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LC-Neurorehab: a Working Memory Training tool to enhance attentional control in people suffering from Long Covid syndrome

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Abstract

This thesis is a contribution to the project "Happy Again", with the University of Essex, aimed to assess the neurological consequences of COVID-19.
The project focuses on identifying which psycho behavioural markers are influenced by Long Covid syndrome and their interrelations to assist researchers, clinicians, and rehabilitation therapists in better assessing risks, charting recovery paths, and restoring optimal mental and physical functioning. Through the "Happy Again" online platform (https://happyagain.essex.ac.uk/), we involved participants in a series of cognitive assessments to identify behavioural markers associated with potential neuropsychological deficits.

Building upon this foundation, the current thesis project seeks to expand the investigation into the effects of cognitive training on neurorehabilitation for patients suffering of Long Covid.

"LC-Neurorehab" was created in direct response to this requirement: it is a desktop application that focuses on enhancing working memory and improving attentional control among individuals affected by Long Covid who experience attentional difficulties and dealing with significant functional limitations.

LC-Neurorehab is based on the key findings presented in papers such as "The Role of Practice and Strategy in Mental Rotation Training" [1] and "Training Working Memory to Improve Attentional Control in Anxiety" [2]. In particular, the implementation of the Mental Rotation Test and the Adaptive Dual N-Back aims to explore how targeted practice and the use of specific strategies can positively influence cognitive abilities.

The adopted methodology includes a rigorous analysis of both functional and non-functional requirements to ensure a smooth and interactive user experience, while the development of features such as the homepage, authentication, registration, and administrative management aims to create an environment accessible to both patients and professionals. The primary goal is to provide a significant contribution to the field of neurorehabilitation, demonstrating how dedicated technologies can facilitate the improvement of cognitive functions in patients with Long Covid syndrome.

The desktop application has been developed using the Python programming language, chosen for its versatility and the extensive support it offers for data analysis and manipulation. Python's ability to interact real time with external devices, such as EEGs, and its extensive libraries for scientific computing make it an ideal choice for the optimization of performance and ensures that the application can be easily extended and integrated with new tools and methodologies in the future.

The purpose of this thesis is to document the activities carried out as part of the research study described above, providing details on the design, architecture, and implementation of the application with a primary focus shifted towards the implementation of the Adaptive Dual N-Back task. This task, designed to be adaptive and targeted, dynamically adjusts the difficulty level based on the user's performance, offering a personalized approach to cognitive training. By training both working memory and attentional control, the Adaptive Dual N-Back task represents a significant contribution to Long Covid neurorehabilitation.

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Introduction

At the end of 2019, the world faced an unprecedented health crisis with the emergence of an unknown virus in the city of Wuhan, Hubei province, China. This pathogen, initially identified as 2019-nCoV and later renamed SARS-CoV-2, sparked an epidemic of acute respiratory illnesses. The situation quickly escalated, surpassing the scope of a mere epidemic to evolve into a global pandemic, alarming the international community. On March 11, 2020, the World Health Organization (WHO) officially declared COVID-19 a pandemic [3], underscoring the magnitude and severity of a health crisis that had already begun to profoundly impact the globe, infecting millions of individuals, resulting in a significant number of deaths, and overwhelming the healthcare systems of numerous countries: up until September 2022 alone, more than 600 million confirmed cases of COVID-19 have been estimated, with around 6 million deaths [4].

During the COVID-19 pandemic, it has emerged that the virus can lead to a wide range of clinical manifestations, ranging from asymptomatic infections to severe acute respiratory distress syndrome and multiorgan failure with a high risk of mortality. Fortunately, the majority of individuals infected with COVID-19 recover within a few days or weeks, regardless of symptom severity. However, there is a subset of individuals who experience long-term effects, which can last for weeks, months, or even longer, known as Post-COVID-19 Syndrome or Long Covid.

Patients affected by Long Covid can present with a variety of symptoms, which may persist from the acute infection or emerge as new symptoms, affecting various organs and systems. Estimates of the impact of Long Covid vary depending on the definitions used and the populations studied. However, research indicates that a significant proportion of individuals infected with the SARS-CoV-2 virus experience prolonged symptoms. Recent studies suggest that between 10% and 30% of COVID-19 patients develop symptoms of Long Covid, with some reports indicating even higher percentages in specific subgroups, such as those with initially severe infections or individuals with pre-existing medical conditions [5,6].

The symptoms of Long Covid are extremely varied, ranging from headaches to persistent loss of smell and taste, to psychological symptoms such as anxiety and depression, and more severe symptoms like cardiac issues and thromboembolic complications. Among cognitive impairments, "brain fog," a colloquial term used to describe difficulty concentrating, memory problems, confusion, and inability to perform normal mental tasks, emerges as the most common and debilitating symptom. Other neurological issues include persistent headaches, dizziness, sleep disturbances, peripheral neuropathies, and in some cases, more severe symptoms such as seizures or signs of encephalitis.

The exact causes of Long Covid are not yet fully understood, but it is believed that a combination of immunological, inflammatory, and neurological factors may contribute to the persistence of symptoms over time. Systemic inflammation, hyperactive immune responses, and direct damage from the virus to tissues and organs may all play a role in the etiology of the post-infectious syndrome. Additionally, psychological and social factors, such as stress and social isolation, may influence the severity and duration of symptoms in Long Covid.

The management of Long Covid requires an integrated and multidisciplinary approach involving clinicians, researchers, therapists, and patients themselves. It is necessary to develop targeted treatments that can specifically address persistent symptoms and improve the quality of life of patients affected by this complex post-infectious syndrome. Furthermore, further research is needed to fully understand the causes, pathophysiological mechanisms, and long-term implications of Long Covid in order to develop more effective preventive and therapeutic strategies to address this continuously evolving global challenge.

In this context, the University of Essex initiated "Happy Again," a research project focused on investigating Post-COVID Syndrome, particularly its neurological effects. The project aims to study specific behavioral markers that may indicate neural integrity and cognitive functioning, such as response speed and accuracy to visual and auditory stimuli, the "temporal binding window" for sensory integration, sensory adaptation responses, and retention of verbal information. These markers could serve as biomarkers for neurological damage caused by COVID-19. "Happy Again" seeks to understand how COVID-19 affects these aspects of brain function and whether there is a systematic correlation with the intensity and persistence of symptoms.
The goal is to provide researchers, clinicians, and rehabilitation therapists with crucial data to guide risk assessment and recovery, contributing to the restoration of mental and physical well-being after COVID-19. The project leverages a web platform for administering behavioral tests and data collection, facilitating participation from home, thus promoting a broad collection of valuable information for current and future studies.

This thesis outlines the contribution to the development and implementation of "LC-Neurorehab," an advanced neurorehabilitation program that emerged as a direct evolution of the "Happy Again" project. Focusing on the integration of the Adaptive Dual N-Back and the Mental Rotation Test activities, the work involved collaboration with a multidisciplinary team of students, led by specialists from the University of Essex. In this project, together with my team, I handled the entire application development process, starting from gathering functional and non-functional requirements to the final implementation of the application, with a particular focus on implementing the Adaptive Dual N-Back task. The outcome was the creation of a desktop application specifically designed to facilitate cognitive recovery in patients affected by Long Covid, enabling them to perform targeted exercises and track progress over time.
"LC-Neurorehab" aims to address post-COVID neurological and cognitive disorders, providing assessment and intervention tools based on data collected from its predecessor "Happy Again," with the goal of improving patients' quality of life through rehabilitative pathways.

Bearing in mind what has been told so far, this thesis is organized as follows:

- **Chapter I** introduces the context of Long Covid and the need for specific neurorehabilitation interventions. An overview of the neurological and cognitive disorders affecting post-COVID patients is provided, emphasizing the importance of developing evidence-based therapeutic strategies.
- In **Chapter II**, the desktop application project is described thoroughly, emphasizing its objectives and enumerating its functional and non-functional requirements.
- In **Chapter III**, the developed solution is documented and elaborated upon, delineating the various layers constituting the application.
- In **Chapte**r **IV**, discusses the application development process, highlighting the impact of selected technologies and strategies on the software. It examines the design, development, and implementation phases, with a particular focus on the architecture and design choices, and the results achieved in implementing them.
- Lastly, in **Chapter V** the thesis' conclusions are presented, together with some possible future developments.

Chapter I

Justification

1.1 COVID-19: Context and Origins

Coronaviruses, a diverse family of viruses known as Coronaviridae, have long been recognized for their distinctive crown-like appearance under the microscope, a characteristic attributed to the club-shaped glycoprotein spikes that adorn their envelopes [7]. These viruses are enveloped RNA viruses, containing a single strand of positive-sense RNA that serves as their genetic blueprint. This RNA is crucial for the virus's ability to replicate and for encoding the proteins necessary for infecting host cells.

While coronaviruses predominantly infect animals, several strains have made the jump to humans, causing illnesses ranging from the common cold to more severe respiratory diseases. The novel coronavirus, SARS-CoV-2, which emerged in late 2019, marked a significant point in the history of these viruses. It led to a global pandemic of COVID-19, a respiratory illness that underscores the zoonotic nature of coronaviruses—capable of being transmitted between animals and humans. The origins of SARS-CoV-2 are believed to trace back to bats, with potential transmission to humans via an intermediate animal host, highlighting the complex interplay between wildlife and human health. COVID-19, caused by SARS-CoV-2, primarily spreads through close human-to-human contact, illustrating the highly contagious nature of this virus.

1.1.1 Impact of COVID-19

The COVID-19 pandemic, caused by SARS-CoV-2, has highlighted the ability of coronaviruses to profoundly affect not just the respiratory system but also the human nervous system. The wide range of neurological complications observed, from confusion and stroke to neuromuscular disorders and depression, underlines the complexity of the infection's consequences. These long-term effects have been shown to persist well beyond the acute phase of the illness, affecting individuals of all ages and conditions, including those who experienced mild forms of the infection.

Research conducted on patients with COVID-19 has revealed a significant incidence of various neurological and psychiatric conditions, including anosmia (loss of smell), encephalopathy, and various psychiatric and peripheral nerve disorders. Such findings suggest the involvement of complex and diverse pathogenic mechanisms. Initially, it was believed that the virus could directly attack the central nervous system; however, the analysis of cerebrospinal fluid generally showed a low presence of viral RNA, shifting the focus to the hypothesis that neurological complications might rather stem from an exacerbated immune response and inflammatory processes within the nervous system.

This situation is reminiscent of the previous SARS epidemic, caused by the SARS-CoV coronavirus, which led to Severe Acute Respiratory Syndrome (SARS). Like its successor SARS-CoV-2, SARS-CoV was characterized by airborne transmission and was one of the first alarming signals in the 21st century about the ability of coronaviruses to rapidly cross international borders, leveraging global air travel networks. Both viruses have highlighted how coronaviruses can transmit not only directly through respiratory droplets but also indirectly via contaminated surfaces.

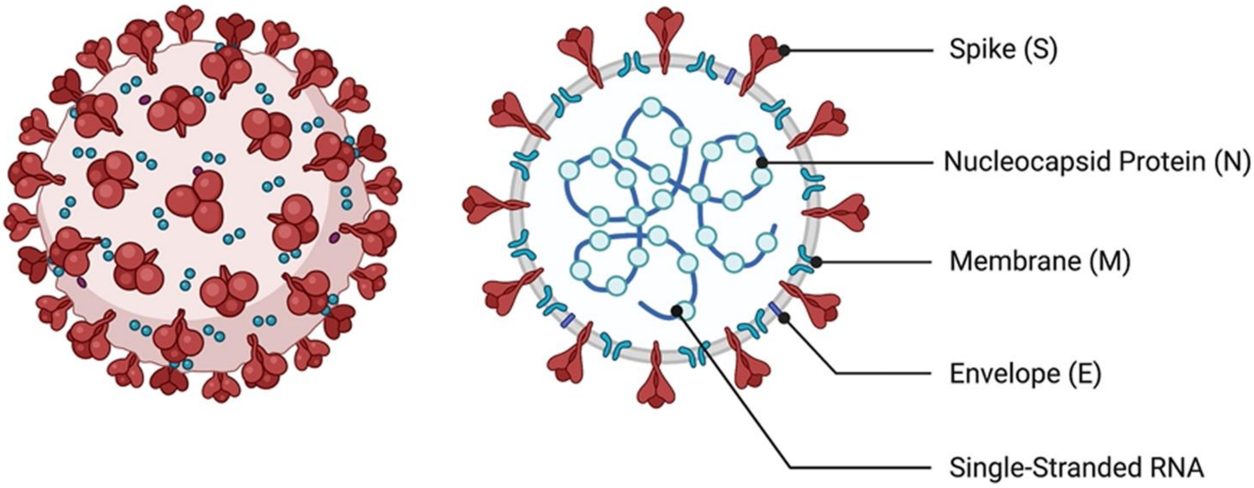


Figure 1: SARS-CoV-2 [8].

