among workers at the wet market in Wuhan, China, and by the early weeks of January 2020, scientists had identified pneumonia caused by the novel coronavirus. The similarity of SARS-CoV-2 to at least 70% of its genetic sequence with SARS-CoV captured the attention of researchers.

By the end of January 2020, the precise characteristics of the virus were not yet well-determined, but its ability for human-to-human transmission prompted timely responses in China and globally. Travel restrictions, quarantines, and curfews became common in response to the increasing cases.

In the vast landscape of the COVID-19 pandemic, an enigma unfolds within the experiences of some individuals, the mysterious realm of "Long COVID" or "Post-COVID-19 Syndrome". Characterized by the National Institute for Health and Care Research and the OMS, this condition traces a complex web of symptoms that persist over time, extending for weeks, months, or in some cases, even longer periods. It presents as a lingering shadow of the initial infection, affecting various organs and systems within the body, with implications for the individual's quality of life.

The scientific community, aware of the intricate enigma of Post-COVID-19 Syndrome, has focused its efforts on understanding this unique manifestation. Although Long COVID is formally recognized as a clinical entity with evident impacts on the population, ongoing research endeavors aim to further unveil its characteristics. These investigations include determining prevalence, the nature and severity of persistent effects, as well as understanding the interconnections with variables such as the severity of the initial illness and the presence of pre-existing medical conditions.

Long COVID shapes up as an enigmatic and intriguing chapter in this pandemic saga. Through the persistence of symptoms such as fatigue, cardio-respiratory difficulties, headaches, and a wide array of neurological, neuropsychological, psychological, logopedic, and physical manifestations, a complex narrative unfolds. The enduring

presence of "brain fog", with its trilogy of fatigue, difficulty concentrating, and memory issues, adds additional layers of mystery and complexity to this intricate story of post-COVID-19 survival.

The University of Essex, inspired by profound motivations, has launched the "Happy Again" project dedicated to investigating the health impacts on COVID-19 patients, exploring both physical and psychological aspects of post-COVID-19 syndrome. This initiative aims to understand persistent symptoms, ranging from fever and cough to severe respiratory and cognitive difficulties. The main objective is to determine whether these indicators of cognitive and neural functioning are influenced by the virus and whether they are systematically correlated with the experience and severity of long-term symptoms.

As part of this research, developed in collaboration with the University of Essex, I played an active role. As a member of a multidisciplinary team of fellow students, my contribution focused on the design and development of a desktop application called "LC-Neurorehab". This application was conceived in response to the needs identified through "Happy Again", with particular attention to anxiety-related aspects arising from concentration difficulties experienced by patients.

"LC-Neurorehab" represents a further step in collaboration with the University of Essex and aims to provide a specific approach to the neurorehabilitation of Long Covid. Two distinct tasks, Adaptive Dual N-Back and Mental Rotation Test, are integrated into rehabilitation and closely monitored by medical professionals.

My specific role within this collaboration was crucial in designing and developing the application, from defining the main objectives to choosing the framework and programming language. Collaboration with other students was essential, with each team member taking on specific responsibilities.

The application was developed using the Python programming language, chosen for its flexibility and extensibility, necessary to integrate the tool into a neurofeedback loop where EEG is recorded. The planned AI will leverage EEG analysis to establish real-time training parameters, such as task speed. A key aspect of the project is the in-depth exploration of the Mental Rotation Test, assessing the effectiveness of teaching specific spatial strategies to patients during the execution of mental rotation tasks.

In summary, my role in this collaboration with the University of Essex has been crucial for the development of targeted and personalized neurorehabilitation solutions for Long Covid patients through the "LC-Neurorehab" application.

The thesis document is divided into six chapters, allowing for a comprehensive review of all the stages of development conducted.

- The **first chapter** contextualizes the project by explaining the phenomenon of COVID-19 and examining the virus's impact on the nervous system, with a particular focus on neurological aspects. Additionally, it addresses issues related to attention and anxiety in Long Covid patients, providing a comprehensive overview of the challenges faced in the project.
- The **second chapter** focuses on the main objectives of neurorehabilitation and perspectives for patient improvement. It introduces the Adaptive Dual N-Back and the Mental Rotation Test as tools for cognitive assessment, delving into spatial abilities and the capacity for mental rotation. Additionally, it provides an overview of mental rotation tests and their role in assessing cognitive abilities.
- The **third chapter** delves into the analysis of requirements, encompassing both functional and non-functional aspects.
- The **fourth chapter** addresses the solution's design, describing the methodology employed. It introduces use cases through tables and diagrams to illustrate the system's usage. Additionally, it analyzes various architectural layers.
- The **fifth chapter** outlines the obtained results, the technologies utilized, database management, data exchange, code structure, and provides a description of the desktop application's user interface with accompanying images.
- The **sixth chapter** outlines the future steps and draws conclusions. This section delineates the anticipated next steps for the project and formulates general conclusions based on the obtained results.

Chapter 1

1.1 Project Contextualization

The COVID-19 pandemic, stemming from the SARS-CoV-2 virus, has unleashed profound consequences, emerging as a phenomenon of significant magnitude. Characterized by symptoms initially akin to common respiratory ailments, the disease extends beyond the exclusive realm of the respiratory system, affecting various parts of the body. While the majority of individuals exhibit mild or moderate symptoms, and viral replication is primarily concentrated in the upper airways, a segment of the population experiences progression toward more severe forms, frequently evolving into a dangerous pneumonia. The significant impact of the disease, highlighted by a death toll exceeding one million in the United States alone, underscores the seriousness and complexity of the challenge that the global community is facing.

1.1.1 SARS-CoV-2

The SARS-CoV-2, the pathogen responsible for COVID-19, was first identified in Wuhan, China, at the end of 2019, within a cluster of patients with pneumonia [1].

This virus, belonging to the Sarbecovirus category and sharing 79% sequence similarity with the previously known SARS-CoV, possesses a complex genetic structure. Its genomic sequence encodes a series of proteins, including key elements such as the membrane protein, nucleocapsid protein, envelope protein, and spike glycoprotein. In addition to these, there are also non-structural proteins, crucial in the viral replication and transcription complex. Similarly, the viral genome includes accessory proteins, although not essential for replication, often exhibiting immune evasion activities. The assembly of these structural proteins, along with a lipid layer derived from the host, forms the virion, a enveloped viral particle that facilitates the transport of viral genomic RNA into the host cell [1].

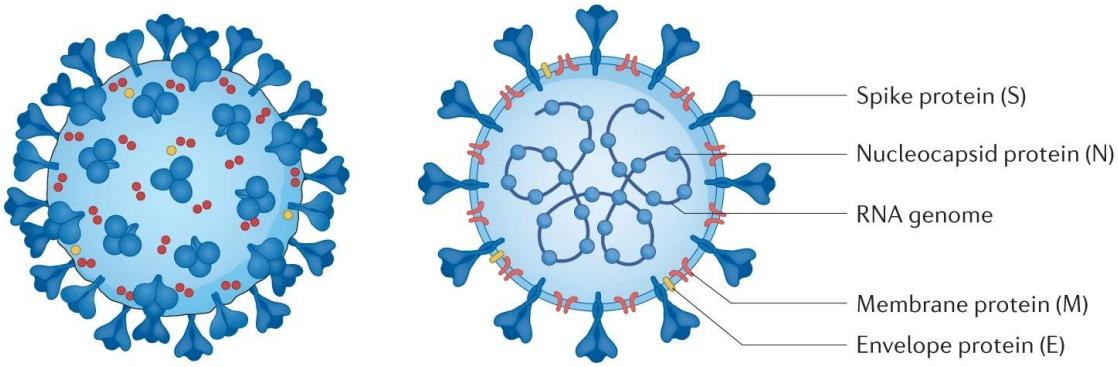

Figure 1: SARS-CoV-2 [1].

Regarding the transmission of SARS-CoV-2, it primarily occurs through respiratory droplets and aerosols, with an average incubation period of about 4-5 days before symptoms become evident. While some individuals may be asymptomatic, most patients experience mild to moderate symptoms, such as cough, fever, headache, myalgia, and, in some cases, diarrhea. In more severe cases, the disease intensifies about a week after the onset of initial symptoms, with dyspnea as the predominant symptom. Subsequently, progressive respiratory failure develops in patients with severe forms of COVID-19 [1].

1.1.2 Long Covid

Some people who have been infected with the virus that causes COVID-19 can experience long-term effects from their infection, known as Long Covid or Post-COVID Conditions (PCC). Long Covid is broadly defined as signs, symptoms, and conditions that continue or develop after acute COVID-19 infection [3]. This definition of Long Covid was developed by the Department of Health and Human Services (HHS) in collaboration with CDC and other partners.

Individuals affected by Long Covid may experience a broad spectrum of symptoms that persist for weeks, months, or even years after the infection. In some cases, these symptoms may alternate between periods of manifestation and temporary relief. This Post-COVID complication can vary significantly from person to person, with some individuals facing prolonged health issues, occasionally leading to disabilities.

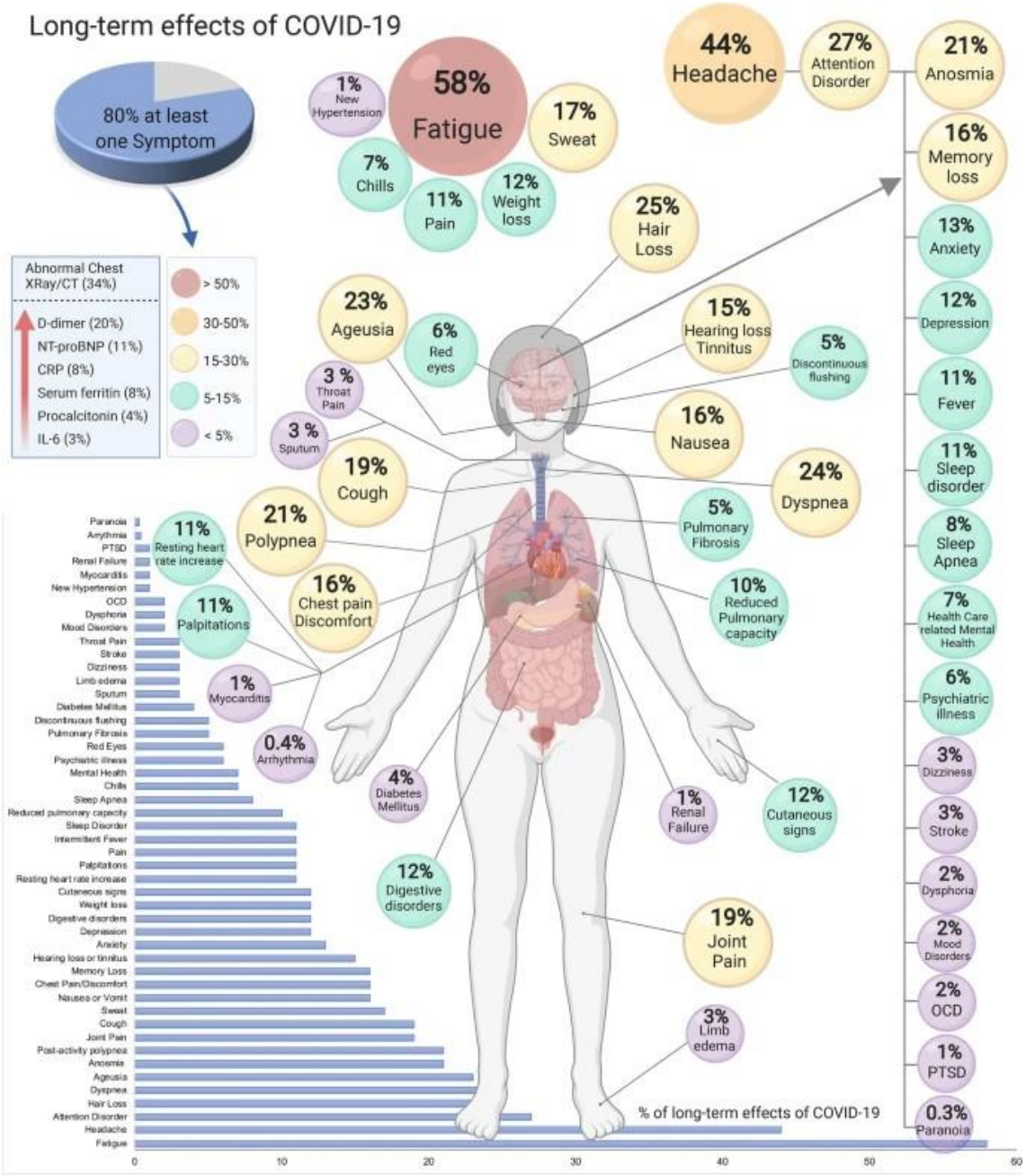

Figure 2: Long-term effects of COVID-19 [4].

1.2 Neurological manifestations of Long Covid syndrome

The coronavirus, in addition to being a respiratory syndrome, also presents many neurological complications: strokes, neuromuscular disorders, impaired concentration, headaches, sensory disturbances, depression, and even psychosis. These can persist for months after infection as part of a set of symptoms now referred to as Long Covid [2].

Long Covid, being a multi-organ condition, entails a wide range of clinical symptoms affecting the lungs, heart, immune system, endocrine glands, kidneys, hematological system, gastrointestinal tract, skin, and the mental and neurological sphere. Although approximately one-third of patients with previous COVID-19 and severe acute respiratory syndrome exhibit involvement of the central or peripheral nervous system, observational studies based on patient reports highlight an approximately threefold incidence of neurological symptoms.

With millions of individuals affected, neurological complications pose a significant challenge to public health, introducing considerable complexity in the rehabilitation and recovery phase. Moreover, there are significant consequences in the workforce due to the loss of functional capacity. Currently, there is an urgent imperative to thoroughly understand the pathophysiology of these conditions and to pursue the development of therapies capable of altering the course of the disease.

Initially, early reports of neurological syndromes related to COVID-19 could be attributed to any severe acute illness with respiratory and metabolic problems. Subsequently, further reports have highlighted more specific complications, emphasizing a particular involvement of cerebral blood vessels and neural tissues. The variability in the onset over time suggests different pathophysiological mechanisms. For example, cerebrovascular complications occur simultaneously or even precede the onset of respiratory symptoms, while central inflammatory conditions and peripheral nerve conditions manifest on average 2 weeks later, suggesting they may arise from peri- or post-infectious processes [2].

This table provides an overview of neurological manifestations associated with Long Covid, categorized by their localization in the nervous system.

Table 1: Neurological manifestations associated with Long Covid.