1.2 Symptomatology

The clinical presentation of COVID-19 is characterized by a wide spectrum of symptoms, which can vary considerably from individual to individual. Typically, these symptoms manifest within a week of exposure to the virus and can persist for up to two weeks. Among the most common initial symptoms are fever, chills, and sore throat, often accompanied by less common but significant symptoms such as muscle aches, fatigue, headaches, and respiratory problems. Additionally, alterations in smell or taste have been reported as early indicators of infection.
However, it is crucial to recognize that COVID-19 can progress rapidly in some cases, leading to severe symptoms that require immediate medical attention. These include severe breathing difficulties, confusion, chest pain, cold skin, or an unusual inability to communicate or move. Individuals with pre-existing health conditions, such as chronic diseases or immunodeficiency states, should be particularly vigilant and promptly seek medical evaluation if experiencing concerning symptoms associated with COVID-19.

Furthermore, severe outcomes of COVID-19 can lead to potentially life-threatening conditions such as respiratory failure, septic shock, thrombotic events, and damage to organs, particularly the heart, liver, and kidneys. These complications underscore the importance of early diagnosis and intervention in the effective management of the disease.

Even after overcoming the acute phase of COVID-19, a significant number of individuals continue to experience prolonged symptoms, a condition commonly known as Long

COVID. In addition to persistent fatigue and respiratory difficulties, Long COVID can manifest with a wide range of symptoms, including cognitive challenges, difficulty concentrating, depression, anxiety, sleep disturbances, and gastrointestinal problems. The diversity of symptoms associated with Long COVID underscores the complex and multifaceted nature of the virus's long-term impact on health.

Ongoing research is exploring the underlying mechanisms behind the persistence of post-COVID symptoms, with particular attention to immune system dysregulation and autoimmune responses. This research aims to deepen our understanding of Long COVID and to develop targeted therapeutic strategies to alleviate its effects and improve the overall management of COVID-19.

1.3 Coronavirus: Understanding its Impact on the Nervous System and Neurological Aspects

The interaction between COVID-19 and neurological symptoms, as well as the virus's implications in the nervous system, emerge as major areas of interest and concern for the global medical and scientific community. Beyond the well-documented effects on the respiratory system, SARS-CoV-2 has been shown to have significant neurological impacts on some patients, with symptoms ranging from mild and transient to severe and potentially lasting. These neurological symptoms not only complicate the clinical management of the disease but also have profound implications for patients' quality of life.

1.3.1 Neurological Symptoms and Their Impact

Neurological symptoms associated with COVID-19 include headache, dizziness, loss of smell (anosmia) and taste (ageusia) [9], brain fog, alterations in concentration and memory, extreme fatigue, speech difficulties, behavioral changes, psychotic symptoms, seizures, strokes, and, in rare cases, encephalitis. This wide range of neurological manifestations underscores the complexity of COVID-19's impact on the nervous system.

"Brain fog," characterized by confusion, forgetfulness, and a lack of concentration and mental clarity, is among the most alarming and persistent symptoms. It can significantly impact daily activities, affecting work capacity and overall life quality, with some patients reporting symptoms lasting months after recovering from the acute phase of the disease.

1.3.2 Impact Mechanisms on the Nervous System

The virus can affect the nervous system through several mechanisms. One is the direct invasion of the CNS, exploiting the ACE2 receptor to access neural cells. Another mechanism is indirect damage mediated by an overactive immune response, which can lead to inflammation and tissue damage. Additionally, systemic complications of COVID-19, such as hypoxia (low blood oxygen levels) and coagulation abnormalities, can contribute to brain damage and strokes.

1.3.3 Scientific Evidence and Implications for Treatment

Research has confirmed the presence of neurological symptoms in patients with COVID-19 through clinical studies, hospital data analyses, and autopsies. These findings have spurred growing interest in developing treatments that specifically address the neurological aspect of the disease, in addition to managing respiratory symptoms. Treating neurological symptoms requires a personalized approach, given their variety and complexity, and might include antiviral medications, anti-inflammatory therapies, and supportive interventions for cognitive and physical rehabilitation.

1.3.4 Biomarkers and Their Importance

Research on biomarkers has played a crucial role in studying the neurological impact of COVID-19. Biomarkers, such as localized brain atrophy and reduced metabolic activity in the brains of individuals with Long Covid, identified through imaging studies and analysis of body fluids, offer a valuable window into the underlying mechanisms of the disease and suggest possible avenues for targeted therapeutic interventions. These biomarkers can help predict the disease's progression, monitor treatment response, and facilitate the development of new therapies.

1.3.5 Future Perspectives

Despite advances in understanding the neurological impact of COVID-19, many questions remain unanswered. One of the major challenges is determining the long-term duration of neurological symptoms and their overall impact on the neurological health of survivors. Additionally, developing effective screening strategies to early identify patients at risk of severe neurological complications and implementing targeted rehabilitative interventions is essential.

Continued research into the neurological impact of COVID-19 is crucial for developing effective treatments and rehabilitation strategies that can significantly improve patients' quality of life.

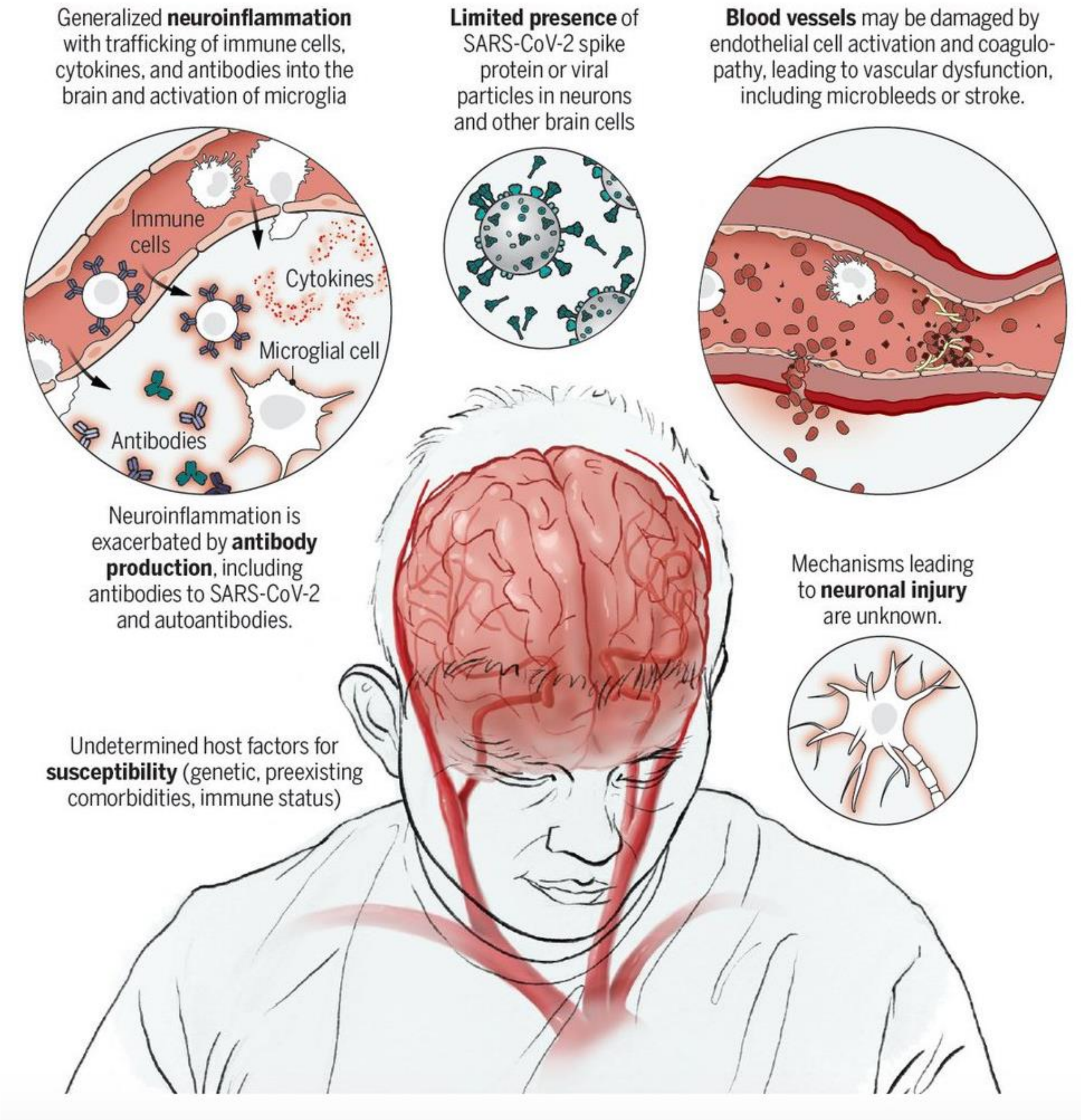


Figure 2: Putative neuropathogenic effects of SARS-CoV-2. Infection with SARS-CoV-2 can lead to neuropsychiatric effects during the acute phase of COVID-19, such as confusion, stroke, and neuromuscular disorders, attributed to neuroinflammation, coagulopathy, and neuronal injury. In cases of Long Covid, persistent symptoms may stem from the persistence of these mechanisms in the nervous system [9].

1.4 The Persistent Neurological Echoes of Long Covid

As stated in previous paragraphs, Long COVID, also known as Post-Acute Sequelae of SARS-CoV-2 infection (PASC), represents a complex set of symptoms that persist for weeks or months after the acute phase of the COVID-19 infection. This condition has attracted the attention of the global scientific community due to its pervasive nature and significant impact on patients' quality of life. The neurological aspects of Long Covid, in particular, pose a clinical and research challenge due to the variety of manifestations and the impact on cognitive and emotional functioning of patients.

1.4.1 Neurological Manifestations of Long Covid

Neurological manifestations of Long Covid vary widely among individuals, reflecting the heterogeneity of the body's response to infection. Symptoms include, but are not limited to, brain fog, persistent headaches, dizziness, sleep disorders, paresthesias, alterations in smell and taste, and mood changes. These neurological symptoms suggest a wide range of dysfunctions from inflammation of the central nervous system to alterations in neural circuits responsible for cognition and emotional regulation.

1.4.2 Pathophysiological Mechanisms

Long Covid presents a unique challenge in terms of understanding the underlying pathophysiological mechanisms. Hypotheses include:

- **Immune Dysfunction:** An altered or prolonged immune response can cause chronic inflammation, contributing to neurological symptoms through cytokines and inflammatory mediators that can cross the blood-brain barrier.

- **Autoimmunity:** Some evidence suggests that Long Covid may trigger autoimmune responses, with the immune system mistakenly attacking healthy nerve tissue.

- **Endothelial Dysfunction and Microangiopathy:** Alterations in small brain blood vessels can reduce blood flow to the brain, affecting neurological function.

- **Viral Persistence:** The continuous presence of the virus in certain areas of the body, including neural tissues, may contribute to the persistence of symptoms.

1.4.3 Therapeutic and Rehabilitation Approaches

Given the complexity and variety of neurological symptoms of Long Covid, therapeutic approaches require customization based on the individual patient. This can include:

- **Management of Fatigue and Pain:** use of medications, physical therapies, and stress management techniques.

- **Cognitive Rehabilitation:** programs aimed at improving cognitive function and managing brain fog.

- **Psychological Support:** therapies to address depression, anxiety, and other mood alterations associated with Long Covid.

1.4.4 Challenges in Research and Clinical Management

Long Covid poses numerous challenges, from diagnosis to clinical management, requiring further research for a deeper understanding of its mechanisms and the development of effective therapeutic strategies. A multidisciplinary approach integrating medical, neurological, psychological, and rehabilitative skills is essential to address the neurological symptoms of Long Covid.

As we advance in our understanding of Long Covid, it becomes clear that its neurological aspects are among the most debilitating and persistent. Future research will need to focus on deciphering the complex pathogenetic mechanisms underlying these neurological manifestations and on developing targeted therapeutic interventions. Additionally, the implementation of patient registries and biobanks collecting longitudinal data and biological samples is crucial to support observational and interventional studies that can shed light on the clinical trajectories of Long Covid and identify predictive biomarkers of risk, progression, and treatment response.

Beyond the biomedical aspects, it is essential to consider the psychosocial dimensions of Long Covid. Interventions should include psychological support and strategies to improve resilience, adaptation to disease-imposed limitations, and quality of life. Long Covid, with its complex neurological aspects, represents an unprecedented challenge. As research proceeds, there is hope that we can develop effective therapeutic strategies that alleviate the burden of this condition and significantly improve the lives of millions of affected people worldwide.