Localization	Manifestations
Central nervous system	▪ Fatigue ▪ 'Brain fog' ▪ Headache ▪ Sleep disorders ▪ Cognitive impairment ▪ Emotional/mood disorders ▪ Dizziness ▪ Dysautonomia
Peripheral nervous system	▪ Muscle weakness ▪ Myalgias

- Hyposmia
- Hypogeusia
- Hearing loss/tinnitus
- Sensorimotor deficits (hypoesthesia, dysesthesia, tremor)

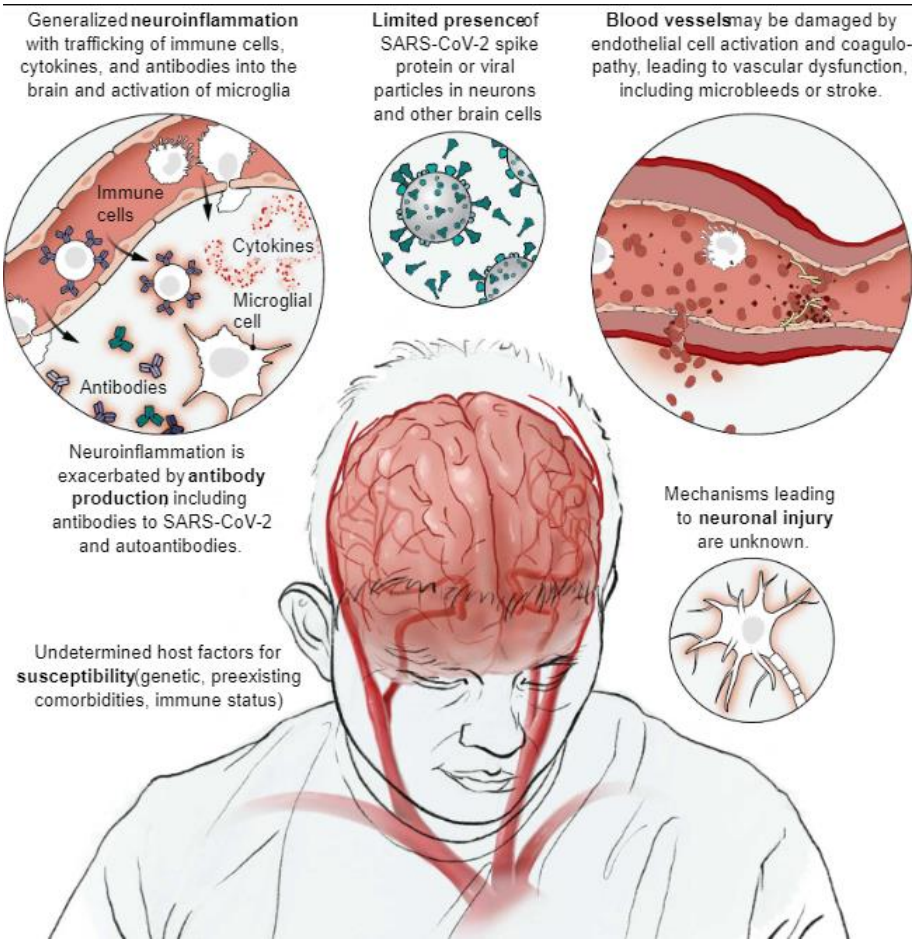

Figure 3: Neuropathogenic effects of SARS-CoV-2 [2].

1.3 Emergence of issues related to attention and anxiety in Long Covid patients

In recent times, Post-COVID syndrome has raised growing concerns regarding persistent symptoms affecting the recovery of patients, posing significant questions about associated cognitive issues.

In individuals with long-term COVID-19 effects, fatigue emerges as one of the central symptoms, often persisting for more than 6 months and indicating a potentially worse prognosis. This symptom, a subjectively challenging experience to quantify, has been described as a physical, mental, and emotional energy deficit. Fatigue hinders the performance of normal daily activities, frequently leaving the patient with a post-exertional malaise. The experience of fatigue, as subjectively described by patients, includes the need to adjust basic activities and disrupt work life, leading to a severe decline in functional status due to exhaustion. Fatigue, in addition to affecting physical and mental performance, can contribute to the cognitive problems observed in Post-COVID patients [5] [6].

Cognitive deficits encompass difficulties in concentration, attention, and executive functions. "Brain fog" is a term often used by patients to describe difficulty thinking and concentrating, with compromised mental clarity [5]. Patients face a persistent challenge in maintaining an optimal level of concentration and focus [6].

In addition to fatigue, significant neuropsychiatric sequelae emerge in Post-COVID patients. Anxiety, post-traumatic stress disorder, and depression are common, along with more extreme manifestations such as psychosis and delirium. It has been documented that external circumstances, such as isolation, prolonged quarantine, financial difficulties, and pandemic-induced stress, increase anxiety, prompt behavioral changes, intensify loneliness, and lead to avoidance behaviors. Obsessive-compulsive disorder (OCD) has also been reported, likely caused by additional stress factors such as masking, hygiene, and isolation. For some patients, neuropsychological symptoms are accompanied by post-traumatic stress disorder with potentially debilitating flashbacks, hyperarousal, and intrusive thoughts [5] [6].

Chapter 2

2.1 Project objective

My thesis project aims to combine the potential of neurofeedback-based therapies, utilizing closed-loop systems, with the use of brain-computer interfaces (BCIs) to develop an innovative neurorobotics system dedicated to Long Covid patients. This approach not only seeks to address neuropsychiatric challenges without resorting to medications but also aims to establish direct connections between brain activity and the external environment, thereby significantly improving the lives and independence of individuals affected by this complex condition.

In this context, having software tools specifically designed to simplify neuroscientific experiments is crucial. These tools are essential for advancing understanding of the brain and neurotechnologies, accelerating experiments, and reducing costs. Despite numerous advanced options for signal and image processing, alternatives for experimental design are currently limited.

In the research environment I am in, flexibility is a crucial quality to quickly adapt methodologies to specific studies or projects. While there are existing solutions on the market, they have limitations: they struggle with handling multiple signals, are implemented in C++, a complex and impractical programming language, lack flexibility, and can only be applied to specific activities.

The project underlying my thesis aims to overcome these current limitations through the implementation of advanced technologies, comprising three fundamental components, each contributing to the creation of an innovative system. The first component is dedicated to advanced signal processing, with a particular focus on electroencephalography (EEG). By acquiring signals directly from patients' brains, we delve into their brain activity, paving the way for a new understanding and intervention possibilities.

The equally crucial second component embraces the field of artificial intelligence. Here, the goal is to create a system that not only actively processes incoming signals but also learns actively, adapting and responding to the specific needs of individual patients. This dynamic interaction between machine and the human mind becomes the beating heart of the project, ushering in a new paradigm of personalized neurorobotics.

The third, the core of my thesis project, involves the development of a desktop application in Python. This application serves as a bridge between sophisticated

technology and the patient, offering a series of targeted and engaging tasks. Each proposed activity is carefully designed, with the ultimate goal of guiding the patient through an effective and rewarding neurorobotics journey. In the development process of the desktop app, I contributed to various aspects, including login, registration, homepage, and administrative area. However, regarding the two specific tasks, I focused on the implementation of the Mental Rotation Test. For the other task, Adaptive Dual N-Back, I actively participated in the analysis phase.

My thesis project fits into this context, focusing on neurorobotics and cognitive training.

2.2 LC-Neurorehab

The key component of my thesis project is the development of a desktop application called "LC-Neurorehab", built in Python, dedicated to the neurorehabilitation of patients affected by Long Covid. The app features a dual interface, catering to both patients and healthcare professionals.

The user interface provides patients with an interactive and engaging environment, offering access to two adaptive tasks focused on neurorehabilitation: the Adaptive Dual N-Back and the Mental Rotation Test. These tasks are designed to stimulate working memory and mental rotation.

The Adaptive Dual N-Back task was chosen for the LC-Neurorehab application based on studies indicating its potential to improve attention control and reduce anxiety, critical aspects in the rehabilitation of Long Covid patients. This task involves the simultaneous memorization of positions and sounds, adapting to the patient's capacity to ensure an optimal challenge. The main objective is to enhance cognitive functions, including fluid intelligence and working memory, through a gradual and personalized approach that promotes adaptability and long-term neurological recovery [7].

The other task featured in the application is the Mental Rotation Test, which I focused on the most and thus dedicated a separate paragraph to [**2.4 Mental Rotation Test**].

The administrative section of LC-Neurorehab, reserved for healthcare professionals, allows monitoring and evaluation of the results obtained by patients during neurorehabilitation activities. Within this section, detailed tables are implemented to record and archive individual results, including completion times, accuracy of responses, and other relevant parameters for cognitive assessment. The admin dashboard provides a detailed overview of each patient's performance, facilitating the analysis of trends over time. This enables healthcare professionals to adapt intervention strategies

promptly, customizing the neurorehabilitation path based on the specific needs of each individual.

The main goal of LC-Neurorehab is to understand whether the execution of these adaptive tasks has positive effects on neurorehabilitation, leading to the improvement of cognitive abilities and the quality of life of individuals affected by Long Covid.

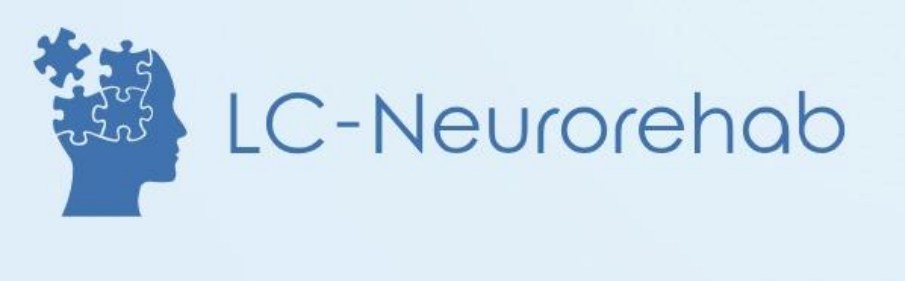

Figure 4: Desktop app logo.

2.3 Perspectives for Patient Improvement

The future prospects for patient improvement constitute a crucial element within the LC-Neurorehab application. The primary goal is to offer an innovative approach to neurorehabilitation, aimed at enhancing the cognitive abilities of Long Covid patients. The flexibility and customization of activities provided in the application allow for the adaptation of the neurorehabilitation journey to the individual needs of each patient, offering a tailored approach.

Through LC-Neurorehab, we anticipate that patients can experience significant improvements in their cognitive abilities. Specifically, enhancing attention control and executive functions, promoting a positive impact on the management of depression and anxiety. Furthermore, we hope for tangible enhancements in working memory, attention, and concentration.

2.4 Mental Rotation Test

As already mentioned in the previous chapter, LC-Neurorehab is a desktop app designed to support the cognitive rehabilitation of patients suffering from Long Covid and experiencing serious neurological issues. It focuses on two key adaptive tasks, one of which particularly catches my attention and upon which I focused during both the analysis and development phase the Mental Rotation Test.

Mental rotation training is a dynamic process aimed at enhancing the ability to imagine and rotate objects in mental space. This practice involves various processing stages, from perceptual phases involving the identification and discrimination of stimuli to the actual mental rotation and decision-making phases leading to a response. The main goal is to stimulate spatial abilities, a crucial element in numerous daily activities, ranging from science and technology to engineering, mathematics, navigation, and even sports [9].

Spatial skills, essential in various disciplines, find a valuable ally in mental rotation training. Dedicated exercises not only improve the ability to mentally manipulate objects but also bring benefits to other activities requiring similar spatial skills but with new stimuli. The basic idea is that mental rotation training can catalyze significant advantages in diversified contexts, transforming the practice into a long-term investment for cognitive enhancement [8].

An essential element to improve the effectiveness of training is the use of mental rotation strategies. The broad spectrum of spatial strategies includes rotating the entire object or analyzing individual pieces, and some studies show that those who consciously implement such strategies tend to achieve superior performance in mental rotation tasks. This finding opens the door to further customization of training, adapting it to the preferences and individual capacities of patients [9].

The Mental Rotation Test was introduced with a specific goal: to improve the quality of life for patients with Long Covid. This category of patients often experiences concentration problems, necessitating targeted intervention to increase working memory and attention levels.

The task aims to stimulate the cognitive sphere by providing intensive mental rotation exercises. Through consistent practice of imagining and rotating objects mentally, the goal is to strengthen basic cognitive abilities, offering tangible relief to patients facing challenges related to concentration and attention.

2.4.1 Rules and dynamics of the task

The Mental Rotation Test involves the use of 384 images, of which 48 are target images. The images were taken from the drive of this paper [10]. For each of these target images, there are 8 figures, which can be mirrored or rotated in relation to the target. Rotations are performed at 0, 50, 100, and 150 degrees. Therefore, in the same stimulus, the object on the right is identical to the one on the left if it is rotated around the vertical axis by 0, 50, 100, or 150 degrees; it is not identical if it is mirrored or mirrored and rotated.

Angular disparities reflect the common behavioral range in mental rotation studies without causing significant self-occlusion in any of the orientations. While smaller angular increments were possible, they often led to occlusion of spatially relevant information for some orientations [10].

All objects in the images are on a black and white background and contain 7 to 11 cubes. The test is adaptive, with levels ranging from 0 to 4. It starts at level 0, which includes the first 4 target images along with their variants (32 in total). In this level, 16 images are shown, with the initial 8 images representing 2 for each group to help the patient understand the task, and the other 8 images also representing 2 for each group, initiating accuracy calculation. If accuracy remains low, the patient stays at level 1 and cannot return to level 0.

Starting from level 1, target images range from 5 to 15, along with their respective variants. In level 2, target images range from 16 to 26 with corresponding variants. In level 3, target images range from 27 to 37 with corresponding variants. Finally, in level 4, target images range from 38 to 48 along with their respective variants. This division was made by analyzing the number of cubes that make up the various solids.

The purpose of the test is to understand whether the figure on the right is rotated or mirrored compared to the target figure on the left. The user must press two buttons on the keyboard: "C" indicates that the image on the right is identical but rotated compared to the target, while "M" indicates that the image on the right is mirrored compared to the target.

Each trial starts with an empty screen for 250 ms, followed by the presentation of one of the stimuli until participants respond by pressing one of the two buttons, with a time limit of 7500 ms. In case of no response, it is considered incorrect. During the activity, adaptability is calculated based on the accuracy of responses.

The patient starts from level 0. Once this level is completed, if their accuracy is between 0% and 25%, inclusive, the patient advances to level 1; if the accuracy is between 25% and 50%, with 50% included, the patient moves to level 2; if the accuracy is between 50% and 75%, with 75% included, the patient progresses to level 3; finally, if the accuracy is between 75% and 100%, with 100% included, the patient proceeds to level 4. From this point onwards, the criteria for evaluating accuracy change. When a patient completes a level, if accuracy is grater or equal than 95%, the participant advances to the next level; if it is between 75% and 95%, with 75% included, they stay at the same level; if it is less than 75%, they regress to the previous level. Each level lasts 3 minutes, and in total, the Mental Rotation Test takes 12 minutes.

In the Mental Rotation Test, each time the patient completes a level, various data related to that level are recorded. These data include the level number, accuracy of

responses, the total number of images viewed, the number of correct responses, the number of incorrect responses, and the date when the level was completed. All of this data is recorded in an array, which is then included in a larger array. This larger array contains all the levels that the patient has tackled, one after the other, maintaining the order in which they were completed. At the end of the task, we have an array containing many internal arrays, each corresponding to a level completed by the patient. This data is then saved to the database, where each row of the database corresponds to one of these internal arrays, thus keeping track of all completed levels and their associated data.

Chapter 3

3.1 Requirements Analysis

For a desktop application dedicated to the neurorehabilitation of long-term covid affected patients, requirements analysis plays a critical role as the success of the application directly impacts the health and well-being of the patients. Requirements analysis is a fundamental process involving the collection, documentation, and thorough understanding of user needs and expectations, as well as system goals. This process helps clearly and comprehensively define the application's requirements, categorizing them into two main types: Functional Requirements, which describe specific features and interactions of the application, and Non-Functional Requirements, which pertain to aspects such as performance, usability.

Table 2: Functional Requirements vs Non-Functional Requirements [11].

Functional Requirements	Non-Functional Requirements
A functional requirement defines a system or its component.	A non-functional requirement defines the quality attribute of a software system.
It specifies “What should the software system do?”	It places constraints on “How should the software system fulfill the functional requirements?”
Functional requirement is specified by User.	Non-functional requirement is specified by technical peoples e.g. Architect, Technical leaders and software developers.
It is mandatory.	It is not mandatory.
It is captured in use case.	It is captured as a quality attribute.
Defined at a component level.	Applied to a system as a whole.
Helps you verify the functionality of the software.	Helps you to verify the performance of the software.
Functional Testing like System, Integration, End to End, API testing, etc are done.	Non-Functional Testing like Performance, Stress, Usability, Security testing, etc are done.
Usually easy to define.	Usually more difficult to define.

3.2 Actors

Initially, the main actors, or external users that the system is designed to support, were identified. These actors are as follows:

- **Administrator (Admin):** this is a professional involved in the neuropsychological rehabilitation of patients, such as a neurologist or psychologist. The administrator monitors the activities of patients through the desktop app.
- **Patient:** this is the individual affected by Long Covid with cognitive decline. The patient uses the desktop app to perform activities and tasks as part of neurological rehabilitation.

3.3 Functional Requirements

The following table provides a detailed overview of the functional requirements, outlining the essential specifications for the features that the system must implement to meet user needs and achieve predetermined goals.

Table 3: Functional Requirements.

Identifier	Description
FR1	The application must manage patients' registration.
FR2	The application must allow all registered patients to log in.
FR3	The application must allow patients to log in and log out.
FR4	The application should present patients two tasks and allow them to undergo each one.
FR5	The application must allow each patient to return to the home page.
FR6	The application must let patients undertake the "Adaptive Dual N-Back" task and record the results.
FR7	The application must let patients undertake the "Mental Rotation Test" task and record the results.
FR8	The application will only allow patients to go to the next trial of the task after answering the current one.
FR9	The application will show a detailed instruction description for the "Adaptive Dual N-Back" task before allowing patients to start.
FR10	The application will show a detailed instruction description for the "Mental Rotation Test" task before allowing patients to start.

FR11	The application will allow patients to undertake the next level of the task when the accuracy is grater or equal then 95% and will save the results of the just completed level.
FR12	The application will allow patients to remain in the same level of the task when the accuracy is grater or equal then 75% and minor the 95% and will save the results of the just completed level.
FR13	The application will allow patients to return back to the previous level of the task when the accuracy is minor then 75% and will save the results of the just completed level.
FR14	The application will allow patients to answer through specific keys on the keyboard.
FR15	The application will have to illuminate on the screen the buttons relating to the keys pressed by the patients on the keyboard
FR16	The application must not allow the patients go back once the task is started
FR17	The application must permit patients to take the two tasks whenever requested.
FR18	The application presents a pop-up informing patients when they have completed a level.
FR19	The application presents a pop-up informing patients when they have completed a task.
FR20	The application presents a pop-up informing patients when they log out.
FR21	The application must manage admins' registration through security code.
FR22	The application must allow all registered admins to log in as admin.
FR23	The application must allow admins to log in and log out.
FR24	The application should present admis a table containing patients registered.
FR25	The application should enable admins to view the page containing each patient's personal information.
FR26	The application must allow each admin to return to the admin area.
FR27	The application should enable admins to write and save notes on the page containing the patient's personal information.
FR28	The application presents a pop-up informing admins when notes have been successfully inserted, modified and deleted.
FR29	The application must allow admins to access the page related to tasks performed by the specific patient in order to view the stored data based on the date it was completed.
FR30	The application must display to admins "Data not available" if a patient has not completed a task selected in order to view the stored data.

FR31	The application presents a pop-up informing admins when they log out.

3.4 Non-Functional Requirements

The following table provides a detailed overview of non-functional requirements, outlining essential criteria beyond system functionality that are crucial to ensuring optimal performance and usability.

3.4.1 Performance

Performance defines how fast a software system (or its component) responds to certain users' actions under a certain workload. It is the core type of nonfunctional requirements no system can do without [12].

Table 4: NFR01.

Attribute	Description
Identifier	NFR01
Name	High Performance
Description	The application must load and respond quickly to user interactions, ensuring short response times even when processing large volumes of data.
Metric target	Response within 2 seconds for each user action
Priority	High

3.4.2 Security

Security is the capability of a system to protect its data, resources, and functionalities from unauthorized access, undesired manipulations, or damages. Security requirements may involve data encryption, user authentication, access control, vulnerability management, and other cybersecurity practices [12].

Table 5: NFR02.

Attribute	Description
Identifier	NFR02

Name	Data Security
Description	Personal and clinical data of patients must be protected against unauthorized access.
Metric target	None
Priority	High

Table 6: NFR03.

Attribute	Description
Identifier	NFR03
Name	Privacy
Description	User credentials must be managed with the utmost confidentiality and protected through the use of cryptographically secure hash algorithms for password authentication.
Metric target	Use of standard cryptographic hash functions.
Priority	High

3.4.3 Portability

Portability determines if a system or its elements can work in different environments. It usually includes hardware, software, or other usage platform specifications. In other words, it establishes how well actions performed via one platform are run on another [12].

Table 7: NFR04.

Attribute	Description
Identifier	NFR04
Name	Cross-Platform Compatibility
Description	The application must operate smoothly across different desktop operating systems, including Windows, macOS, and Linux.
Metric target	No critical errors on supported platforms.
Priority	Medium

Table 8: NFR05.

Attribute	Description
Identifier	NFR05
Name	Timestamps in international format

Description	All timestamps collected in the application must be in UTC format when stored in the database.
Metric target	None
Priority	High

3.4.4 Usability

Usability is basically about user-friendliness. That means the product interface must be intuitive and easy to navigate, its features must be understandable and easy to find, and, most importantly, it must meet the user's needs [12].

Table 9: NFR06.

Attribute	Description
Identifier	NFR06
Name	User-friendly interface for patient
Description	All interfaces and activities that can be performed by the patient in the application should be intuitive and easy to use.
Metric target	None
Priority	High

Table 10: NFR07.

Attribute	Description
Identifier	NFR07
Name	User-friendly interface for admin
Description	All interfaces and activities that admin can perform in your application should be intuitive and easy to use.
Metric target	None
Priority	Medium

3.4.5 Reliability

Reliability specifies how likely the system or its element would run without a failure for a given period of time under predefined conditions. Traditionally, this probability is expressed in percentages [12].

Table 11: NFR08.

Attribute	Description
Identifier	NFR08
Name	Reliability
Description	The application must be stable and operate correctly without crashing or interruptions, ensuring constant availability for clinical use.
Metric target	99.9% uptime.
Priority	High

3.4.6 Maintainability

Maintainability defines the time needed for a solution or its component to be fixed, changed to increase performance or other qualities, or adapted to a changing environment [12].

Table 12: NFR09.

Attribute	Description
Identifier	NFR09
Name	Maintainability
Description	The source code should be well-organized and documented to facilitate easy updates and efficient issue resolution.
Metric target	Ability to implement updates or bug fixes within a maximum of 48 hours.
Priority	High

3.4.7 Interoperability

Interoperability involves ensuring that the application establishes efficient and reliable communication with the database, in this case local. This includes aligning the data formats used by the application with those supported by the database, optimizing the handling of requests and responses, and ensuring secure and dependable communication between the two.

Table 13: NFR10.

Attribute	Description
Identifier	NFR10
Name	Local Database Connectivity

Description	The application must efficiently store and retrieve data from the local database to ensure fast and reliable access to patient information and task results. This includes optimizing database queries and ensuring that the data storage mechanism supports quick data manipulation and retrieval operations.
Metric target	Database response time for queries should not exceed one second under normal operation conditions.
Priority	High

Chapter 4

4.1 Design of the Solution

In this chapter, we will tackle an in-depth analysis of the key aspects, subdivided into the following subsections. The adopted methodology will be scrutinized to outline the stages of research, data collection, and analysis that guided the entire process. Subsequently, we will explore a series of specific use cases, accompanied by tables and an explanatory diagram, with the aim of highlighting practical applications and contexts for the implementation of the discussed concepts. In the third aspect, we will delve into the architectural levels of the system. This section will be structured into three main components: the presentation layer, concerning the user interface and visual experience; the application logic layer, focusing on the business logic and system functionalities; and finally, the data layer, dedicated to the management and organization of information.

4.2 Strategy Exploration

The software development life cycle is a concept that describes the path an application takes from its conception to its final retirement. It is a structured process involving a series of well-defined phases, each playing a specific role in ensuring efficient, dependable, and high-quality software development.

LC-Neurorehab was conceived and developed following this methodology. Collaboration with a multidisciplinary team of people coming from both the University of Essex and the Polytechnic of Turin was crucial, as the team included not only developers like me but also psychologists. The psychologists focused on analyzing the neurological consequences observed in patients with Long Covid. The goal was to understand how this desktop app could be structured and effectively used for neurological rehabilitation in such contexts.

There were four phases executed in the creation process of LC-Neurorehab:

- **Analysis:** the team focused on analyzing the project's needs and requirements. We sought to fully understand the neurological challenges faced by Long Covid patients and clearly define the application's objectives. In-depth research was conducted to understand user needs and the practical implications of neurological rehabilitation through a desktop app.

- **Design:** after gaining a thorough understanding of the needs, the team moved to the design phase. The app's architecture has been defined, feature layout, and user interface. This phase aimed to translate the requirements identified in the analysis phase into a detailed plan that would guide the app's development.
- **Implementation:** with the design solidified, the process moved to the actual implementation of the application. During this phase, the source code was written following project specifications. The development team worked collaboratively to translate the design plan into a functioning application.
- **Testing:** the application underwent a series of usability tests and verification of compliance with initial requirements.

These phases form an iterative cycle where feedback obtained from tests can lead to changes and improvements in the analysis, design, and implementation phases.

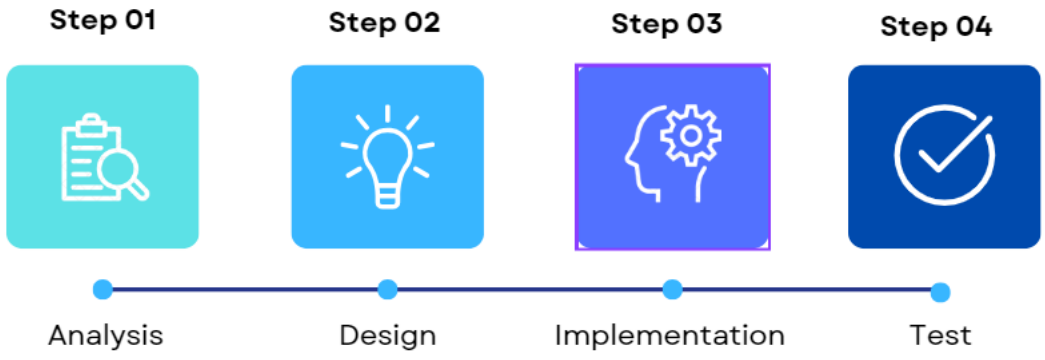

Figure 5: Strategic Development Steps for this project.

4.3 Use Cases

In UML (Unified Modeling Language), a use case is a graphical and textual representation of how a system interacts with external actors (which can be people, other systems, or external entities) to perform a specific functionality or achieve a particular goal. In other words, use cases describe scenarios of system usage by users or other systems. They outline the functional requirements of the platform, serving as the foundation for the incremental development of features supported by the system. The involved actors and use cases are depicted in the use case diagram, illustrating the relationships and interactions between them.

The tables below provide a detailed description of identified use cases, along with corresponding functional requirements, the goal of the use case, the condition that must

be verified before executing the use case, the system state after the use case has been successfully completed, the main flow of actions, and finally, additional and/or extension scenarios. Below, the resulting diagram has been inserted.

4.3.1 Use Cases Patient

Table 14: UC1P - Register.

ID	**UC1P**
Name	Register
Functional requirement	FR1
Goal	The patient is able to register in the application.
Pre-condition	The patient was shown a Login page.
Post-condition	The system records the patient's data in a secure stand-alone database under a username.
Main success scenario	1. The patient clicks on the "Register now" button. 2. The registration page is shown. 3. The patient fills all the entries, name, surname, date of birth, username and password, with valid data clicks on the "Register" button. 4. The system stores the entered user data into a secure database.
Includes/Extends	Validation: 3.a.1. The patient's username has already been used and it is recorded in the database. The application informs the participant about their existing account. 3.a.2 A pop-up informs the patient about his successful registration.

Table 15: UC2P - Log in.

ID	**UC2P**
Name	Log in
Functional requirement	FR2, FR3
Goal	The patient is able to log into the application.
Pre-condition	The patient is successfully registered.
Post-condition	The system shows to the patient the Home page.

Main success scenario	1. The patient fills all the entries, username and password 2. The patient clicks on the “Login” button. 3. The system authenticates the patient’s entered data. 4. The patient is logged in and presented the Home page.
Includes/Extends	Authentication: 2.a.1. The system is unable to find the patient’s data. The application displays a “Username or password is incorrect” message.

Table 16: UC3P - Log out.

ID	**UC3P**
Name	Log Out
Functional requirement	FR3, FR20
Goal	The patient is able to log out from the application.
Pre-condition	The patient is logged in.
Post-condition	The patient is redirected to the Log in page.
Main success scenario	1. The participant clicks on the “Log Out” button. 2. The application shows the Log in page.
Includes/Extends	1.a.1 The system asks the patient if he is sure to log out. 1.a.2 A pop-up informs the patient about his successful log out.

Table 17: UC4P – Home.

ID	**UC4P**
Name	Home
Functional requirement	FR4, FR5, FR6, FR7
Goal	The patient is able to see the two tasks to work on.
Pre-condition	The patient is logged in.
Post-condition	None
Main success scenario	1. The application displays two task options in the form of buttons.
Includes/Extends	None

Table 18: UC5P - Adaptive Dual N-Back.