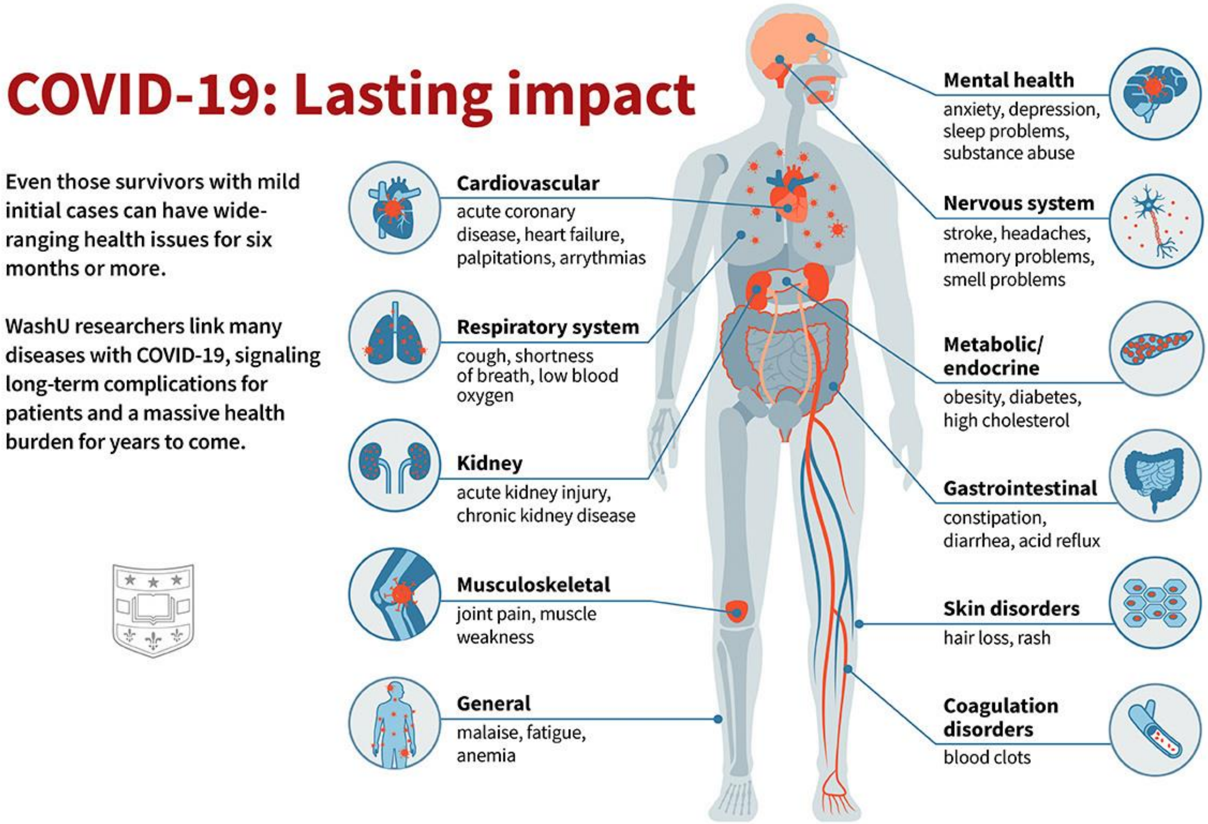


Figure 3: COVID-19: A View of Long-Term Health Effects. This infographic from Washington University researchers outlines the extensive and persistent health complications linked to COVID-19, which can affect survivors for months or years, creating a substantial long-term health burden [10].

1.5 Behavioural Markers in the Rehabilitation of Long Covid

Building on the previously discussed neurological impacts of Long Covid, the emerging research into behavioral markers offers a vital lens through which we can further our understanding and management of these effects. As we've seen, Long Covid can lead to significant neurological and cognitive repercussions, underscoring the necessity for precise methodologies to evaluate these outcomes.

To bridge this gap, the focus has shifted toward analyzing specific behavioral markers that reflect the cognitive and sensory changes experienced by individuals recovering from COVID-19. These markers include sensory responsiveness, temporal integration, sensory adaptability, and verbal memory. Each of these aspects serves as a window into the altered cognitive functions and sensory processing abilities post-infection, providing concrete data points for assessment.

The "Happy Again" web application emerges as a pivotal tool in this context, employing scientifically based behavioral tests to capture data on these crucial markers. This approach not only aids in delineating the cognitive and sensory profiles of individuals post-COVID but also in tailoring personalized rehabilitation strategies. By integrating these findings with the broader understanding of Long Covid 's neurological effects, it becomes possible to craft targeted treatment plans that address the unique challenges faced by each patient.

This innovative method of using behavioral markers not only enriches our comprehension of the aftereffects of COVID-19 but also heralds a new era in the targeted intervention and rehabilitation for survivors. Through scientifically validated tests, researchers and clinicians can now take a more informed and specific approach to managing the long-term complications of COVID-19, aiming ultimately to enhance the quality of life for those affected. This strategy underscores the importance of a multidisciplinary approach, combining insights from neurology, psychology, and clinical rehabilitation to address the complex landscape of Long Covid recovery.

Chapter II

Project Description

2.1 Introduction

The primary goal of this project is to assess and enhance the impact of COVID-19 on cognitive function and neural integrity in patients suffering from Long Covid. This project aims to develop and implement a personalized cognitive training system through a desktop application, focusing specifically on strengthening working memory and improving attentional control.

2.1.1 From “Happy Again” to “LC-Neurorehab”: The Process of Post-COVID Neurorehabilitation

Amid the COVID-19 pandemic, the University of Essex launched "Happy Again," a research project aimed at investigating Post-COVID Syndrome, especially its neurological effects. The initiative sought to assess a range of behavioral markers to uncover neural health and cognitive functions, to better understand potential neurological damage and functional variations that might result from COVID-19 infection. The "Happy Again" program employed various tasks, each designed to isolate and measure specific aspects of cognitive and behavioral functioning:

- **Demographics**: it collects essential data on participants to correlate findings with demographic variables such as age, sex, and pre-existing health conditions.
- **Covid Survey:** it investigates participants' direct experiences with the virus, assessing how their symptoms and health have changed over time.
- **Flash Beep Task:** a test exploring sensory processing and attention capabilities, useful for identifying difficulties in perception or stimulus processing.
- **Personality Survey:** a psychometric test assessing participants' personality traits.
- **Word Categorization:** a linguistic task measuring categorization and language processing skills.
- **Movement Perception:** examines how participants perceive visual motion or orient and navigate through space.
- **Quality of Life Survey:** Assesses the impact of physical and mental health on participants' daily lives.
- **Fatigue Survey:** Measures the levels of fatigue experienced by participants.
- **Target Detection:** a cognitive task involving the search for a specific object/symbol among various stimuli.
- **Loudness Perception:** assesses how participants perceive volume to help identify potential damages or alterations in the nervous system that affect auditory perception.

Through the analysis of collected data, it was possible to identify target areas for cognitive rehabilitation.

The direct evolution from "Happy Again" led to the development of "LC-Neurorehab," an advanced neurorehabilitation program implemented through a desktop application. This customized system is designed to support the cognitive recovery of patients affected by Long Covid, focusing on integrating activities such as the Adaptive Dual N-Back and the Mental Rotation Test. The goal is to provide specialists with assessment and intervention tools based on the data collected, enhancing patients' quality of life through targeted rehabilitative pathways.

2.1.2 Scope of the project

The primary objective of "LC-Neurorehab" is twofold: on one hand, it aims to provide concrete and personalized support to patients affected by Long Covid through the rehabilitation of compromised cognitive functions; on the other hand, it seeks to contribute to the scientific understanding of the long-term neurological effects of COVID-19. This advanced neurorehabilitation program, born as a direct evolution of the "Happy Again" research project, uses a desktop application to implement a cognitive training system. In addition to offering direct support to patients, "LC-Neurorehab" serves as an important research tool, enabling the collection and analysis of data on participants' cognitive performance. This aspect of the application paves the way for new discoveries about the underlying mechanisms of post-COVID cognitive dysfunctions and their evolution over time, thus contributing to the creation of increasingly effective and personalized intervention strategies.

2.2 Application's idea: Mental Rotation Test and Adaptive Dual N-Back Task

As previously mentioned, the development of "LC-Neurorehab" stems from the crucial insights gained from the "Happy Again" project. Acknowledging the varied and lasting cognitive impairments encountered by survivors, "LC-Neurorehab" was conceptualized as a desktop application to meet the nuanced rehabilitation needs of these individuals. Designed to be available in specific medical laboratories, this application provides a structured environment where users, following registration and login, have access to a collection of carefully curated tasks. These tasks, which users can undertake in any sequence they prefer, are uniquely formulated to target and enhance core cognitive functions affected by Long Covid. The application employs a dual-task approach, centered on the Adaptive Dual N-Back task and the Mental Rotation Test. It's worth noting that the Adaptive Dual N-Back task has been shown to have beneficial effects on attentional control, cognitive performance, and anxiety levels, while the Mental Rotation Test has been found to improve working memory and concentration.

Mental Rotation Test

Specifically, the Mental Rotation Test has been incorporated into the application for its vital role in assessing and enhancing spatial cognition and mental flexibility. This task challenges users to mentally rotate two-dimensional and three-dimensional objects to determine whether they are identical but rotated, or mirror images, thereby engaging and strengthening brain areas responsible for spatial awareness and cognitive flexibility. Patients are required to press the "SAME" button if the objects are identical but rotated, or the "DIFFERENT" button if they are mirror images.

Adaptive Dual N-Back

The Adaptive Dual N-Back has been integrated into the application for its targeted role in improving working memory and attentional control among patients affected by Long Covid. This dynamic task requires users to simultaneously monitor two streams of information (visual and auditory) and identify when a current stimulus matches one presented N steps earlier in the sequence. As participants improve, the task progressively becomes more challenging, ensuring that their cognitive abilities are continuously pushed to their limits.

Data collected from user interactions in these tasks are meticulously stored in a secure database, allowing researchers and medical professionals to analyze the outcomes, draw meaningful conclusions, and tailor further rehabilitation strategies.

The planned functionalities include:

Administrator Role:

1. **Administrator Registration:** Allows individuals to register as administrators, granting them access to the administrative interface of the application.
2. **Administrator Login:** Facilitates administrators to securely access their accounts through authentication mechanisms.
3. **Access to the Administrative Dashboard:** Grants administrators the ability to view and interact with the administrative dashboard.
4. **User (Patient) Selection:** Enables administrators to select and view profiles of users (patients) within the system to perform further actions such as analysis or notes addition.
5. **Adding Notes to the Patient:** Administrators can add notes to the personal information of a patient, facilitating the documentation and tracking of observations or medical notes relevant to the patient's condition and progress.
6. **Task Assignment Review:** Enables administrators to view the tasks assigned to or performed by a specific user, providing insights into the user's engagement and performance.

7. **Viewing Task-Specific Data:** Administrators can access detailed data related to specific tasks performed by a user, aiding in the analysis of cognitive performance and task outcomes.
8. **Administrator Logout:** Securely logs out the administrator from the system.

User Role:

1. **User Registration:** Allows individuals to register as users of the system, granting them access to its functionalities designed for cognitive assessment and rehabilitation.
2. **User Login:** Enables users to securely log into their accounts to access the system's functionalities.
3. **Homepage Viewing:** Upon login, users are directed to the homepage, which provides an overview of available tasks.
4. **Task Selection:** Users can choose the task to perform, each designed to assess or improve specific cognitive functions.
5. **Task Engagement:** Directs the user to the page of the selected task, where instructions and the task itself are presented for completion.
6. **User Logout:** Allows users to securely log out of the system, ensuring their session is safely terminated.

2.3 Enhancing Cognitive Function and Attentional Control through Adaptive Dual N-Back Training

Recent research has highlighted how working memory (WM) training, through the adaptive dual n-back task, emerges as an effective strategy not only in mitigating attentional control deficits linked to anxiety but also in addressing the cognitive challenges associated with Long Covid. This condition includes among its manifestations memory problems, concentration issues, and brain fog, similarly to what is observed in some anxiety disorders [2].
In this context, the Adaptive Dual N-Back, with its focus on enhancing WM and attentional control, proposes itself as a tool to improve processing and inhibition capabilities. Training can help reduce cognitive symptoms related to Long Covid, thus offering a complementary strategy to existing treatments.

The Adaptive Dual N-Back task is an advanced cognitive exercise designed to improve working memory and attentional control [2]. Its principle is based on monitoring and responding to a series of stimuli presented in succession, requiring the user to remember and recognize if the current item matches the one presented "n" positions back in the sequence. This task is considered "Adaptive" because the difficulty of the task automatically adjusts based on the user's performance, ensuring that the challenge level remains optimal to stimulate cognitive improvement without causing excessive frustration.

2.3.1 Task Structure

The task is defined as "Dual" because it simultaneously challenges two channels of information: a visual and an auditory one. In the visual channel, users are shown a sequence of positions where squares appear on a grid pattern. In the auditory channel, concurrently, a sequence of letters is played. The user must indicate when the current position of a square or the current letter matches the one presented n steps back in the sequence.

2.3.2 Levels of Difficulty

The "n" in n-back represents the number of steps back the user must remember. Initially, "n" might be set to 1 (1-back), making the task relatively simple. As the user responds correctly, the difficulty level increases, moving to 2-back, 3-back, and so on. If the user makes mistakes, the system can lower the difficulty level, thus adapting to the performance level and keeping the task challenging yet feasible.

2.3.3 Response and Feedback

The user responds through keyboard input when recognizing a match for "AUDIO", "BOTH", "VISUAL".

2.3.4 Cognitive Benefits

Through regular practice, the Adaptive Dual N-Back has been shown to improve working memory, i.e., the ability to maintain and manipulate information in the short-term memory. These improvements transfer to better attentional control, meaning the ability to maintain focus on relevant tasks while ignoring distractions.

Studies have indicated that improvements obtained through training with the Adaptive Dual N-Back can transfer to other cognitive activities not directly trained during the exercise, highlighting the potential of the task in a wide range of applications, from cognitive rehabilitation to performance optimization in healthy individuals [2].