ID	**UC5P**

Name	Adaptive Dual N-Back
Functional requirement	FR8, FR9, FR11, FR12, FR13, FR14, FR15, FR16, FR17, FR18, FR19
Goal	The patient is able to accomplish adaptive dual n-back task.
Pre-condition	The patient is logged in.
Post-condition	The application stores for each level the level, the number of correct “audio”, the number of correct “visual”, the number of correct “both”, the score and date in the database.
Main success scenario	1. The patient clicks on “Adaptive Dual N-Back” button on the home page. 2. The application displays a screen with the instructions of the task. 3. The patient clicks on the “Start Game” button to start the game or on the “Back” button to return to the home page. 4. The application presents on the screen a 3x3 black grid and three disabled buttons “Audio”, “Visual”, “Both”. The patient clicks again on the “Start Game” button to start the game or on the “Back” button to return to the home page. 5. The task starts from level 1 and for a number of trials equal to 20+n (n=level) pairs of flashes and audio follow one another. 6. The patient must understand if there is a correspondence or visual or auditory or visual and auditory between the current trial and n back trial. He must click the corresponding key on the keyboard. 7. When the level ends the data is saved in the database and based on the accuracy the task proceeds adaptively until the end of the time. 8. At the end of the task the application notifies that the task is completed and returns the patient to the home page.
Includes/Extends	7.a.1. A pop-up informs that a level is completed or not. 8.a.1 A pop-up informs that the game is over.

Table 19: UC6P - Mental Rotation Test.

ID	**UC6P**
Name	Mental Rotation Test
Functional requirement	FR8, FR10, FR11, FR12, FR13, FR14, FR15, FR16, FR17, FR18, FR19
Goal	The patient is able to accomplish mental rotation task.

Pre-condition	The patient is logged in.
Post-condition	The application stores for each level the level, the accuracy, the number of images, the number of correct answers, the number of wrong answers and date in the database.
Main success scenario	1. The patient clicks on “Mental Rotation Test” button on the home page. 2. The application displays a screen with the instructions of the task. 3. The patient clicks on the “Start Game” button to start the game or on the “Back” button to return to the home page. 4. The application presents on the screen the random image and two buttons “Same” and “Different.” 5. The task starts from level 0 and images will appear randomly for the duration of the level. 6. The patient must understand if the two figures in the image are the same or different. He must click the corresponding key on the keyboard. 7. When the level ends the data is saved in the database and based on the accuracy the task proceeds adaptively until the end of the time. 8. At the end of the task the application notifies that the task is completed and returns the patient to the home page.
Includes/Extends	7.a.1. A pop-up informs that a level is completed or not. 8.a.1 A pop-up informs that the game is over.

4.3.2 Use Cases Admin

Table 20: UC1A – Register.

ID	**UC1A**
Name	Register
Functional requirement	FR21
Goal	The admin is able to register in the application.
Pre-condition	The admin was shown a Login page.
Post-condition	The system records the admin’s data in a secure stand-alone database under a username.
Main success scenario	1. The admin fills the entries, username and password. 2. The admin clicks on the “Login as Admin” button. 3. The application asks the admin to insert a security code to confirm the admin’s identity.

	4. The system stores the entered admin's data into a secure database.
Includes/Extends	Validation: 3.a.1 A pop-up informs the admin about his successful registration if the security code is correct otherwise a pop-up informs to try again.

Table 21: UC2A - Log in.

ID	**UC2A**
Name	Log in
Functional requirement	FR22, FR23
Goal	The admin is able to log into the application.
Pre-condition	The admin is successfully registered.
Post-condition	The system shows to the admin his Admin Area.
Main success scenario	1. The admin fills all the entries, username and password. 2. The admin clicks on the "Login as Admin" button. 3. The system authenticates the admin's entered data. 4. The admin is logged in and presented the Admin Area.
Includes/Extends	Authentication: 2.a.1. The system is unable to find the admin's data. The application displays a "You are not an admin" message.

Table 22: UC3A - Log out.

ID	**UC3A**
Name	Log Out
Functional requirement	FR23, FR31
Goal	The admin is able to log out from the application.
Pre-condition	The admin is logged in.
Post-condition	The admin is redirected to the Log in page.
Main success scenario	e admin clicks on the "Log Out" button. e application shows the Log in page.
Includes/Extends	1.a.1 The system asks the admin if he is sure to log out. 1.a.2 A pop-up informs the admin about his successful log out.

Table 23: UC4A - Admin Area.

ID	**UC4A**
Name	Admin Area

Functional requirement	FR24
Goal	The admin is able to see the table containing all the patients registered in the application.
Pre-condition	The admin is logged in.
Post-condition	None
Main success scenario	1. The application displays the table containing all the patients registered in the application.
Includes/Extends	None

Table 24: UC5A - User Page.

ID	**UC5A**
Name	User Page
Functional requirement	FR25, FR26, FR27, FR28, FR29, FR30
Goal	The admin is able to see the user page of a specific patient.
Pre-condition	The admin is logged in.
Post-condition	None
Main success scenario	1. The admin clicks on the button “Show” related to a specific user in the Admin Area. 2. The application displays the user page of a selected patient. 3. The admin can access the personal information of the patient; he can add, modify, delete notes and save the changes. 4. The admin clicks on the buttons related to the two tasks. 5. The application shows the page related to the chosen task to access data. 6. The admin clicks on the “Show Data” button to access data related to a task completion date.
Includes/Extends	6.a.1 A pop-up shows data.

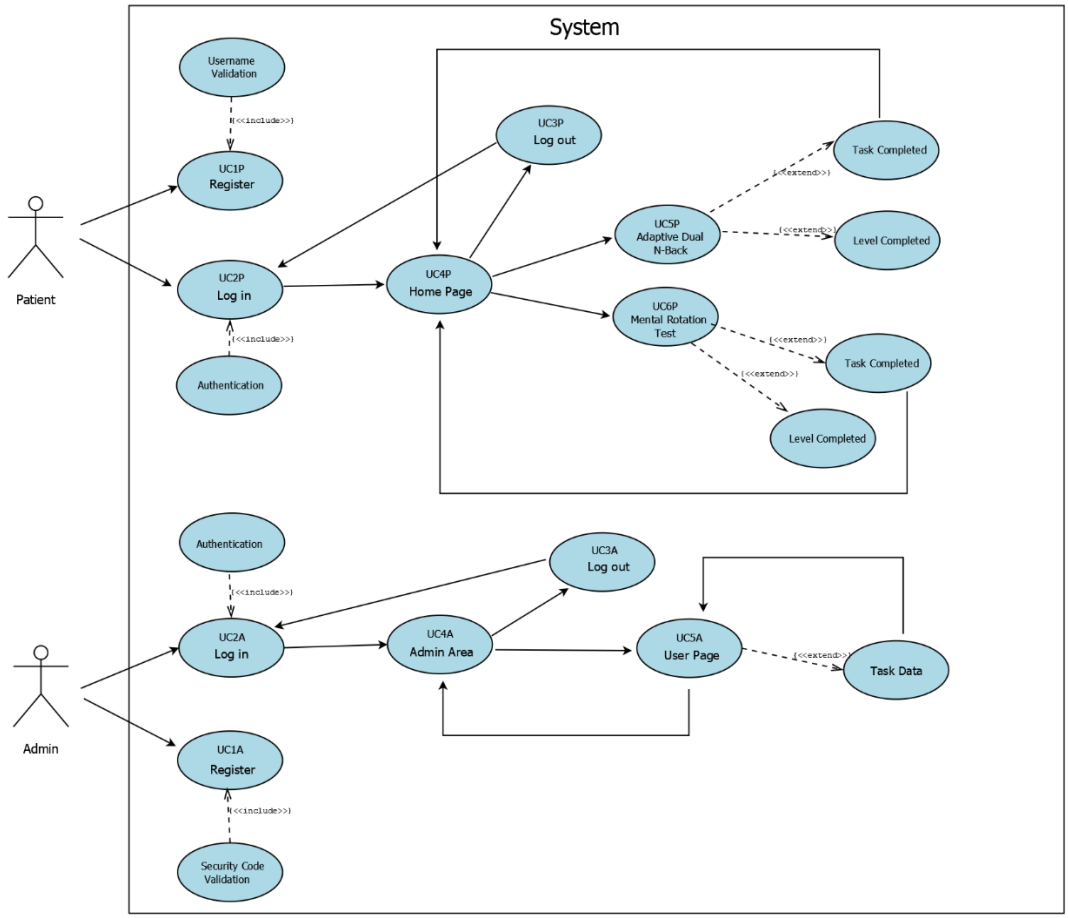

Figure 6: Actors interactions as use cases.

4.4 Architecture Layers

The architecture of the desktop application is structured into three main levels, each playing a crucial role in providing a smooth and reliable user experience. These levels are:

- ❖ User Interface Layer
- ❖ Application Logic Layer
- ❖ Data Layer

In this context, LC-Neurorehab, developed entirely in Python and accessible via the executable file (.exe), leverages a local SQLite database to efficiently manage data.

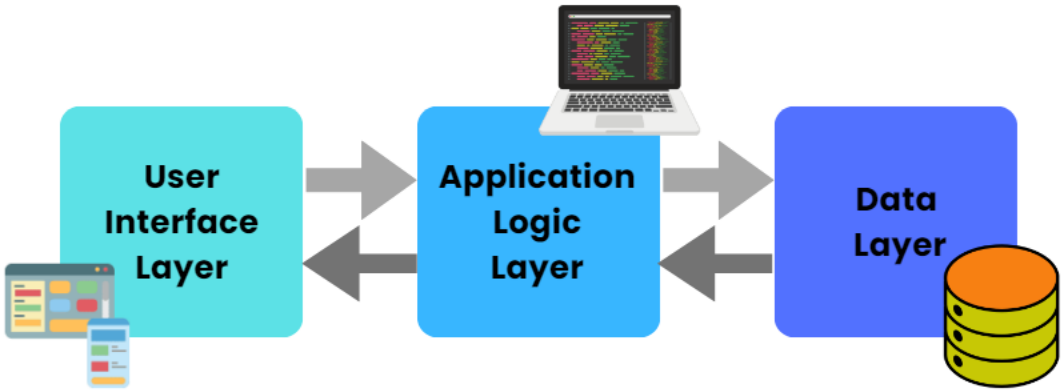

Figure 7: Layered architecture of LC-Neurorehab.

4.4.1 User Interface Layer

The "User Interface Layer" is the direct point of contact between the user and the application. It serves as the visual interface through which users (both patients and admins) interact with the provided functionalities. The desktop app features an intuitive and well-designed interface, delivering a pleasant user experience. Each visual element is carefully crafted to ensure user-friendly navigation, with utmost attention to clarity and design coherence.

4.4.2 Application Logic Layer

The "Application Logic Layer" constitutes the beating heart of the application, orchestrating user request processing and data manipulation.

An essential part of this layer is dedicated to handling data from the "Data Layer." Here, operations such as reading, writing, and updating data in the local database are managed. Business logic is rigorously applied to ensure data integrity and consistency.

Moreover, the "Application Logic Layer" is responsible for interpreting and processing user actions originating from the "User Interface Level." For instance, when a user interacts with an interface element, such as clicking a button or entering data into a form, this interaction is interpreted and translated into specific operations to be performed on the data. Specifically for patients, it coordinates the initiation and execution of rehabilitation activities, while for admins, it processes data access requests,

allowing control over progress and the ability to annotate feedback. Error handling and notifying the user of any issues are also integral parts of this layer, ensuring a clear and timely response during application usage.

4.4.3 Data Layer

The "Data Layer" represents the repository of information manipulated by the application. LC-Neurorehab utilizes a local SQLite database, enabling quick and efficient storage and retrieval of data without the need for an internet connection. The local database, integrated within the application itself, ensures data persistence even in the absence of a connection. The use of SQLite, known for its lightweight and reliable nature, contributes to maintaining optimal performance levels for the desktop application.

Chapter 5

5.1 Results Obtained

In this chapter, we delve into the intricate details of the technologies employed in the LC-Neurorehab project, the underlying database design, the fundamental structure of the source code, and finally, provide a comprehensive overview of the user interface. These elements form the technological and visual backbone of our product, enhancing its efficient functionality and ensuring user satisfaction.

5.2 Technologies Used

Figure 8: The technology used - Python.

The implementation of the desktop application took place in Python, a programming language renowned for its versatility and adaptability. The choice of Python was driven by the need to integrate the application into a neurofeedback loop, where EEG data is recorded. Given the complexity of the project, it was essential to use a language that would allow our developers to easily tailor the system to meet the evolving needs of neuroscientific research.

Python simplifies the development of complex programs while maintaining acceptable performance, a crucial requirement for research environments. The extensive Python developer community is an added value, ensuring continuous support and a wide range of resources, tools, and specific libraries. This has led to greater efficiency in developing and implementing the necessary functionalities for real-time EEG analysis and for potentially integrating artificial intelligence for training [13].

Python's open-source nature, combined with the availability of community-oriented packages, further facilitated the implementation of specific signal processing, learning, and deep learning functionalities. This approach has helped reduce development costs

and the complexity of the code required to achieve the same functionalities as other languages [13].

The main library utilized is PyQt5. It is a Python wrapper for the Qt GUI (Graphical User Interface) framework by Digia. Qt is a cross-platform framework widely used for desktop application development. PyQt5 enables Python developers to create rich and interactive user interfaces leveraging the power and flexibility of Qt.

Here are some key concepts of PyQt5 used in the code:

- *Widget*: PyQt5 offers a wide range of widgets, which are graphical components such as buttons, labels, text boxes, tables, and more. These widgets can be arranged and organized within windows to create the desired user interface.
- *Layout*: PyQt5 provides several types of layouts (such as QVBoxLayout, QHBoxLayout, QGridLayout, etc.) that allow organizing widgets flexibly and responsively within windows and containers.
- *Signals and Slots*: PyQt5 utilizes a mechanism called "Signals and Slots" for event handling. Widgets emit signals when certain actions occur, such as a mouse click, and these signals can be connected to slots (functions or methods) to manage the corresponding event. This mechanism provides a flexible and efficient way to manage events within PyQt5 applications.
- *Styling and Customization*: PyQt5 allows for the customization of the appearance and behavior of widgets through CSS and subclassing widgets to add custom functionality. This enables developers to create visually appealing and tailored user interfaces that align with the overall design and branding of their applications.

5.3 Database

In the design of LC-Neurorehab, SQLite is used as the primary database for several key reasons. Its portability makes it perfect for desktop applications as it is lightweight and does not require configuring a separate server, greatly simplifying the application deployment process. Additionally, the seamless integration of SQLite with Python means it can be immediately utilized without installing or configuring additional libraries, saving time and ensuring ease of development. Despite its lightweight nature, SQLite is fast and performs exceptionally well, managing significant data volumes and transactions efficiently. Its transactional support is crucial, providing ACID compliance for secure write operations, ensuring data integrity and consistency without concerns of corruption. SQLite's flexibility in schema allows agile modifications, and its single-file-based approach simplifies backup procedures.

The image below provides a detailed view of the database structure, unveiling the organization and arrangement of essential tables. We will explore the distribution of columns and relationships between data, offering a clear perspective on the fundamental informational framework beneath.

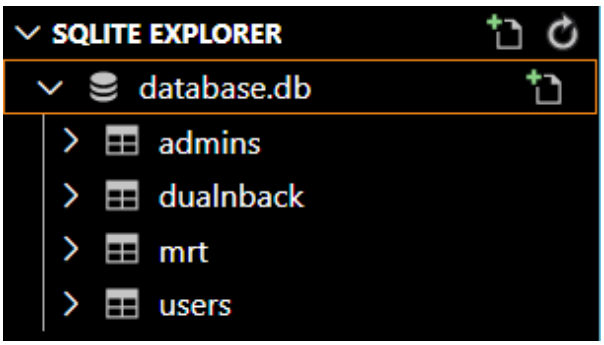

Figure 9: Database – Tables.