2.3.5 Fundamental Rules and Structural Dynamics

Here are the fundamental rules and the structure of the task:

1. **Game Grid:** the grid on which visual stimuli are presented consists of a 3x3 layout. Each cell of the grid has dimensions of 200x200 pixels, with a separation of 200 pixels between cells. The center of the grid is located at coordinates (750, 500) within the interface.

2. **Number of Trials per Level:** each level of the task consists of "20+N" trials, where "N" is the current level number. This incremental scheme ensures that difficulty and attention demand increase as levels progress.
3. **Interval Between Trials:** there is an interval of 2500 milliseconds (2.5 seconds) between the end of one trial and the start of the next. This time allows the user to prepare for the next trial and helps prevent cognitive fatigue.
4. .**Visual Flash Duration:** the duration of the visual flash is set to 3 seconds. This means that when a square on the grid is highlighted, it remains visible for 3 seconds.
5. **Presentation of Stimuli**: visual stimuli (blue squares) and auditory stimuli (letters) are presented sequentially, with the squares appearing in random positions on the grid, except for the central cell marked with a "+". The central cell is not used for presenting active visual stimuli but serves as a reference point.
6. **Interval Between Audio and Visual Stimulus:** 500ms.
7. **User Response:** the user responds to stimuli using the keyboard, pressing specific keys to indicate match or mismatch of stimuli presented "N" positions back in the sequence. The keys used are "C" for auditory matches, "M" for visual matches, and "Space" for simultaneous matches.
8. **Accuracy Calculation:** at the end of each level, accuracy is calculated by comparing the user's responses with a predefined result vector. This calculation assesses the user's performance, determining overall accuracy.
9. **Level Progression:** progression is based on accuracy. High accuracy (>= 95%) leads to advancement to the next level, while lower accuracy (>=75% and <95%) causes repetition of the current level or regression (<75%).

2.4 Requirements

For the development of the project in question, it is crucial to articulate the requirements into two main areas: functional and non-functional requirements.
Functional requirements include all the specific functions, capabilities, and essential behaviors that the application must incorporate. These requirements precisely outline the operations and methods by which the application handles and processes user requests, highlighting the main actions and interactions expected with the interface.
As for non-functional requirements, these focus on the qualitative properties and attributes that the desktop application must exhibit. These criteria ensure that the application adheres to high standards in terms of operational efficiency, data protection, ease of use, performance consistency, and ease of management and updating.

2.4.1 Functional Requirements

In essence, functional requirements outline "What should the software system achieve?". They are technically defined as follows:

- A list of services and functions that the system is required to provide.
- Specification of the behavior that the system exhibits in response to specific circumstances.
- Description of how the system should react to certain inputs.
- Indication of operations that the system should not perform, where applicable.

The core features of the application, identified during the preliminary phase of study, have been synthesized and updated based on the needs that emerged from the analysis of the feedback received and have been summarized in the table below.

Identifier	**Description**
FR1	The application must handle patients' registration.
FR2	The application must allow all registered patients to log in.
FR3	The application allows patients to log in and log out .
FR4	The application should present patient two tasks and allow them to undergo each one.
FR5	The application allows each patient to return to the Home Page.
FR6	The application must let participants undertake the ”Adaptive Dual N-Back” task and record the results.
FR7	The application must let participants 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 accuracy is grater or equal then 95% and save the results of the just completed level.

FR12	The application will allow patients to remain the same level of the task when accuracy is grater or equal then 75% and minor then 95% and 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 accuracy is minor then 75% and 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 patient to go back when the task is started.
FR17	The application must permit patients to take the two task 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 handle admins' registration through a security code.
FR22	The application must allow all registered admins to log in as admin.
FR23	The application allows admins to log in and log out .
FR24	The application should present admins a table containing patients registered.
FR25	The application should enable admins to view the page containing each patient's personal information.
FR26	The application allows 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.

Table 1: Functional Requirements FR.

2.4.2 Non-functional requirements

The non-functional requirements represent the quality characteristics of a software system, establishing how functionalities should be implemented to ensure optimal performance, security, usability, and reliability. They define the "how" rather than the "what" of the system's behavior, deeply influencing the general architecture of the software and the end-user experience. These requirements include the application's ability to operate without errors, the protection of users' sensitive data, an intuitive and accessible user interface, and the ease with which the software can be updated and maintained. Ultimately, non-functional requirements ensure that "LC-Neurorehab" not only meets the clinical objectives for which it was designed but does so in a safe, reliable, and user-friendly manner, representing a fundamental pillar for the long-term success and adoption of the application in the field of cognitive rehabilitation. The non-functional requirements are shown in the tables below.

2.4.2.1 Performance

The performance requirement dictates that the application must load and respond promptly to user actions, ensuring short response times, even when handling large volumes of data, to facilitate a smooth and effective user experience.

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

Table 2: NFR01.

2.4.2.2 Security

Security is a non-functional requirement that guarantees that every piece of data inside the system will be safe from unauthorized access.

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 3: NFR02.

Attribute	Description
Identifier	NFR03
Name	Privacy
Description	User credentials must be handled 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

Table 4: NFR03.

2.4.2.3 Portability

Portability describes the capability of a system, or a component thereof, to be transferred and operated effectively across different environments.

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 5: NFR04.

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

Table 6: NFR05.

2.4.2.4 Usability

Usability measures the ease and efficiency with which users can navigate and operate a system.

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

Table 7: NFR06.

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

Table 8: NFR07.

2.4.2.5 Reliability

The reliability of a system or component reflects its ability to perform consistently as expected over a defined period, under given conditions.

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

Table 9: NFR08.

2.4.2.6 Maintainability

Maintainability represents the span of time required to correct a flaw, alter a solution or its elements to boost performance or other qualities, or to adapt to environmental changes.

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

Table 10: NFR09.

2.4.2.7 Interoperability

Interoperability facilitates data sharing across different systems, improving efficiency and effectiveness in the use of information across various domains and applications.

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 1 second under normal operation conditions.
Priority	High

Table 11: NFR10.

Chapter III

Design of the solution

This chapter details the design phases undertaken for the development of the desktop application “LC-Neurorehab”. Initially, it outlines the selected methodology to guide the development process; subsequently, it describes the use cases, identifying the key success scenarios, and conducts a layered analysis, useful for evaluating and selecting the appropriate components for the application's system architecture.

3.1 Methodology

The methodology adopted for the development of the "LC-Neurorehab" desktop application was infused with the ethos of Design Thinking, utilizing a hybrid approach that combined key elements of Agile methods with the structured principles of the Software Release Life Cycle (SRLC). This fusion was specifically chosen to harness the empathetic focus of Design Thinking, which prioritizes understanding user needs as the foundation of the development process.

This methodological choice aimed to maximize the efficiency and flexibility of the development process, while simultaneously maintaining high standards of quality and reliability of the produced software. The agile principles adopted during the development emphasized continuous collaboration with the team of specialists in the field of psychology and biomedicine. This close collaboration allowed for rapid cycles of feedback and iterations that contributed to shaping the application in a way that precisely met the final users' needs. The ability to quickly adapt to changes was fundamental from the perspective of agile design. Concurrently, the integration of SRLC principles ensured that each phase of the project, from conception to final release, was well-defined and monitored. This approach included detailed planning, requirement analysis, design, development, testing, and release, ensuring that each step was aligned with the predefined functionality and timing objectives. Particular attention was paid to the testing phase, which, although initially limited, followed rigorous protocols to effectively identify and correct any defects or usability issues. A distinctive element of our methodology was its iterative and feedback-based nature. Open and constant communication between the development teams and specialists fuelled a virtuous cycle of improvement, where each software iteration was evaluated, tested, and refined. This not only accelerated the development process but also ensured that the final application was highly customized and effectively met the users' needs.

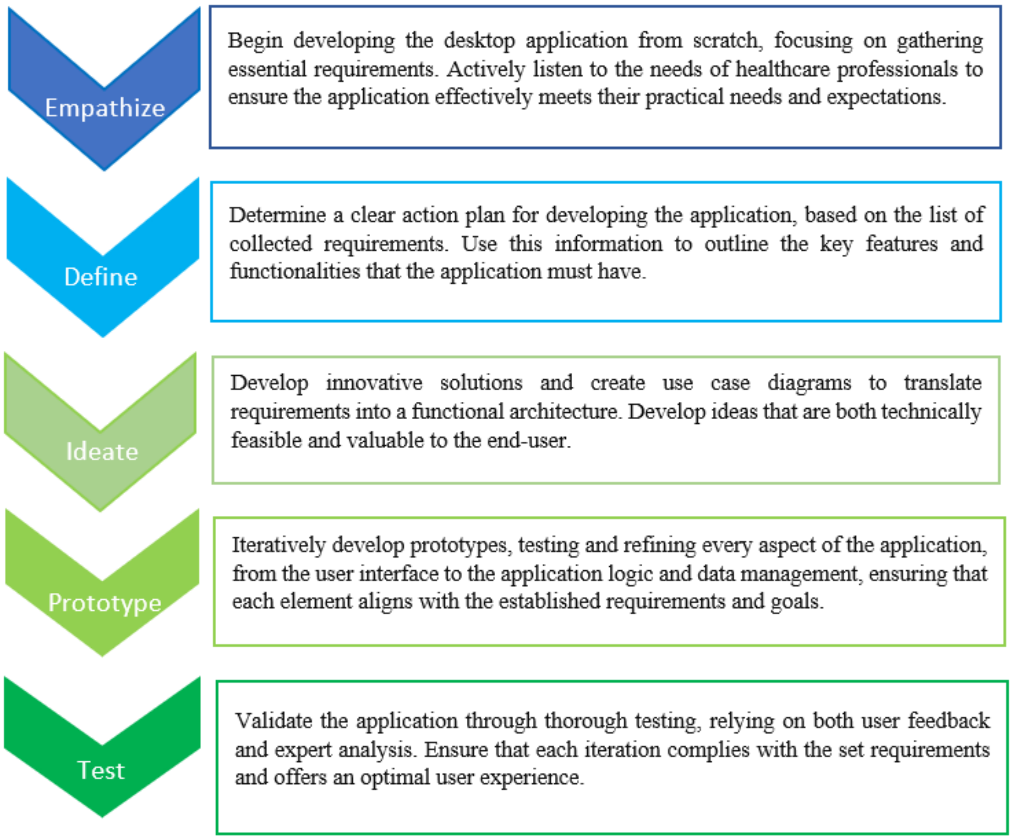


Figure 4: Design Thinking steps for this project.

3.2 Use cases

In the context of computer system modeling, UML (Unified Modeling Language) use case diagrams are essential tools for capturing the functional requirements of a system. They provide a high-level description of functions and operational context, outlining the interactions between the system and its actors. A use case represents a series of actions or event steps typically describing how an actor, which could be a human user or another system, interacts with the system to perform a task and produce an observable result that contributes to the system's goals [11].

Use case diagrams are particularly useful in the early stages of a project, providing a common understanding of the system's functionalities among all project participants. During requirement gathering, these diagrams are employed to collect and present the system's needs. In the analysis and design phases, the identified use cases and actors can guide the identification of the necessary classes for the system. Finally, in the testing phase, they can be used to identify appropriate tests for the system

The added value of use case diagrams lies in their ability to clearly define the relationships between model elements and to add semantics to the model by defining the structure and behavior between the model elements. In summary, the use of UML use case diagrams is crucial for understanding, designing, analyzing, and testing computer systems, serving as a bridge between user needs and the tangibility of the system being modeled, ensuring that the final product aligns with the objectives and expectations of stakeholders.

In the development of "LC-Neurorehab," we made extensive use of UML use case diagrams to outline the system's functional requirements. This practice proved fundamental not only for capturing the interactions between the system and its actors but also for developing a deep and shared understanding of the functionalities the application had to offer.

Through the use cases, we were able to detail the sequences of actions that end-users, including patients and healthcare professionals, would undertake to achieve specific goals, such as selecting rehabilitative tasks, authenticating users, and accessing monitoring and progress analysis tools. The actors in our diagrams represented not only the roles of human users but also any other external system that interacted with "LC-Neurorehab," ensuring that every usage scenario was carefully explored and designed.

The implementation of "LC-Neurorehab" focused particularly on creating an intuitive user experience tailored to rehabilitation needs and use case diagrams were an essential means to define these interactions clearly and structurally. This approach allowed us to visualize the system from the users' perspective, facilitating the design of an interface that was not only functional but also welcoming and easy to use for recovering patients.

In the initial stages of the project, use case diagrams facilitated communication between the development team and clinicians, allowing for a common understanding of the desired functionalities and effective collaboration in their realization. Moreover, these diagrams played a crucial role in the analysis and design of the system's components, helping us identify the necessary classes for the system and guide the testing phase with targeted tests based on the use cases.

3.2.1 Patient Use Cases

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's 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 12: UC1P - Register.

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 13: UC2P - Log in.

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 Login Page.
Main success scenario	1. The participant clicks on the "Log Out" button. 2. The application shows the Login 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 14: UC3P - Log out.

ID	**UC4P**
Name	Home Page
Functional requirement	FR4, FR5, FR6, FR7
Goal	The participant is able to see the two tasks to work on.
Pre-condition	The participant is logged in.
Post-condition	None
Main success scenario	1. The application displays 2 tasks options in the form of buttons.
Includes/Extends	None

Table 15: UC4P - Home Page.

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 the 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 3 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 16: UC5P - Adaptive Dual N-Back.

ID	**UC6P**
Name	Mental Rotation Test
Functional requirement	FR8, R10, FR11, FR12, FR13, FR14, FR15, FR16, FR17, FR18, FR19
Goal	The patient is able to accomplish the 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 2 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.

Table 17: UC6P - Mental Rotation Test.

3.2.2 Admin Use Cases

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 18: UC1A - Register.

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 the Home Page.
Main success scenario	1. The admin fills all the entries, username and password. 2. The admin clicks on the "Login as Button" button. 3. The system authenticates the admin's entered data. 4. The admin is logged in and presented the Home Page.
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 19: UC2A - Log in.

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	1. The admin clicks on the "Log Out" button. 2. The application shows the Login 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 20: UC3A - Log out.

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 21: UC4A - Admin Area.

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 administrator 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 the "Show Data" button to access data related to a task completion date.
Includes/Extends	6.a.1 A pop-up shows requested data.

Table 22: UC5A - User Page.

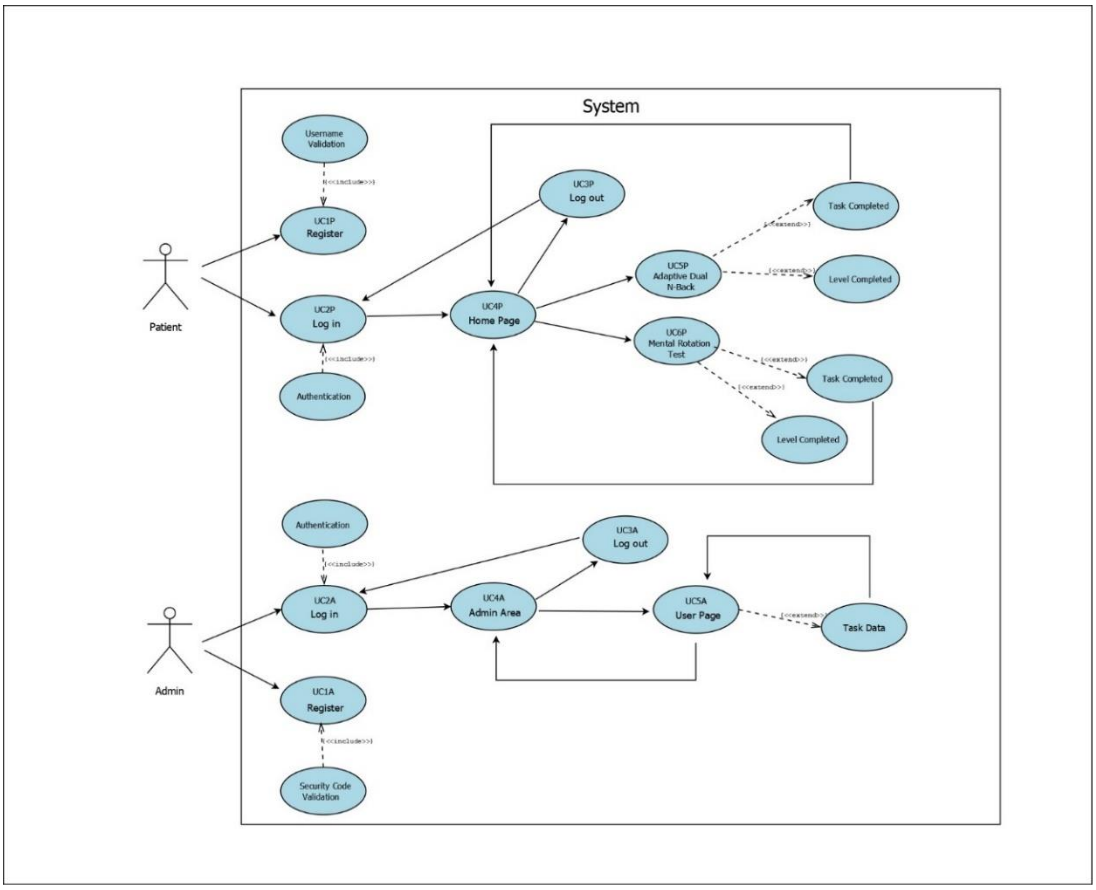


Table 23: Participant interactions as use cases.

3.3 Architecture Layers

During the application development process, an approach focused on creating a standalone desktop solution was adopted. This architectural choice eliminates the need for a client-server infrastructure, instead favoring a fully integrated solution that operates locally on a device within a controlled clinical environment and interacts directly with a local database, thereby emphasizing the security and reliability of the system.

The architecture of "LC-Neurorehab" is structured into the following main layers:

1. **User Interface (UI):** This is the front-end part of the application with which users interact directly. It is responsible for presenting information to users (both patients and administrators) and capturing their inputs. The UI layer is crucial to ensure that the application is user-friendly and accessible, making it a distinctive component focused on user experience and interaction.

2. **Application Logic:** Occupying a central position in the application, it orchestrates the activities allowed to users based on their role. For patients, it coordinates the initiation

and management of rehabilitative tasks, ensuring that the experience is smooth and tailored to therapeutic needs. For administrators, it processes data access requests, allowing detailed control over progress and the addition of clinical feedback through notes, thus supporting a personalized approach to rehabilitation. It acts as an intermediary between the UI layer and the Data Management layer. This layer encapsulates the operational logic of the application, making it distinct from presentation and data management aspects.

3. **Data Management:** Critical for secure storage and access to information, this layer employs a local database to store patients' personal data, task results, and notes entered by administrators. It operates independently of the application's logic and UI layers but interacts with them to provide the necessary data for the application's functionalities.

This architectural choice implies several advantages in terms of:

- **Security:** Operating in a controlled clinical environment and without the need for external connections for data processing, the application significantly reduces the risks associated with data security, ensuring that sensitive information remains protected within the device.
- **Reliability:** The lack of dependence on external servers or network connections for the application's operation guarantees greater operational stability, eliminating potential disruptions due to connectivity issues.
- **Treatment Customization:** The independent architecture facilitates the adaptation and customization of rehabilitation protocols.

Ultimately, this architectural approach not only reflects the specific needs of the clinical context for which "LC-Neurorehab" was designed but also represents a strategic choice to keep the application agile, secure, and easily updatable. Focusing on a modular and well-defined structure facilitates collaboration between developers and healthcare professionals, allowing for rapid adaptation of the application in response to changes in clinical practices or patient needs.

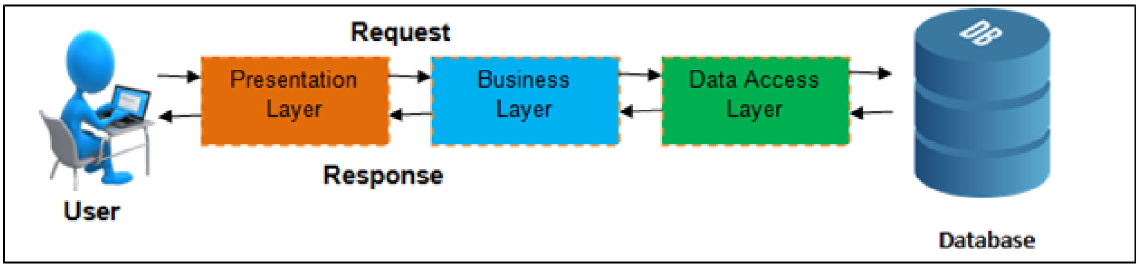


Figure 5: Three-level architecture.

3.3.1 User Interface Layer

The user interface layer serves as a direct bridge between the application and its users, facilitating visual and interactive dialogue. This crucial layer is where both patients and administrators access the application's functionalities, making it essential for intuitive navigation and the software's overall effectiveness. It is designed to meet specific non-functional requirements, such as usability, ensuring all interactions are clear and accessible.

For "LC-Neurorehab," the interface adapts to the user's state within the application, differentiating between patients and administrators:

- **Non-Authenticated:** Before logging in, the interface presents a login form with fields for username and password, accompanied by three buttons: two for access, differentiated for patient users and administrators, and one for new registration. This arrangement facilitates entry into the application, clearly distinguishing the paths for various types of users.
- **Authenticated Patient:** Once logged in, the patient is presented with a simplified interface offering a selection between two rehabilitative tasks. This page is designed to minimize distractions and focus on rehabilitation, with a Log out button to end the session and exit the application.
- **Authenticated Administrator:** After logging in, the administrator gains access to an interface that allows them to manage the application's administrative aspects, such as reviewing patient progress. A Log out button also enables the administrator to disconnect securely.

3.3.2 Application Logic Layer

The core of the application is represented by the application logic layer, often also referred to as business logic. This layer manages all the program's functionalities based on specific requirements for patients and administrators. Acting as an intermediary, this layer ensures the processing and execution of cognitive rehabilitation sessions for patients, as well as access to and management of patient information and progress by administrators.

Within the desktop application, the application logic directly interacts with the local database for secure data storage and retrieval, facilitating operations such as inserting and querying notes added by administrators, as well as recording the results of tasks performed by patients. This layer is organized to allow effective function separation, ensuring code modularity that facilitates software maintenance and updates.

-**User Management:** Includes functionalities for patient and administrator authentication, allowing them to securely and personalized access the application.

-**Task Processing:** Manages the execution of rehabilitative tasks.

-Data Management: Handles the manipulation and management of patient data, including uploading personal information, recording progress, and accessing clinical notes. This section ensures the integrity and security of the application's data.

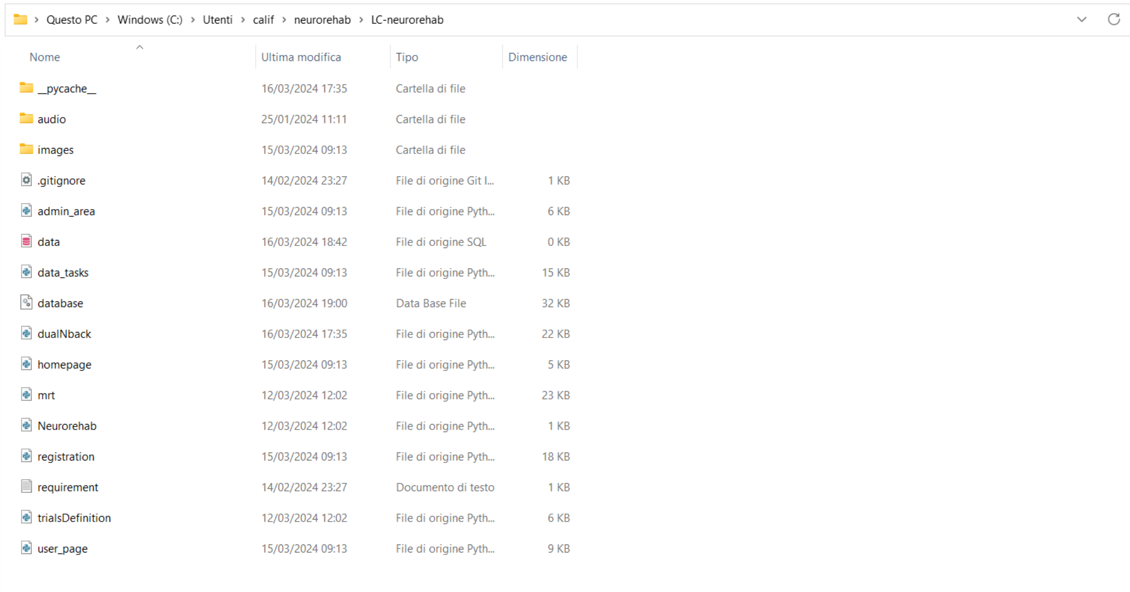


Figure 6: Application Logic Layer contained in LC-Neurorehab directory.

3.3.3 Data Management Layer

The Data Management Layer is the foundation that ensures the integrity, security, and accessibility of the application's data. In "LC-Neurorehab," this layer is critical for maintaining a robust local database that securely stores all clinical information, task outcomes, and administrative notes. Leveraging a structured and efficient data storage system, this layer enables quick access to patient records, facilitating real-time updates and retrieval of patient progress and session results.

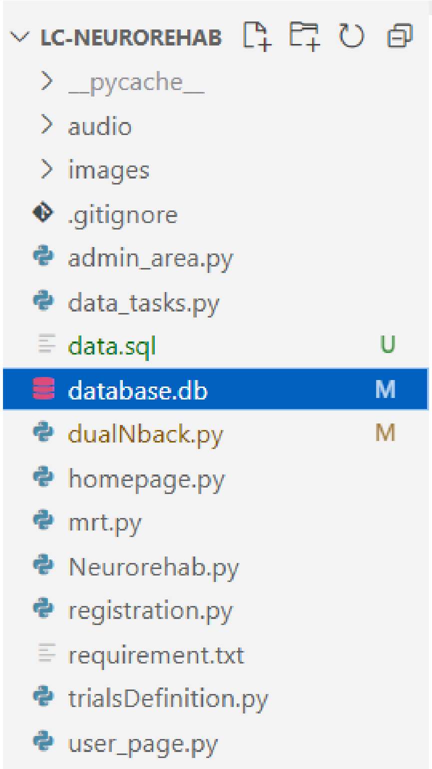


Figure 7: LC-Neurorehab project structure featuring Python scripts and the central database for data management.