Table 25: Tables in the database with description and list of fields.

Tables	Fields
admins This table contains information about the administrators of the desktop app.	▪ username ▪ password ▪ salt
dualnback This table records user performance metrics in an Adaptive Dual N-Back cognitive training task.	▪ username ▪ level ▪ accuracy ▪ n_correct_audio ▪ n_correct_visual ▪ n_correct_both ▪ score ▪ date
mrt This table records user performance metrics in a Mental Rotation Test cognitive training task.	▪ username ▪ level ▪ accuracy ▪ n_images ▪ n_correct

	▪ n_wrong ▪ date
users This table contains information about the patients of the desktop app.	▪ username ▪ password ▪ name ▪ surname ▪ dateofbirth ▪ notes ▪ salt

5.3.1 Data Exchange with Integrated Database

The desktop application directly accesses the embedded SQLite database to retrieve or modify data. When the application needs to obtain information from the database, it executes a query directly on the integrated SQLite database.

After executing the query, the application receives the results directly from the integrated SQLite database. These results can be internally processed by the application according to its needs. For example, the data can be displayed within the application's user interface or used for further calculations or operations.

Similarly, if the application needs to update or modify data in the database, it performs insertion, update, or deletion operations directly on the embedded SQLite database.

```
db_connection = sqlite3.connect('database.db')
db_cursor = db_connection.cursor()
insert_query = "INSERT INTO dualnback (username, level, accuracy, n_correct_audio, n_correct_visual, n_co
insert_values = (self.username, self.n_back, self.accuracy, self.n_correct_audio,
                 self.n_correct_visual, self.n_correct_both, self.score, self.startdate)
db_cursor.execute(insert_query, insert_values)
db_connection.commit()
db_cursor.close()
db_connection.close()
```

Figure 10: Example instructions for performing operations on data in the integrated SQLite database from the desktop application.

5.4 Structure of the Code

The structure of the LC-Neurorehab's code is organized into a main folder containing a series of files and folders, each serving specific roles within the overall application. This

organization reflects a modular approach designed to ensure efficient management and clear division of responsibilities within the project.

The application primarily consists of several Python files, representing different functional components of the application itself. Each Python file manages a particular feature or module of the application. Additionally, there is a database file containing the data used and manipulated by the application.

This organizational structure facilitates the maintenance and development of the application, as it allows developers to focus on specific modules without having to manage a single monolithic file. Furthermore, it promotes a better understanding of the code, as each file has a clearly defined area of responsibility.

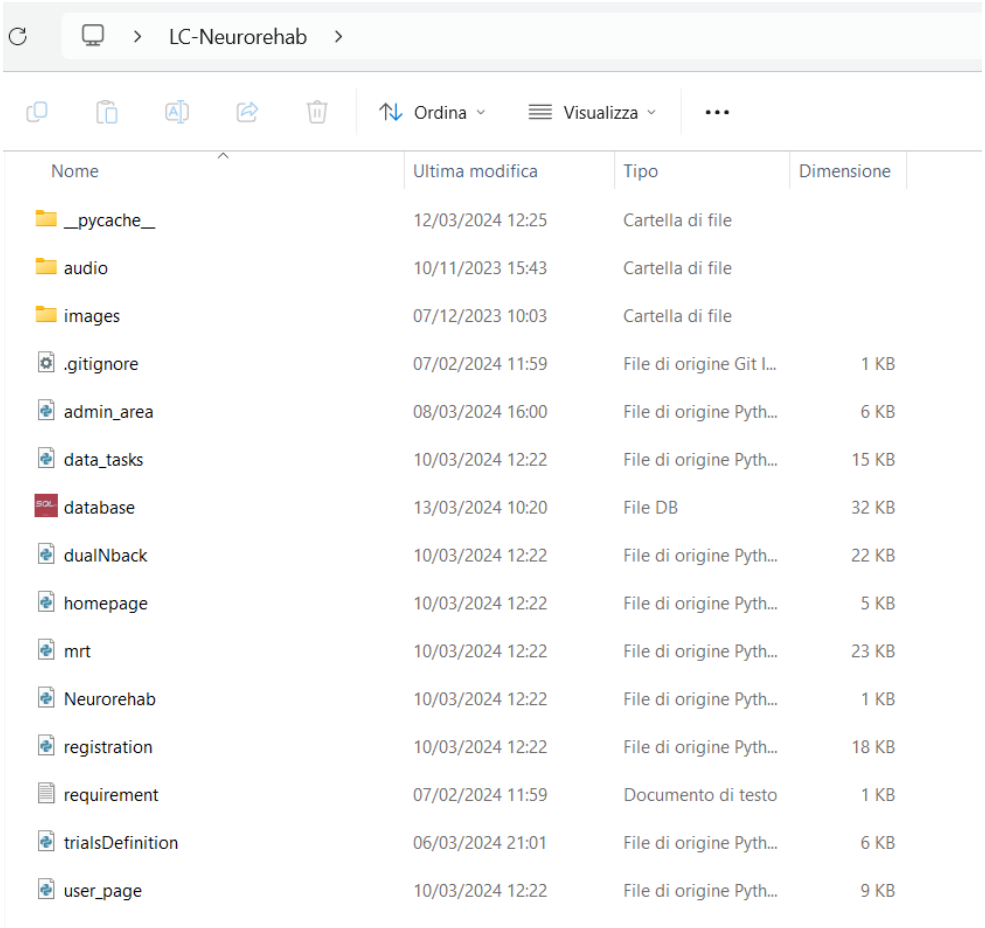

Figure 11: Main folder of the LC-Neurorehab desktop application - Files and key components of the project.

- **Neurorehab.py:** this file serves as the entry point of the application. It instantiates a login window defined in the subsequent file.

- **registration.py:** this file primarily manages the interface for user authentication and registration in the application.
- **home_page.py:** it represents the main page of the application, allowing logged-in patients to access the two available activities: Adaptive Dual N-Back and Mental Rotation Test.
- **dualNBack.py:** it implements the "Adaptive Dual N-Back" task, an exercise designed to improve working memory and attention through a series of stimulating tasks. The task is based on detecting matches between sequentially presented visual and auditory stimuli. The patient must press buttons corresponding to the matches found during the task, and the difficulty level is adaptive, varying based on the patient's performance.
- **trialsDefinition.py:** it defines the logic for generating the audio and visual trials of the "Adaptive Dual N-Back" game.
- **mrt.py:** it implements the "Mental Rotation Test" task, an exercise designed to improve concentration by enhancing mental rotation skills. The task requires patients to compare pairs of images of three-dimensional objects and determine whether the two images are identical or if one is a mirror image of the other. Objects can be rotated to various positions and angles, and the patient must be able to mentally visualize the transformations required to accurately compare the two images.
- **admin_area.py:** it contains the code related to the graphical interface of the administrative area of an application. This area is reserved for admins and provides them with tools and functionalities to manage the patients of the system.
- **user_page.py:** it contains the code related to the graphical interface of the patient's card within the application, accessible only to administrators. This page provides administrators with a detailed view of information regarding a specific patient and allows them to manage such information.
- **data_tasks.py:** it provides essential functionalities for managing and displaying patient activity data, allowing administrators to access and analyze activity results and keep track of patient information within the application.
- **database.db:** it contains the database associated with the desktop app.
- **requirements.txt:** it lists the dependencies required to run the application.

Additionally:

- **audio:** a folder containing all the audio used in the Adaptive Dual N-Back task.
- **images:** a folder containing all the images used in the desktop app (logo, images for the Mental Rotation Test).

5.5 Patient Interface

The "Patient Interface" section provides an overview of the various interfaces accessible to users within the LC-Neurorehab application. This section serves as an entry point for patients, allowing them to access a range of features and activities tailored to their rehabilitation needs. Below, images are presented illustrating the various interfaces available to patients.

5.5.1 Login page

This page (***Figure 12***) serves as the initial interface that patients encounter when launching the application. It allows them to log in by entering the username and password chosen during the registration phase, which will be discussed in the subsequent paragraph. After entering their credentials, patients can then click on the "Login" button to validate them (***Figure 13***). If successful, they will be redirected to the Home page. The page features the LC-Neurorehab logo, symbolizing the objectives of the application.

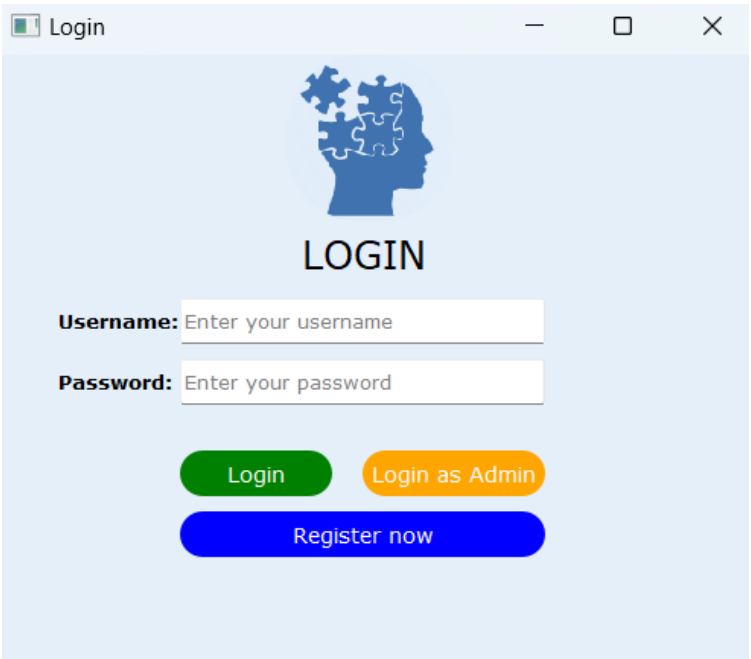

Figure 12: Login page.

Figure 13: Login page - example of field compilations of a patient.

If the patient attempts to log in without filling in the username and password fields and clicks on the "Login" button, an error message will appear stating "Invalid username or password (***Figure 14***).

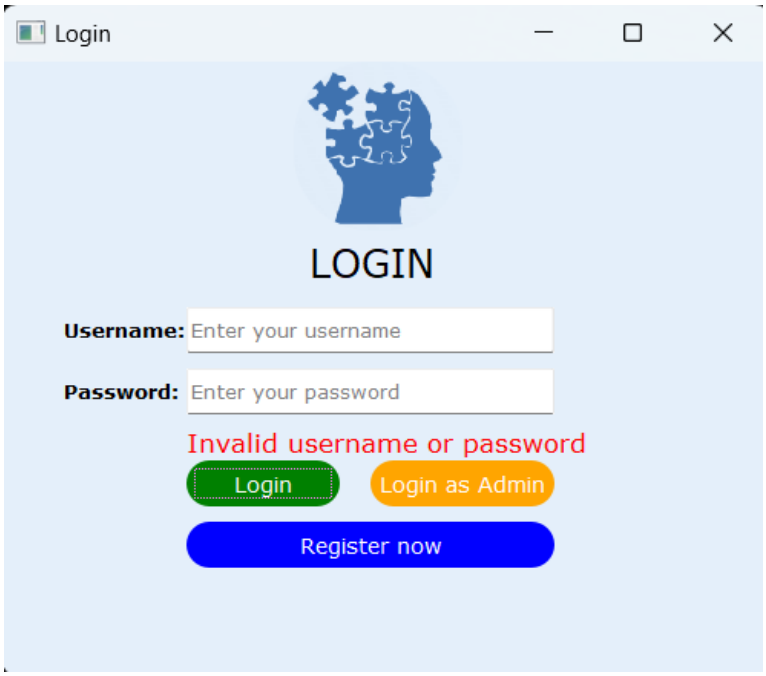

Figure 14: Login page - Invalid username or password.

If the patient enters an incorrect username and/or password, a specific error message will appear informing the user that the entered username or password is incorrect (***Figure 15***).

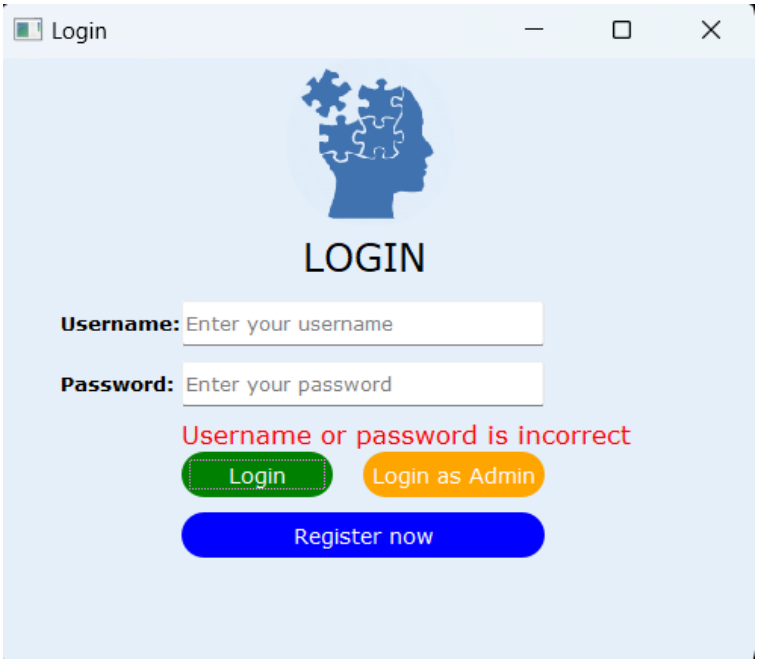

Figure 15: Login page - Username or password is incorrect.

5.5.2 Registration page

Before being able to log in and access the features provided by the desktop application, the patient is required to register. To do so, the patient must access the registration form by clicking on the "Register now" button on the login page (***Figure 12***). Within the registration form, the patient is prompted to provide their personal information: first name, last name, date of birth, username, and password (***Figure 16***). This registration process serves as the initial and crucial step to access the system, allowing each user to be uniquely identified. By providing these details, the patient can create a personalized profile and commence their journey within the application, ensuring a tailored experience and safeguarding the security of their personal information.