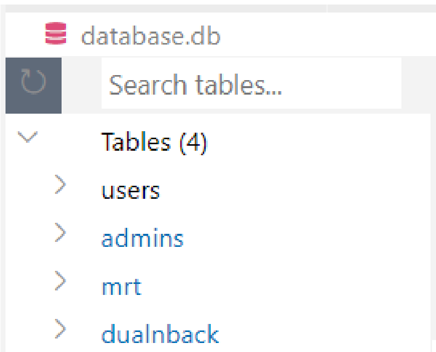


Figure 8 Database 'database.db' interface with tables for users, admins, MRT, and Dual N-back exercise.

The database.db is composed of 4 tables:

- **users:** The "users" table in the database is designed to ensure secure identification and management of user information. Within it, the "username" column acts as a primary key, ensuring that each user is uniquely identifiable. The "password", in conjunction with the "salt", creates a cryptographic barrier that safeguards access to credentials, utilizing SHA-256 for an added layer of security. Additionally, this table stores personal details such as "name", "surname", and "dateofbirth". Furthermore, the "notes" column allows administrators to input specific annotations for each user, thereby enriching the profile with relevant information.

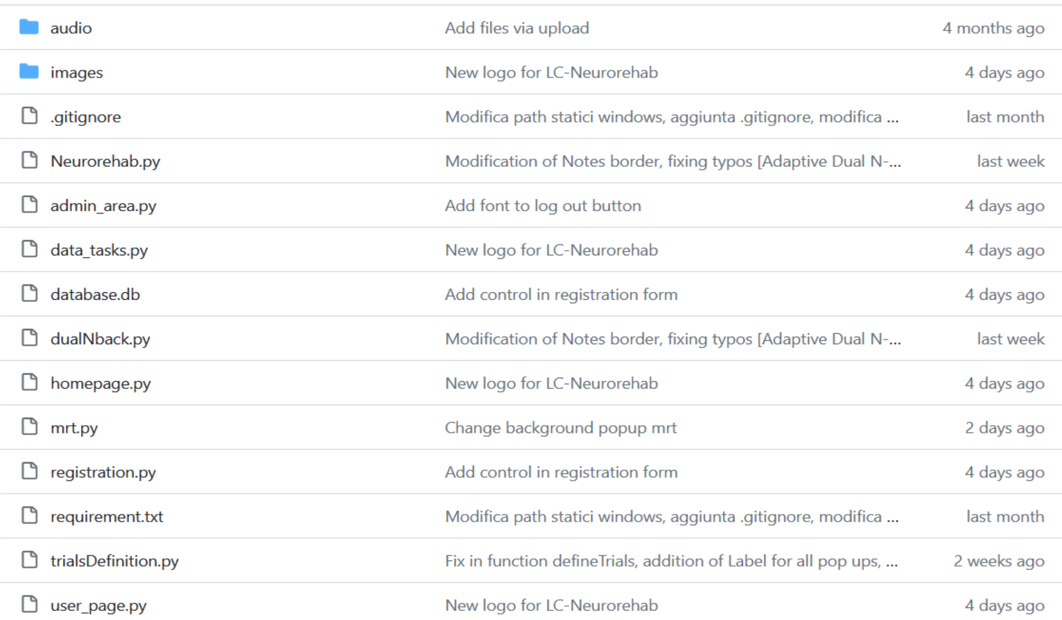
- **admins:** The “admins” table in the database is structured to ensure secure identification of admins. Within it, the "username" column serves as a primary key, ensuring each admin is uniquely identifiable. The "password", alongside the "salt", forms a cryptographic barrier that protects credential access, employing SHA-256 for an additional level of security.
- **mrt:** The “mrt” table in the database is specifically set up to store information related to the Mental Rotation Test. It features 7 columns. The "username" column allows each test attempt to be associated with a specific user. The "level" indicates the difficulty level of the test the patient has taken. "Accuracy" is a percentage that quantifies the correctness of the responses. The "n_images" column reflects the number of visual stimuli presented, and "n_correct" and "n_wrong" track the number of these that have been correctly or incorrectly identified, respectively. Finally, the "date" column records the date when the test was taken.
- **dualnback:** The “dualnback” table in the database is specifically set up to store information related to the Adaptive Dual N-Back task. It features 8 columns. The "username" column allows each test attempt to be linked to a specific user. The "level" indicates the difficulty level of the test tackled by the patient. "Accuracy" is a percentage that quantifies the correctness of the responses. The "n_correct_audio", "n_correct_visual", and "n_correct_both" columns track the number of correct matches for sound sequences, visual matches, and simultaneous matches, respectively. The "score" column represents the total number of correct matches made. Lastly, the "date" column records the date the test was conducted.

Chapter IV

Results Obtained

The creation and updating of "LC-Neurorehab" followed a meticulous planning process based on the precise definition of requirements and the selection of a targeted architecture. The application was developed using Python as the main programming language, leveraging the PyQt5 library for user interface design, and SQLite for local database management. These technological choices enabled the development of a robust and high-performance desktop solution, suitable for the clinical environment for which it was designed. Each phase of updating "LC-Neurorehab" underwent a rigorous verification and testing process. Initially, developers conducted thorough checks to ensure the proper functioning of the application. Subsequently, the software was subjected to testing by clinical collaborators to assess its effectiveness and suitability for the cognitive rehabilitation needs of patients. This methodology ensured that each version of "LC-Neurorehab" optimally met the requirements of the clinical context.

This chapter of the thesis precisely details the development process of the application, highlighting how the synergistic integration of Python, PyQt5, and SQLite contributed to creating a smooth and functional user experience. At the same time, it ensured the security and reliability in managing the application's data, essential for the success of post-COVID neurorehabilitation.



audio	Add files via upload	4 months ago
images	New logo for LC-Neurorehab	4 days ago
.gitignore	Modifica path statici windows, aggiunta .gitignore, modifica ...	last month
Neurorehab.py	Modification of Notes border, fixing typos [Adaptive Dual N-...	last week
admin_area.py	Add font to log out button	4 days ago
data_tasks.py	New logo for LC-Neurorehab	4 days ago
database.db	Add control in registration form	4 days ago
dualNback.py	Modification of Notes border, fixing typos [Adaptive Dual N-...	last week
homepage.py	New logo for LC-Neurorehab	4 days ago
mrt.py	Change background popup mrt	2 days ago
registration.py	Add control in registration form	4 days ago
requirement.txt	Modifica path statici windows, aggiunta .gitignore, modifica ...	last month
trialsDefinition.py	Fix in function defineTrials, addition of Label for all pop ups, ...	2 weeks ago
user_page.py	New logo for LC-Neurorehab	4 days ago

Figure 9: Screenshot of the GitHub repository for the desktop application development project; it displays the list of utilized files and folders, along with corresponding commit messages that track the evolution and teamwork, reflecting the stages of continuous updating of the application.

4.1 Technologies used

The implementation leveraged a selection of advanced technologies, chosen for their reliability and efficiency in the context of desktop application development. In the following paragraphs, we will explore in detail the use of Python, PyQt5, and SQLite, highlighting how each technological component contributes to the functionality and robustness of the application.

4.1.1 Python language

Python is a versatile and object-oriented programming language well-suited for a variety of software development tasks [12]. Its adoption as the primary language for our project was driven by its adaptability and the broad range of available libraries. Python's straightforward syntax and readable code make it ideally suited for the rapid development and iteration of desktop applications such as "LC-Neurorehab," which focuses on cognitive rehabilitation.

Utilizing Python, we were able to develop an effective and responsive user interface, ensuring that patients could interact with the application intuitively. Python's compatibility with SQLite made for efficient data management, critical for tracking patient progress and analyzing the results of rehabilitation sessions.

A major strength of using Python lies in its easy integration with external hardware and sensors, a vital aspect for the application's future. Plans to integrate advanced sensors like EEGs and optical trackers will enhance the monitoring and analysis capabilities, allowing for more accurate assessments of patients' neurological conditions. This feature is a step towards improving rehabilitation strategies, aiming to make "LC-Neurorehab" a more powerful and efficient tool for facilitating cognitive recovery in the post-COVID era.

In conclusion, the careful design and strategic implementation of this programming language have laid the groundwork for an application that not only meets the current needs of patients but is also poised to adapt and incorporate future technological advancements in biometric data collection and analysis.

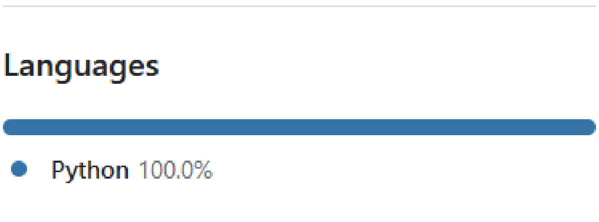


Figure 10: "Languages" section on GitHub, showing that 100% of the project was developed in Python.

4.1.2 PyQt5

PyQt5 has been chosen as the cornerstone for building the graphical user interface (GUI) of our project, thanks to its comprehensive set of tools that make user interface creation an intuitive and accessible process. This technology, which serves as a bridge between the Qt C++ framework and Python, combines the powerful features of Qt with the ease of use and flexibility of Python.

In our work on "LC-Neurorehab," PyQt5 has been key in realizing a user-friendly GUI that not only fulfills the functional requirements of the application but also enhances the user experience. Features such as custom widgets and dialogs ensure that patients can navigate the application effortlessly, focusing on their recovery tasks without unnecessary complexity or distraction.

Moreover, PyQt5's support for advanced graphics and customization has allowed the UI to be tailored to meet the specific needs of the application, making it adaptable for future enhancements, including the potential integration of sensory technologies.

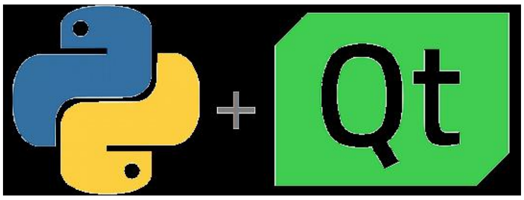


Figure 11: Python + Qt.

4.1.3 SQLite3

SQLite3 was chosen as the database management system for our project "LC-Neurorehab," due to its ability to offer an easily accessible relational database via SQL language. This system stands out for its efficiency, reliability, and direct integration into the application code, eliminating the need for a separate database server [13]. Its inclusion in the Python package makes it particularly suitable for use in desktop applications.

The key features of SQLite3 include:

- **Self-contained:** SQLite3 requires no additional configurations or installations, being a complete database that can be integrated directly into the software.
- **Serverless:** Unlike other database management systems like MySQL or PostgreSQL, SQLite3 eliminates the need for a dedicated server. Data access occurs directly through local library calls.
- **Zero Configuration:** The system requires no configuration or server maintenance, thus avoiding network configuration issues.
- **Transactional:** SQLite3 supports ACID transactions (Atomicity, Consistency, Isolation, Durability), ensuring the integrity of transactions even in the event of system failures or power outages.

- **Lightweight:** Taking up minimal disk space and memory, SQLite3 is ideal for devices with limited resources or for applications that require efficiency and agility.

In the context of our project, SQLite3 offers numerous advantages. Its ability to operate independently of an external server and to seamlessly integrate into our software is particularly valuable, especially in clinical environments where simplicity in data management and system reliability are critical.

The architecture of SQLite3 allows for the effective and secure management of clinical data. By creating a .db file locally on the device, it ensures that all patient-related information is handled securely, without the need for complex external configurations.

Choosing SQLite3 enables "LC-Neurorehab" to utilize a robust and straightforward data storage solution, avoiding the complexities associated with server-based databases and significantly improving the application's performance and stability. The generated .db file provides a compact and efficient data storage solution, perfectly aligned with the project's needs and ready to integrate future innovations.

```
db_connection = sqlite3.connect('database.db')
```

Figure 12: Python code used to establish a connection to our SQLite3 database "database.db".

4.1.4 Data Exchange

As mentioned in the previous paragraph, the application is designed to function as a standalone system, with data exchange internally managed without relying on an external client-server architecture. The data flow within the application is crafted to ensure an immediate and secure exchange of information between the user interface and the local SQLite3 database. This architectural choice guarantees that all Create, Read, Update, and Delete (CRUD) operations are carried out promptly and efficiently, without the need for network transmissions that could introduce latency or complications.

This direct approach to data exchange is particularly advantageous in clinical settings, where speed and accuracy in data access are critically important for monitoring and evaluating patient progress.

4.1.5 Application Launch

To facilitate the execution of the application, an executable file (.exe) has been created, allowing for quick and convenient launch of the application without the need for complex configurations. This executable file streamlines the application startup process, which will be present on devices in clinical environments, enabling therapists and/or laboratory assistants to access the application's functionalities with a single click. The creation of this .exe file adds convenience and accessibility to the overall user experience, minimizing technical barriers and simplifying application startup for less experienced users.