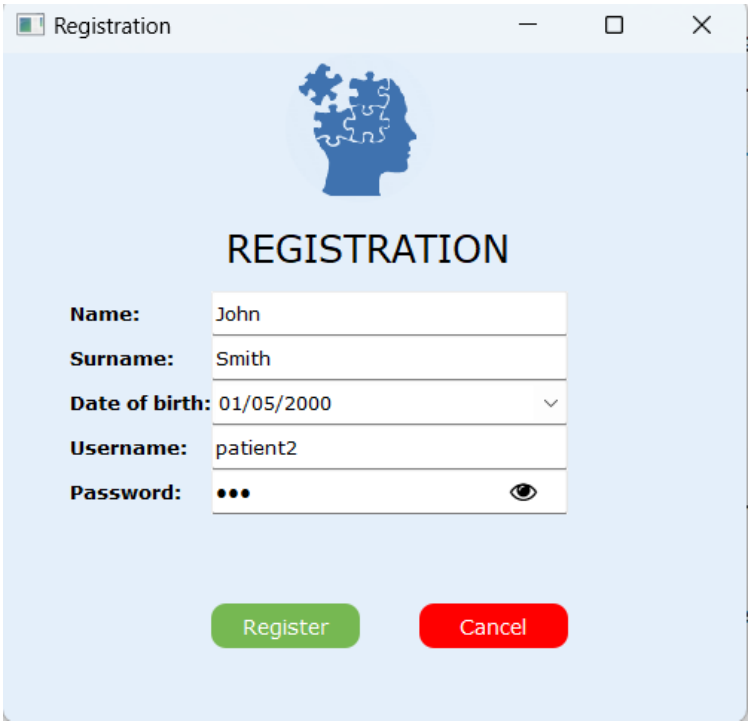

Figure 16: Registration page - example of field compilations.

It is essential for the patient to provide all the required information in the form. In the event that one or more fields are left blank, the system will display an error message indicating the need to complete all mandatory fields before proceeding further (***Figure 17***).

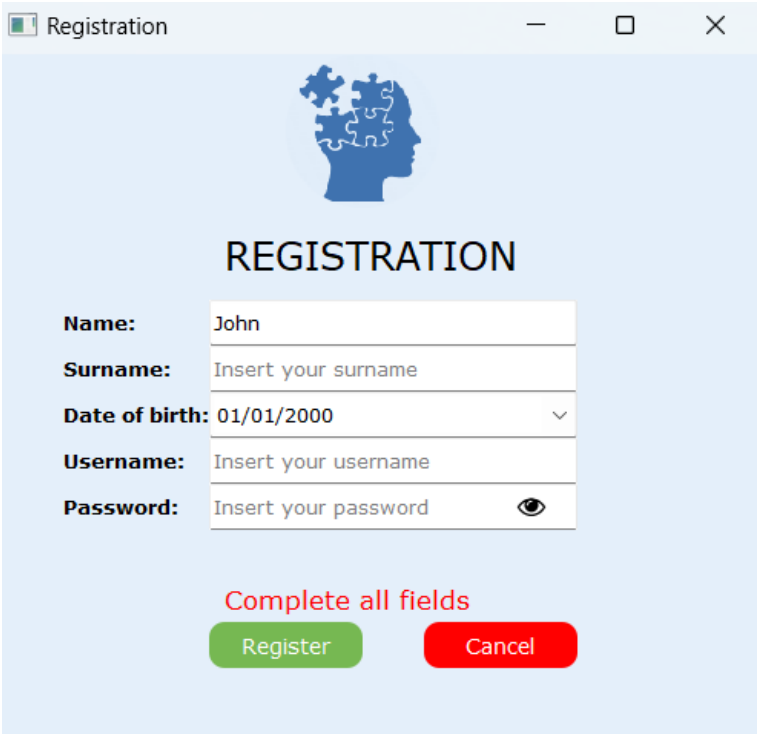

Figure 17: Registration page - Complete all fields.

If the patient enters a username already associated with another user in the system, they will be kindly asked to choose another one (***Figure 18***). This procedure is necessary to ensure the uniqueness of patient identifiers within the platform, in order to avoid confusion and ensure an optimal experience.

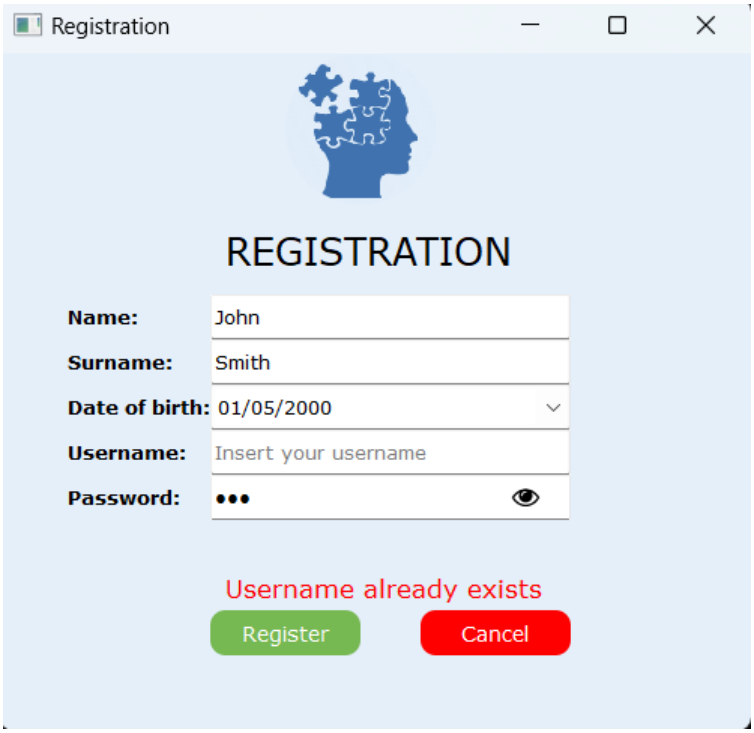

Figure 18: Registration page - Username already exists.

Once the patient fills out all the required fields and chooses a username not already used by another user, they can click on the "Register" button. At this point, the system will register the information of the patient and display a notification confirming successful registration through a pop-up (***Figure 19***). Subsequently, he will be redirected back to the login page, where he can enter their credentials (username and password). Upon logging in, he will be able to access the desktop app and utilize it for his needs.

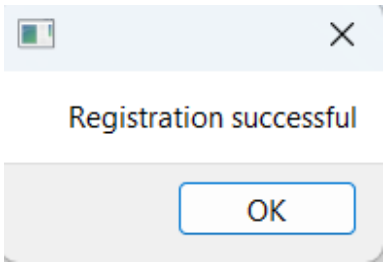

Figure 19: Registration pop-up - registration successful.

5.5.3 Home page

After logging in, the patient will be directed to their homepage, where they will find two buttons allowing access to the two tasks implemented in the application: the Adaptive Dual N-Back and the Mental Rotation Test. Through these buttons, he will be able to select and initiate the desired task. Additionally, he will have the option to log out by clicking on the "Log out" button located in the top right corner of the page (***Figure 20***).

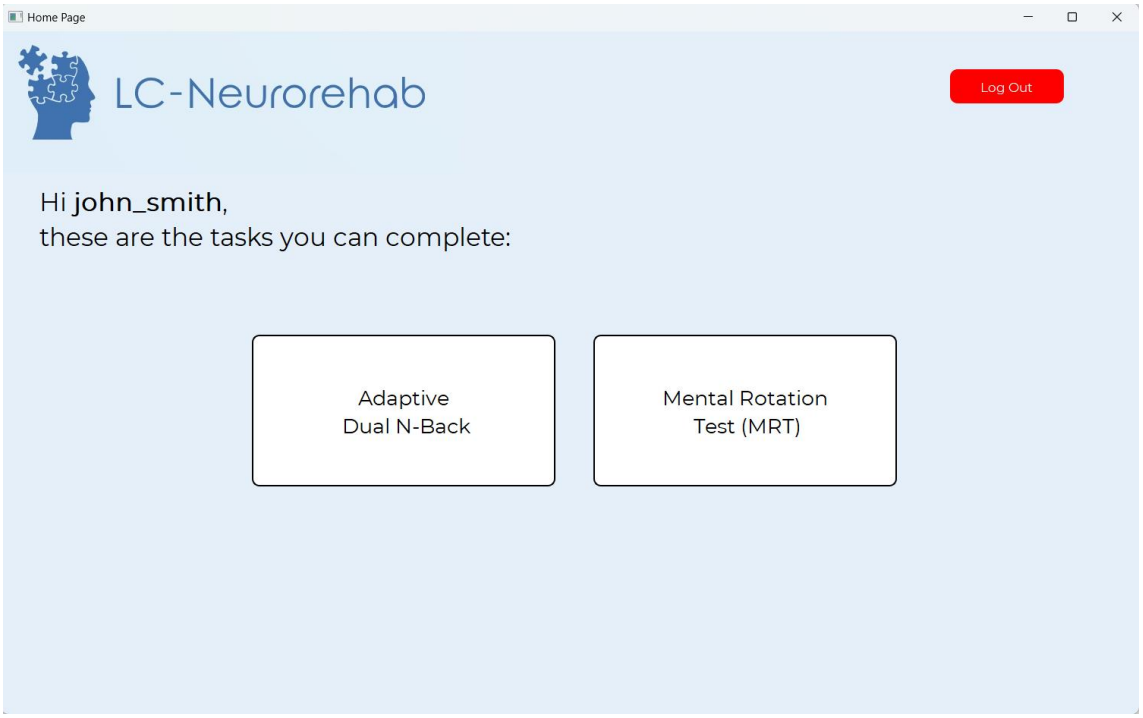

Figure 20: Home page.

5.5.4 Mental Rotation Test

When the patient is on the homepage *(**Figure 20***), they can choose between the two available tasks or be guided in their decision. If he decide to take the Mental Rotation Test, he simply need to click on the corresponding button. He will then be directed to the test introduction page (***Figure 21***) for instructions. From there, he can start the task by clicking "Start Game" or return to the homepage by selecting "Back" in the top right corner.

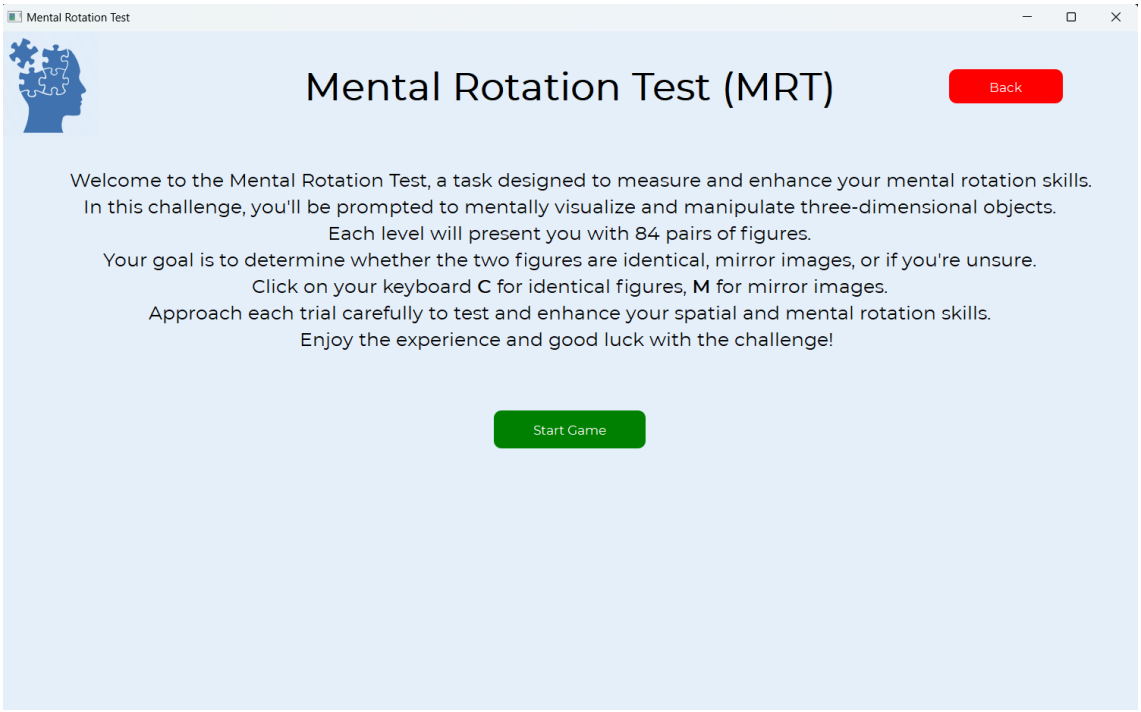

Figure 21: Mental Rotation Test – Introduction page.

During the task, the patient will be shown images representing two solids, with the goal of determining whether the solid on the right is identical or different from the one on the left (referred to as the target figure). Once the game is started, it will not be possible to go back unless the patient closes the window by clicking on the "x" in the upper corner. In the game interface, the initial level and the corresponding keyboard keys that the user will need to press to complete the task will be displayed (***Figure 22***).

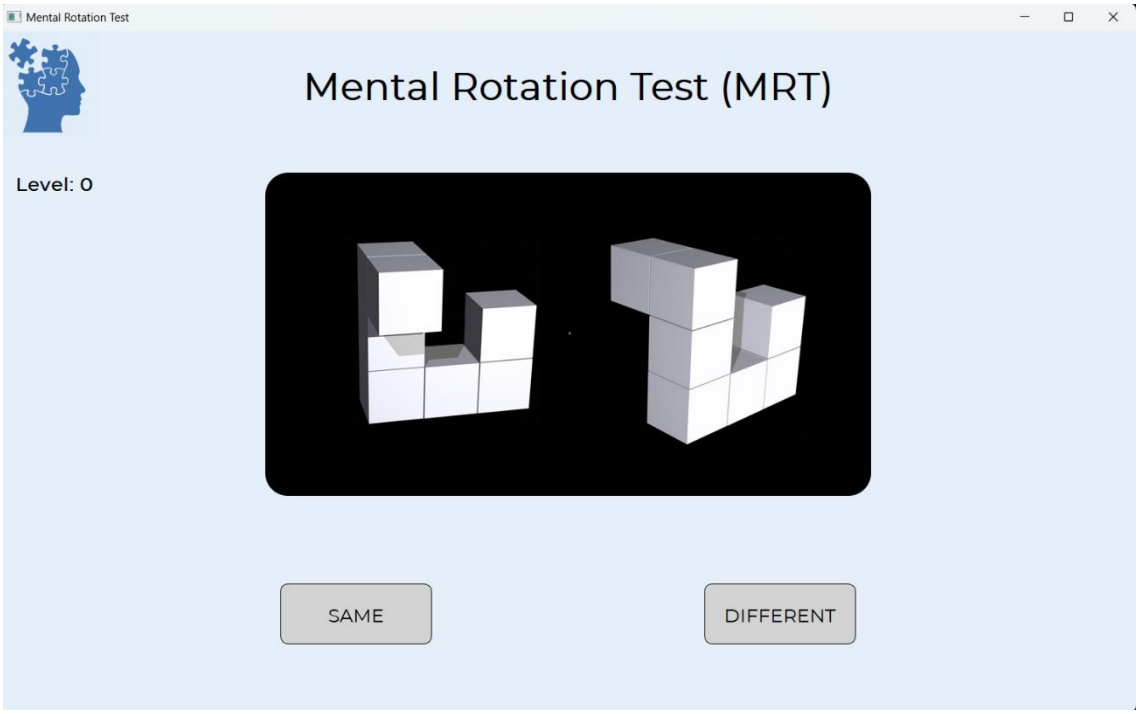

Figure 22: Mental Rotation Test - task simulation.