4.2 Code description

The code, as well as the file structure within the context of realizing the system architecture and meeting the project criteria, are explained in this paragraph. Version control and teamwork were conducted using a dedicated GitHub repository.

- **.gitignore:** this script is used to specify the files and folders that Git should ignore during project versioning. This means that the files listed in the .gitignore file will not be tracked or included in commits, useful for excluding temporary files that are not needed for versioning the source code.
- **admin_area.py:** this script contains the definition of the "AdminArea" class, which represents the administrator's private area within the application. This class is responsible for managing the user interface (GUI) and specific functionalities of the administrative area. It uses the PyQt5 library to create interface elements and handle events, and SQLite to interact with the local database and retrieve data of registered users. Within the "AdminArea" class, methods are defined to display and manage registered users, including buttons to view specific details of each user and the logout button.
- **data_tasks.py:** this script implements a PyQt5 GUI for managing user data and their performance in the two cognitive tasks. Through two main classes, "PopupTableDialog" and "UserDataTasks", it offers features to display detailed information about users and their progress in tasks such as the Adaptive Dual N-Back and the Mental Rotation Test. The GUI allows for editing and saving personal notes, as well as displaying patients' progress through dynamic tables. The script connects to a SQLite database to retrieve and update information.
- **dualNback.py:** this script implements a PyQt5 application for administering the Adaptive Dual N-Back task. It features a graphical user interface that displays visual stimuli on a grid and plays auditory stimuli.

  Key components include:

    - **BackgroundFrame:** renders the game grid and visual stimuli, including mechanisms for flashing effects that highlight the presentation of stimuli.
    - **Introduction:** provides an overview of the game, instructions, and a starting point for users.

  - **MainWindow:** the main game window where users engage with the task, featuring response buttons, a progress bar, and dynamic updates based on user inputs and game progression.

  The game uses pygame for auditory stimuli and integrates with a SQLite database to log user performance. Custom event handling captures and processes user responses. The application is designed to adjust the level of difficulty based on accuracy, encouraging cognitive development through a progressively challenging task.

- **mrt.py:** this script implements a PyQt5 application for administering the Mental Rotation Test (MRT).It is structured into two main classes: “IntroductionMRT”, which provides an overview and instructions for the test, and “MRT”, where the test is conducted. Users are tasked with determining whether pairs of three-dimensional objects are identical, mirror images, or different by using keyboard shortcuts. The application calculates correct and incorrect responses, adjusts the difficulty level based on user performance, and stores the results in a SQLite database.
- **Neurorehab.py:** this script launches a PyQt5 application that displays a login interface, separating the user interface design from the application logic for clarity and maintainability. It initializes the “QApplication”, creates an instance of “LoginWindow” from a module named “registration”, and displays this login window to the user. The application then enters the event loop with “app.exec_()”, waiting for user actions such as entering credentials and clicking buttons. The script ensures a clean exit once the user closes the login window or completes the login process.
- **registration.py**: this script provides a PyQt5-based GUI for user authentication in the application. It defines “LoginWindow“ for user sign-in, where users enter their username and password, and “RegistrationWindow” for new user sign-up. The interfaces interact with an SQLite database for credential storage and verification, using SHA256 for password hashing. Upon successful login or registration, users are redirected to respective areas of the application, indicated by placeholders like Homepage and AdminArea.
- **user_page.py**: this script defines a PyQt5 widget, “UserPage”, which serves as a personal area within the admin section of the application. The interface displays a user's personal information and allows the admin to view and edit notes associated with the user's account, which are saved in an SQLite database. Two buttons, representing the two different cognitive tasks, open respective task data when clicked. The admin can navigate back to the main admin area or save changes to the user's notes directly from the GUI.
- **trialsDefinition.py:** the script provides a function to define the trials for the Adaptive Dual N-Back game. It initializes audio and visual sequences based on a given level of difficulty and ensures that a certain number of trials include matching stimuli from "N" steps back, adhering to the Dual N-Back rules.

The function selects a subset of audio files randomly, queues them, and then creates a mixed list of audio trials, including some that match previous ones in the sequence by the level number. Visual trials are generated similarly with a list of coordinates representing the grid positions, excluding the center. It ensures a certain number of matches and creates a visual vector of trials.
Finally, the function combines audio and visual solutions, determining if the trial contains a match for either or both types of stimuli. The results are sorted and stored in the "dualNBack" object, ready for the game to use.

The audio files and images used for the trials of the two different tasks are stored within directories named "audio" and "images/mrt", respectively. These folders are systematically organized within the application's file structure, ensuring that the necessary resources for the Adaptive Dual N-Back and Mental Rotation Test tasks are efficiently accessible during gameplay. The audio folder contains a variety of sound clips that are randomly sampled during the trial generation process, providing the auditory stimuli that players must remember and recognize. Similarly, the images folder houses a set of visual elements used to create the challenges required for the Mental Rotation Test.

4.3 User Interface

The personal contributions to the project are presented in the paragraphs that follow.
During the development cycle of the desktop application, I played a central role within my team, contributing actively from the initial requirements analysis to the delivery of the "final" product. My main area of expertise focused on the implementation and optimization of the Adaptive Dual N-Back task, where I took a leading role in its development.

4.3.1 Login Page

The login page is designed to be the first point of contact between the user and the application, offering a clear and direct interface that guides users through the login process. It features two text input fields prompting the user to enter a "Username" and "Password," each with a placeholder specifying the required information. Three action buttons - "Login," "Login as Admin," and "Register now" - provide options to proceed with standard authentication, administrative access, or to register a new account.

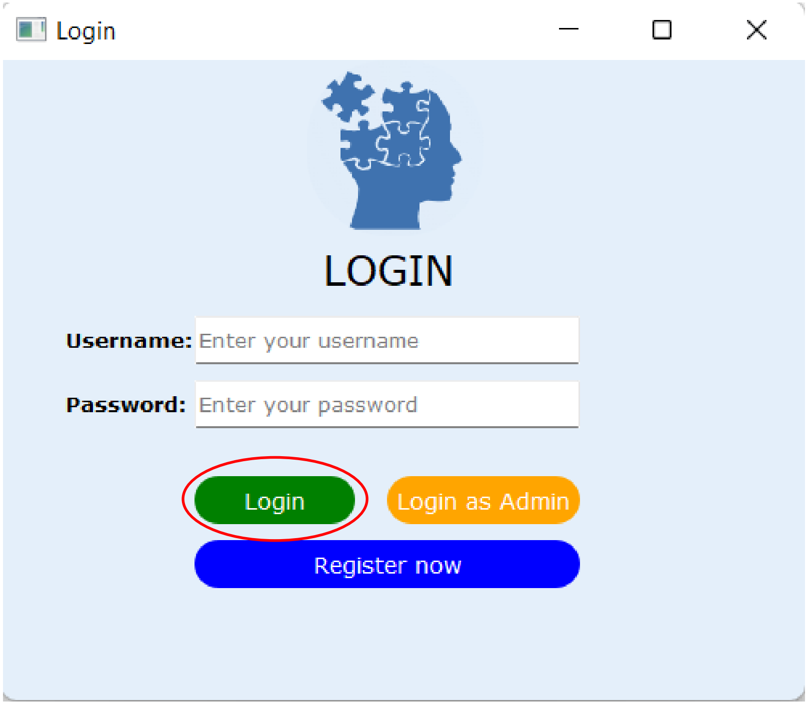


Figure 13: Patient-dedicated login.

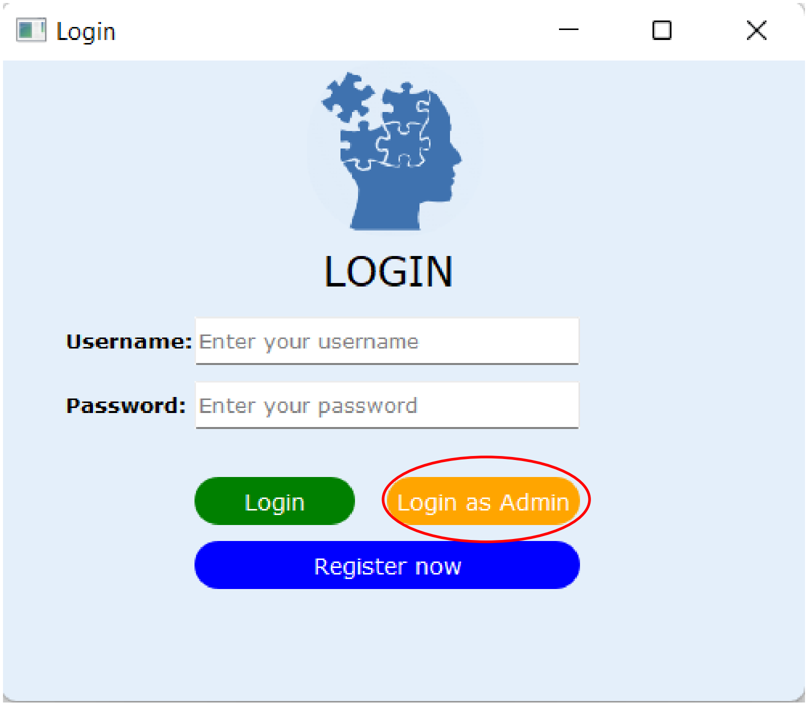


Figure 14: Admin-dedicated login.

Figure 15: The message "Username or password is incorrect" signals an unsuccessful login attempt made by a patient

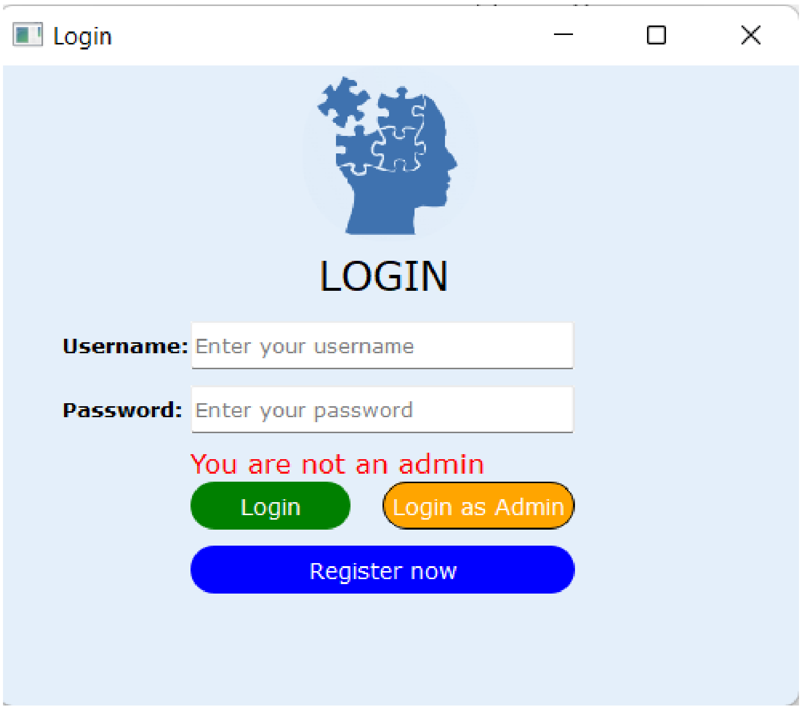


Figure 16: The message "You are not an admin" signals an unsuccessful login attempt made by an admin.

4.3.2 Registration Page

The Registration Page is designed to welcome new patients in the system. There is a distinct registration process for patients and admins.

4.3.2.1 Patient Registration Process

When a patient clicks on "Register now," they are redirected to the Registration Page. The figure 9 depicts the registration window where users can create a new account. Participants are asked to provide personal information such as first name, last name, date of birth, username, and password. These fields are clearly labelled and feature placeholders that indicate the information to be entered. At the bottom, two buttons: “Register”, in green, and “Cancel”, in red, give users the option to complete or cancel the registration process.

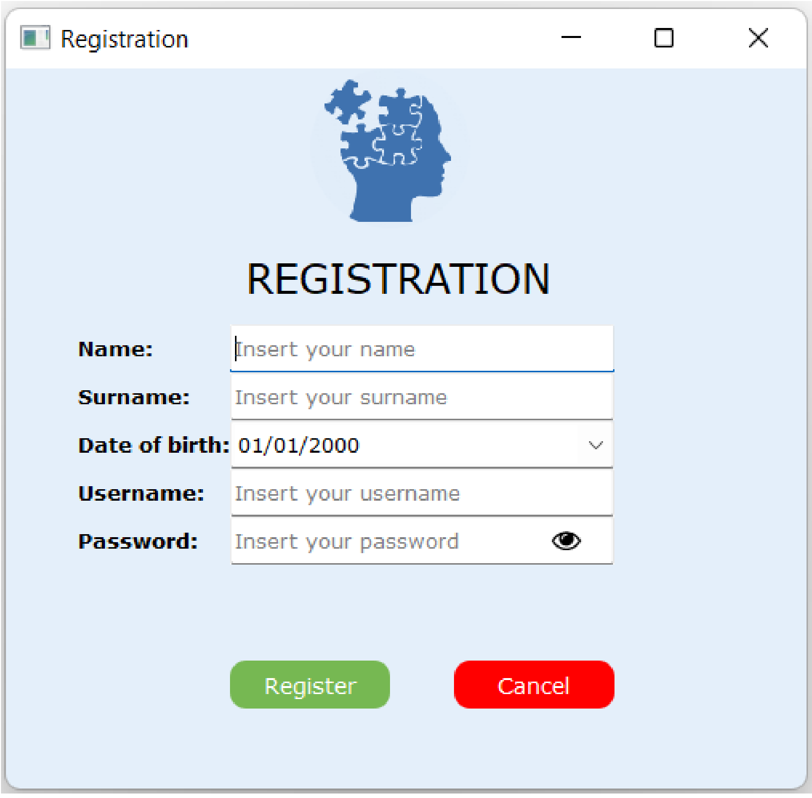


Figure 17: Patient-dedicated Registration Page.