This pop-up (***Figure 23***) appears when the patient completes a level, and if their accuracy reaches a specific value set by the game, he will be allowed to advance to the next level.

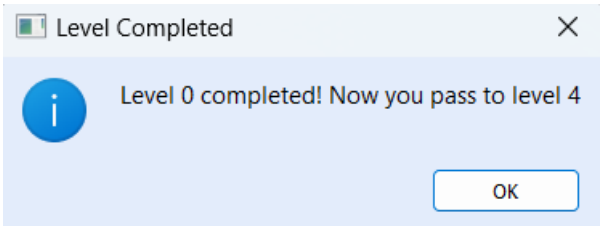

Figure 23: Mental Rotation Test pop-up - level completed, pass to next level.

This pop-up (***Figure 24***) appears in two specific situations: when the patient's accuracy at the end of a level is less than 75%, which will return him to the previous level; or when the accuracy is between 75% and 95%, including 75%, which will result in the repetition of the just completed level.

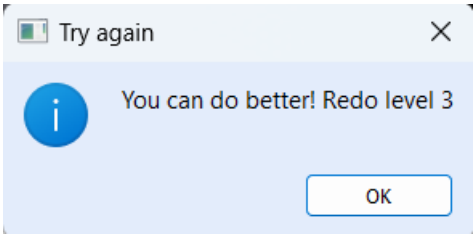

Figure 24: Mental Rotation Test pop-up - redo level.

This pop-up (***Figure 25***) appears when the task is completed, and the patient will be redirected to the home page.

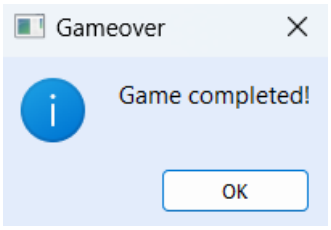

Figure 25: Mental Rotation Test pop-up - game over.

5.5.5 Logout

As mentioned earlier, from the homepage, the patient has the option to log out from the desktop application by clicking the "Log out" button. Before proceeding with the logout, a pop-up window will appear asking the user to confirm his intention to log out (***Figure 26***). In the event of a negative response, the patient will be redirected to the application's homepage. However, if the response is affirmative, a second pop-up (***Figure 27*****Errore. L'origine riferimento non è stata trovata.**) will appear confirming the successful logout, thus ensuring clear communication of the disconnection process.

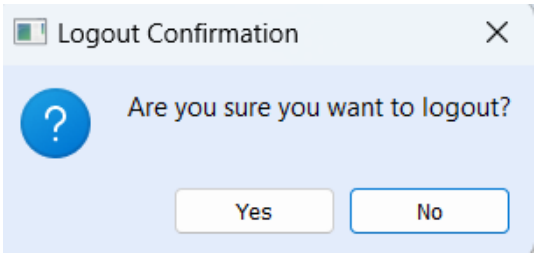

Figure 26: Logout pop-up - confirmation.

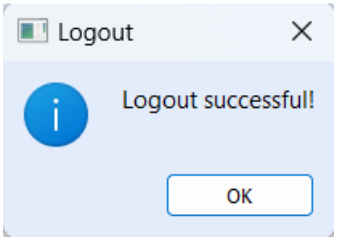

Figure 27: Logout pop-up - logout successful.

5.6 Admin Interface

The "Admin Interface" section provides an overview of the various interfaces accessible to administrators within the LC-Neurorehab application. This space serves as a control center for administrators, equipping them with the necessary tools to efficiently manage patients and analyze data related to their activities. Below, images are presented illustrating the various interfaces available to administrators.

5.6.1 Login/Registration page

In the case of the administrator login interface, it appears identical to that of the patients (***Figure 12*****Figure *12***). However, the process differs significantly. When an unregistered administrator enters their credentials (username and password) and selects the "Login as Admin" button (***Figure 28***), a pop-up (***Figure 29***) appears requesting the entry of a security code. This code serves to confirm the authenticity of the administrator during the registration process. If the entered code is incorrect, an error message (***Figure 30***) appears prompting the admin to retry. Conversely, if the code is correct, a pop-up (***Figure 31***) confirming the administrator's registration appears. Once registration is successfully completed, the administrator can log in and access their dashboard, utilizing all available management functionalities. In the event that an administrator enters incorrect credentials, an error message will appear (***Figure 32***).

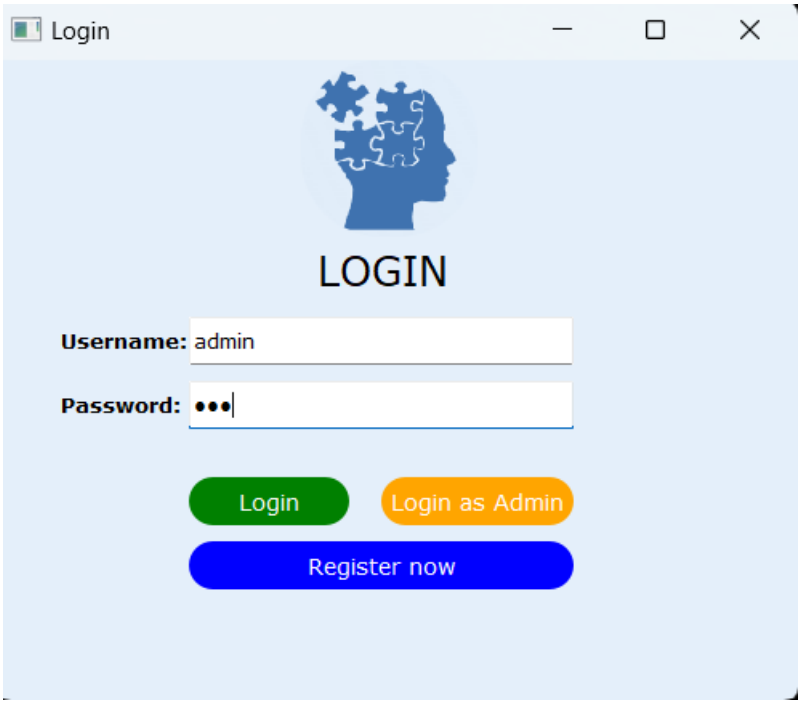

Figure 28: Login page - example of field compilations of an admin.

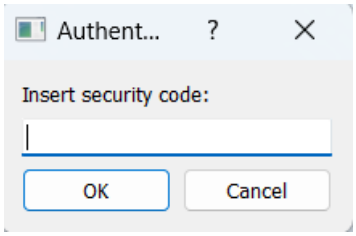

Figure 29: Security code pop-up.

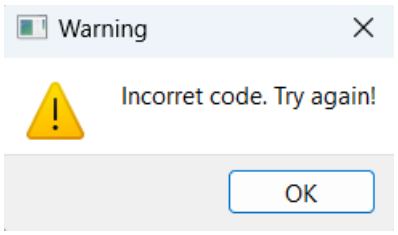

Figure 30: Security code pop-up - try again.

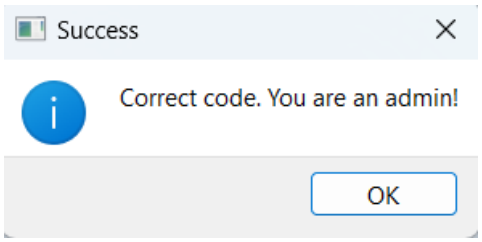

Figure 31: Security code pop-up - success.

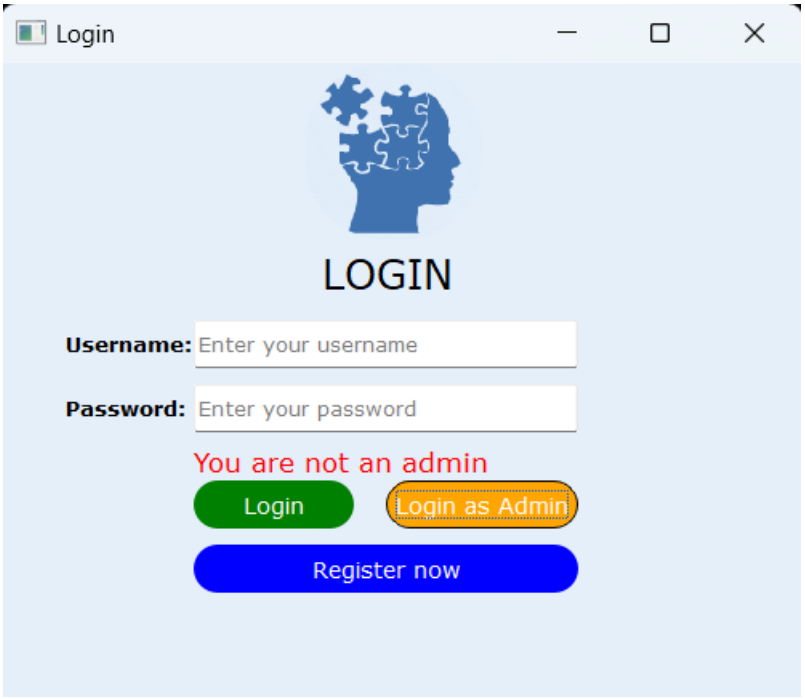

Figure 32: Login page - You are not an admin.

5.6.2 Admin area

After logging in, the admin will be directed to their admin area (***Figure 33***) where they will see a table with all the patients registered on LC-Neurorehab, with the ability to access the personal page of each patient listed. The administrator can select a patient to analyze by clicking on the "Show" button corresponding to the chosen patient. Additionally, he will also have the option to log out from the desktop app by clicking the "Log out" button located at the top right corner. The logout process is the same as that performed by the patient [***5.5.5 Logout***].

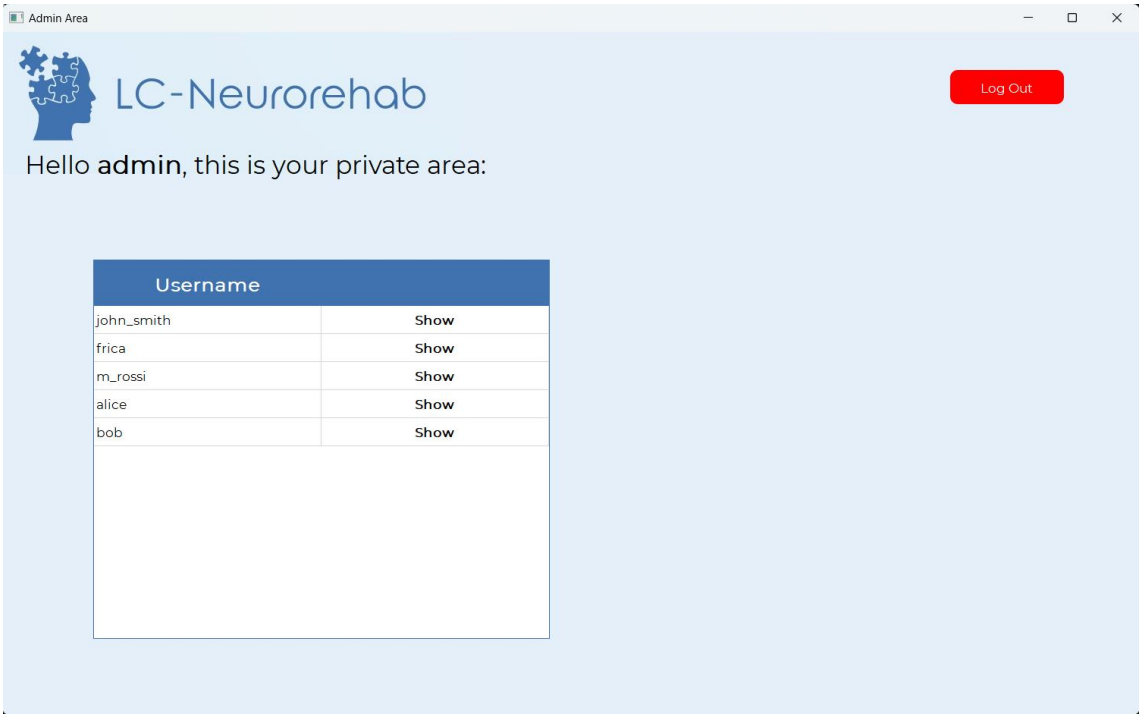

Figure 33: Admin area.

5.6.3 User page

In the specific page of the selected patient there are his personal information (provided during registration: name, surname, and date of birth) and two buttons to access the data related to the activities. Additionally, the administrator will have the option to return to the admin area page using the "Back" button located in the top right corner (***Figure 34***). Additionally, the admin also has the capability to input, delete, and modify notes related to a patient (***Figure 35***). These notes are saved, and during this process, pop-up messages will appear to confirm actions (***Figure 36***) and to indicate successful saving of changes (***Figure 37***).

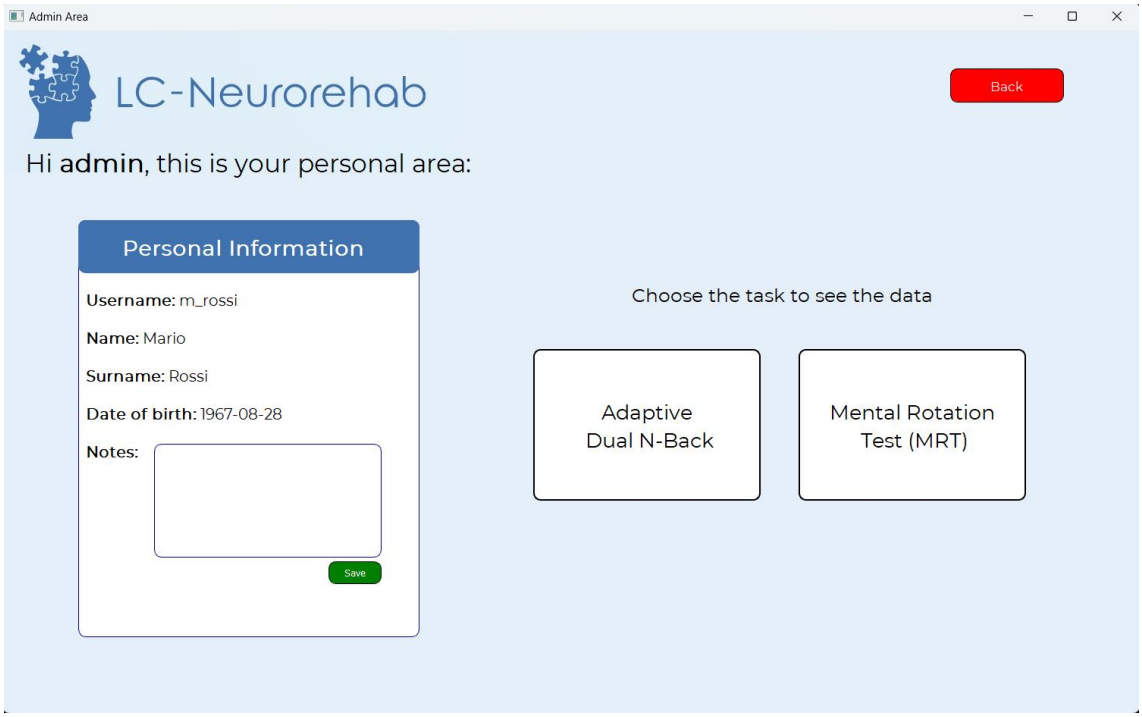

Figure 34: User page.

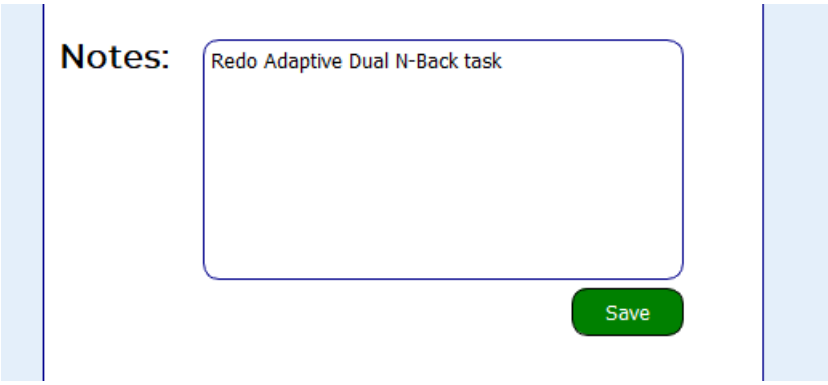

Figure 35: User page - notes.

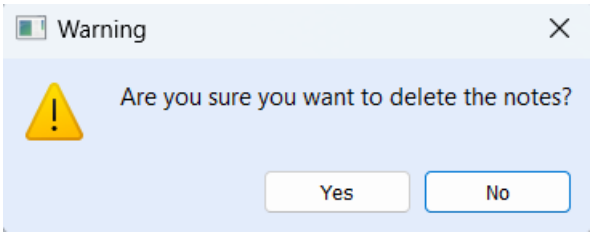

Figure 36: User page pop-up – confirmation.

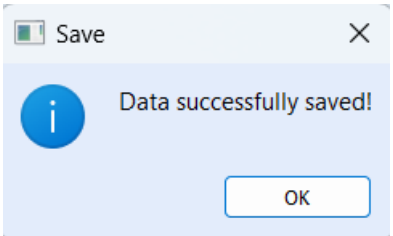

Figure 37: User page pop-up - success.

As mentioned earlier, the admin can view performance data for both tasks by clicking on their respective buttons. Clicking on the buttons he will redirect to the respective task's page, where two scenarios may occur: either the patient has not yet completed the task, and the message "Data not available" will appear (***Figure 38***)(***Figure 39***), or a table will display all the dates on which the patient has performed the task. This table provides the option to view data for a specific date by clicking on the "Show Data" button (***Figure 40***)(***Figure 41***). Of course, the administrator always has the option to go back using the respective button to return to the previous page.

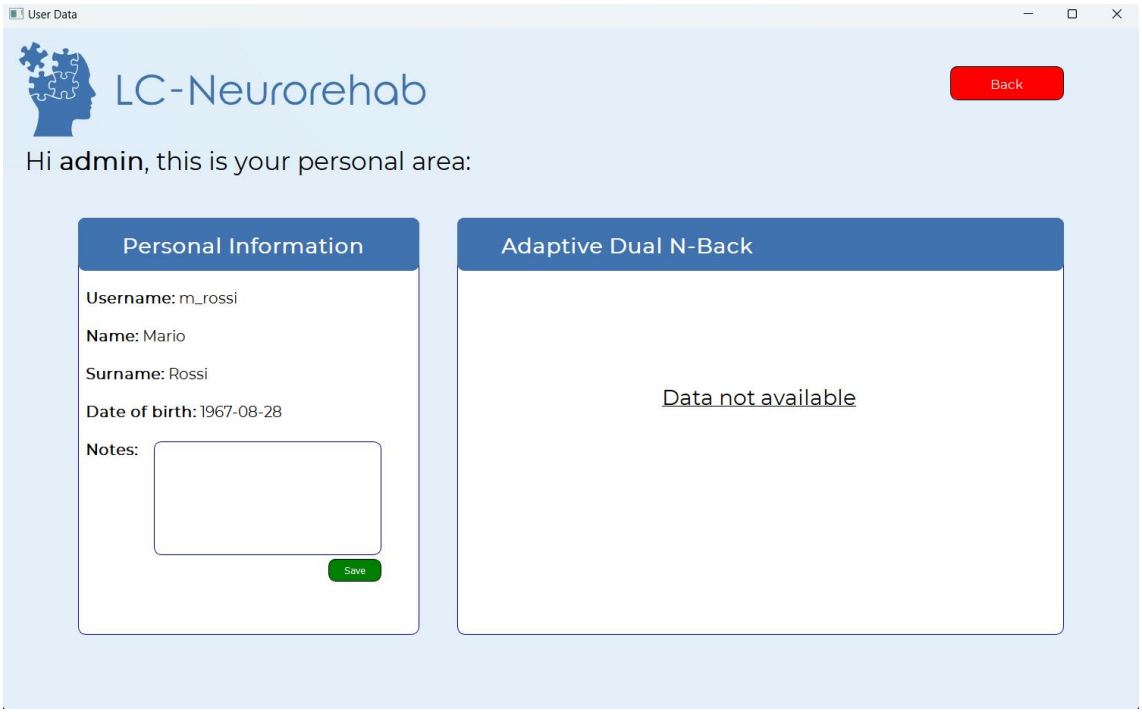

Figure 38: User page - Adaptive Dual N-Back - Data not available.

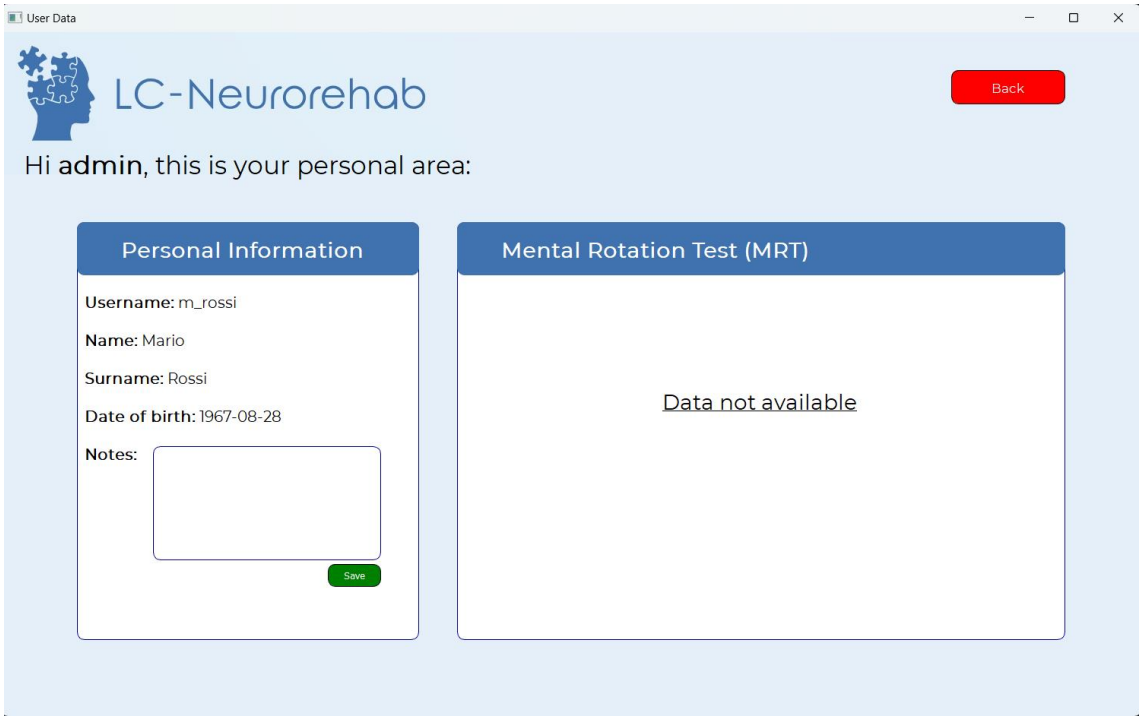

Figure 39: User page - Mental Rotation Test - Data not available.

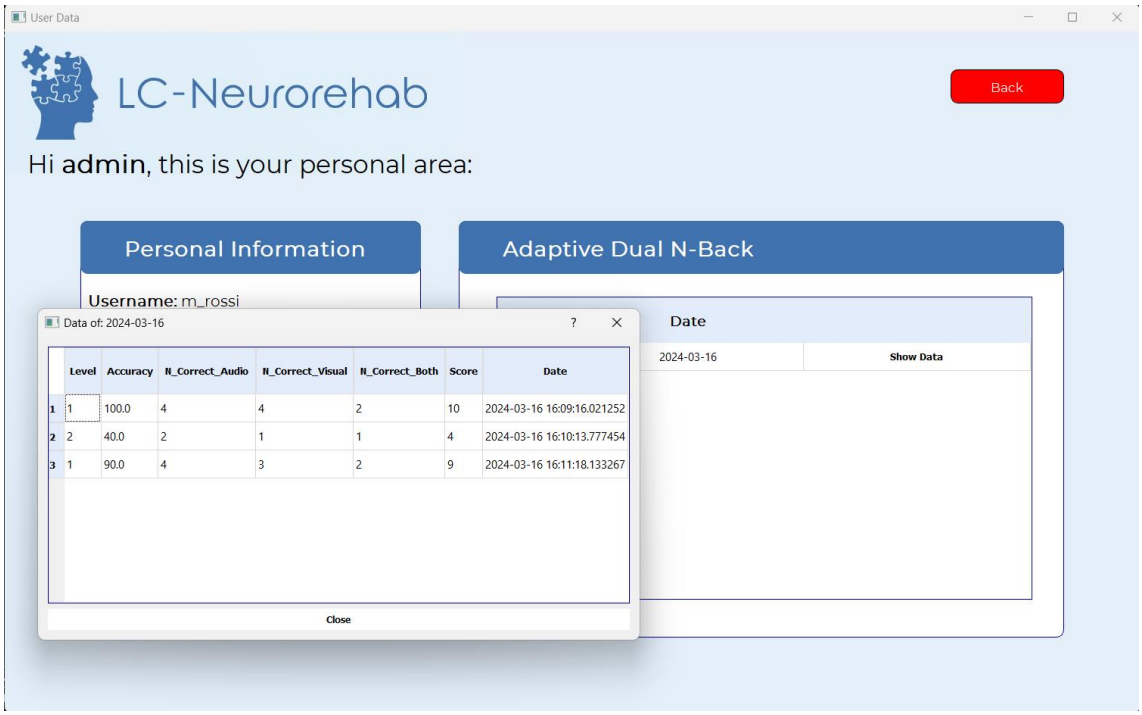

Figure 40: User page - Adaptive Dual N-Back - data.

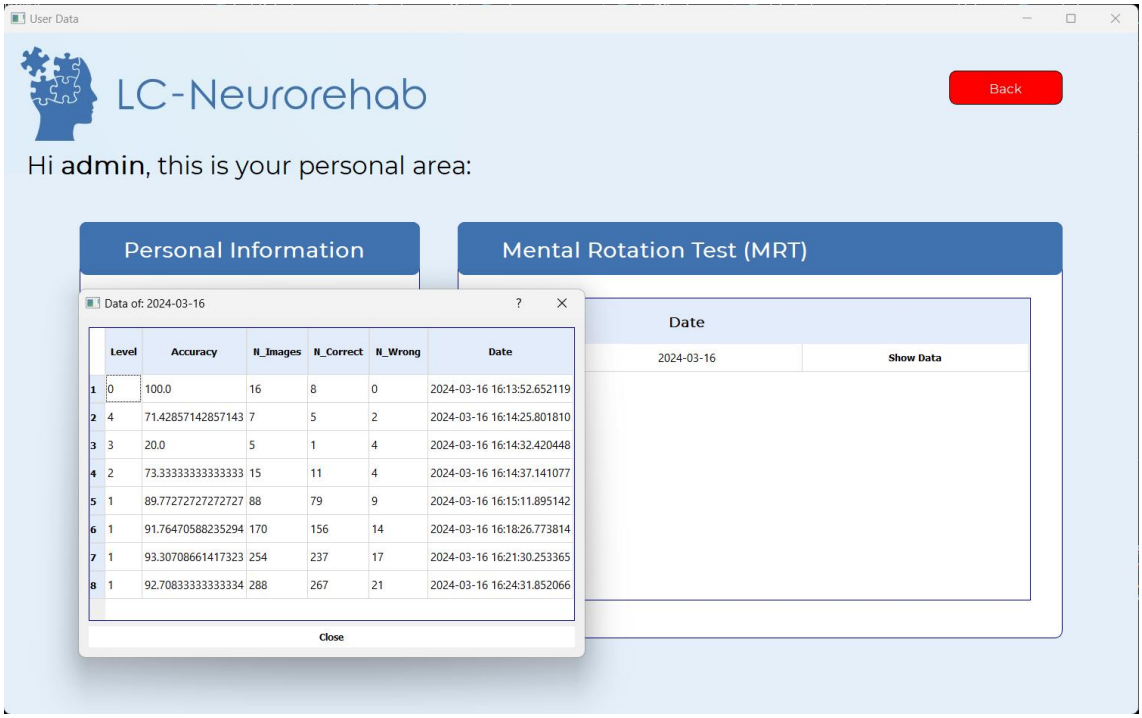

Figure 41: User page - Mental Rotation Test - data.

Chapter 6

6.1 Future steps

In the context of the broader LC-Neurorehab project, this thesis represents just a starting point, as further developments and improvements are needed to make the application fully functional and suitable for the needs of Long Covid patients. Future steps are crucial for the progress and success of the project. Primarily, graphical improvements to the application are planned to make the user experience more enjoyable and intuitive, for example, making the application responsive. The addition of new tasks and greater customization of existing task functionalities is foreseen to better adapt them to the specific needs of patients. Additionally, it will be important to develop a system for customizing the application's language so that it can be tailored to each patient's language preferences. Another crucial aspect will be to conduct an extensive testing process, involving both computer experts to identify and resolve any code-related issues, and psychologists who will function as end users, evaluating the overall user experience and providing feedback to improve the application. Addressing the challenge of integrating EEG signals into the application to allow for a more accurate assessment of patients' cognitive performance will be necessary. This may require the development of artificial intelligence capable of processing EEG signals and providing useful outputs to further personalize tasks based on patients' specific needs. Finally, the ultimate goal will be to implement this system in neurorehabilitation centers to provide effective support for the cognitive recovery of Long Covid patients. The focus will be on improving concentration, attention, and anxiety management through the targeted use of LC-Neurorehab.

6.2 Conclusion

In conclusion, this thesis work, which focused on the development of the LC-Neurorehab desktop app for neurorehabilitation, stands as a significant contribution to the cognitive improvement of Long Covid patients experiencing neurological issues. Through this research, an innovative solution has been introduced, aiming to provide personalized and targeted support, enabling patients to more effectively address cognitive challenges associated with Long Covid. However, this work represents just a starting point, and further developments are necessary to optimize the application and ensure an even more significant impact in the context of neurorehabilitation for Long Covid patients.

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