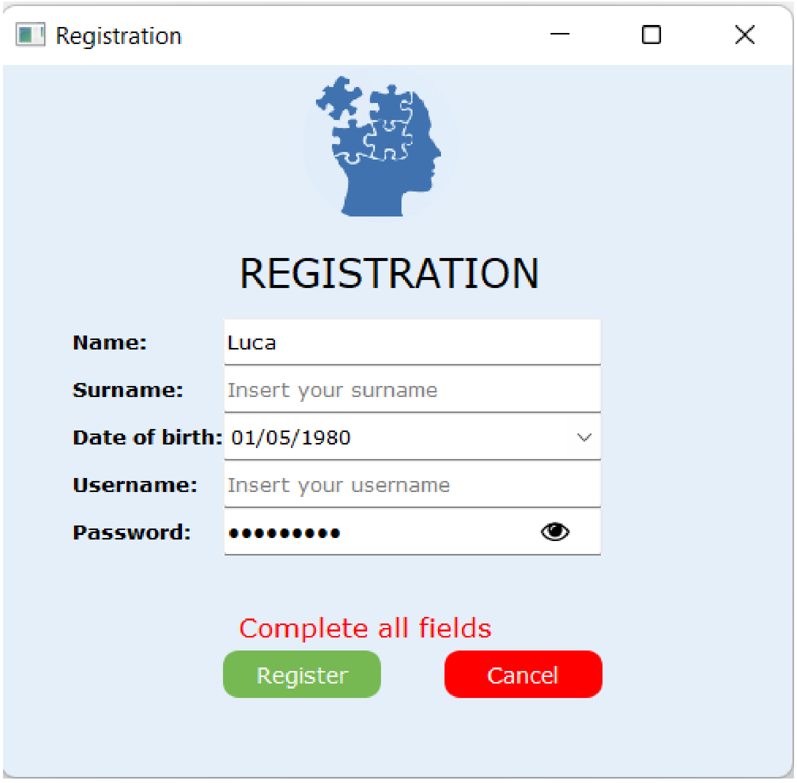


Figure 18: A "Complete all fields" message will indicate to the patient that the registration process cannot proceed until all fields are filled in.

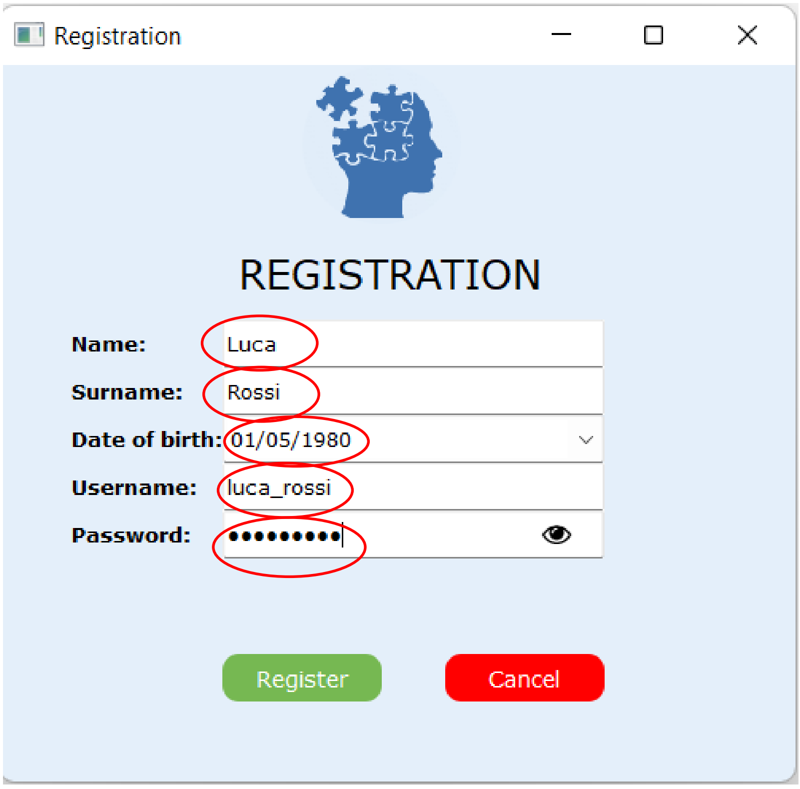


Figure 19: Example of field completion for the patient registration process: entering first name, last name, date of birth, username, and password.

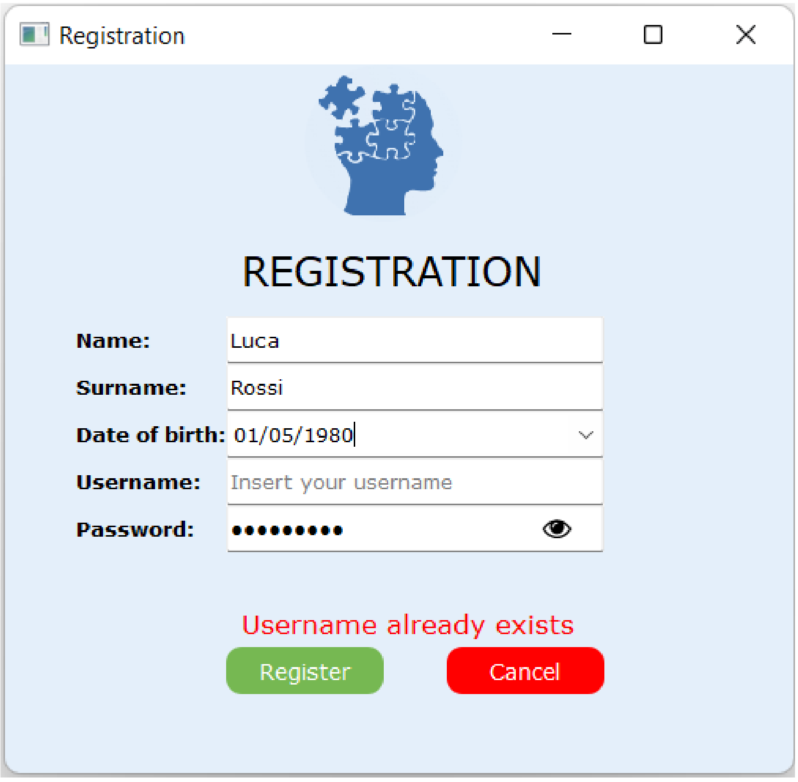


Figure 20: A message "username already exists" will appear if the username with which a patient attempted to register is already in use by another user.

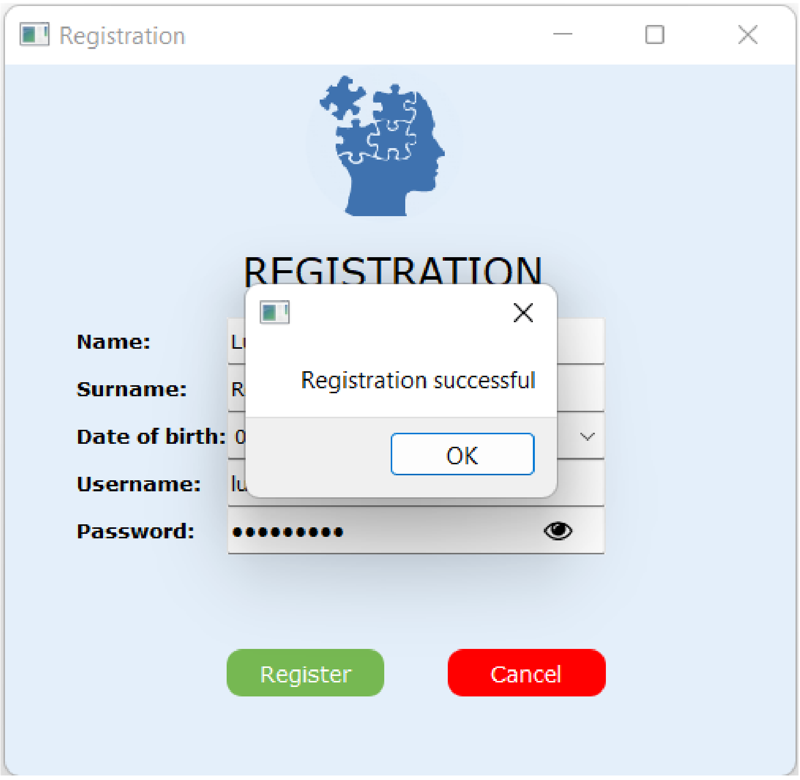


Figure 21: A "registration successful" pop-up will appear if all fields have been filled in correctly and the registration process has been completed successfully.

4.3.2.2 Admin Authentication Process

Regarding administrators, the registration process is more of an authentication: the admin enters their username and password, performs a login as admin, and the system then requests them to enter a security code, which, at the time of developing this thesis, is a code agreed upon among administrators (developers, clinicians, and lab assistants).

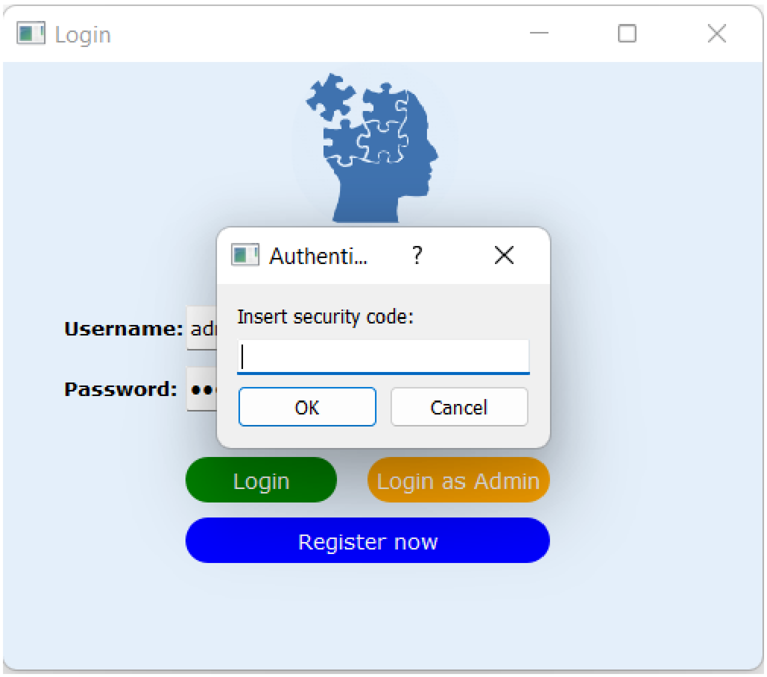


Figure 22: Admin-dedicated Authentication Process.

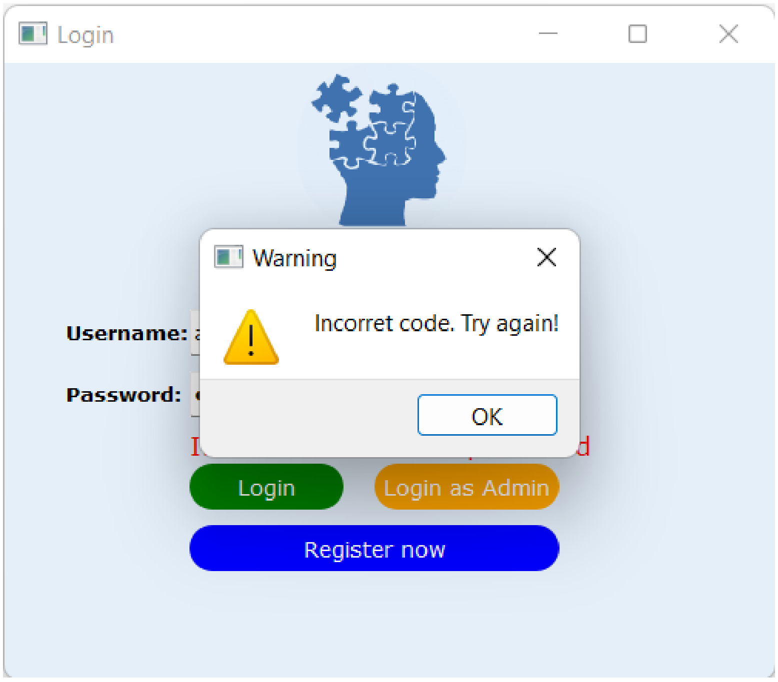


Figure 23: A warning pop-up message appears if the admin does not enter the correct security code, prompting them to try again.

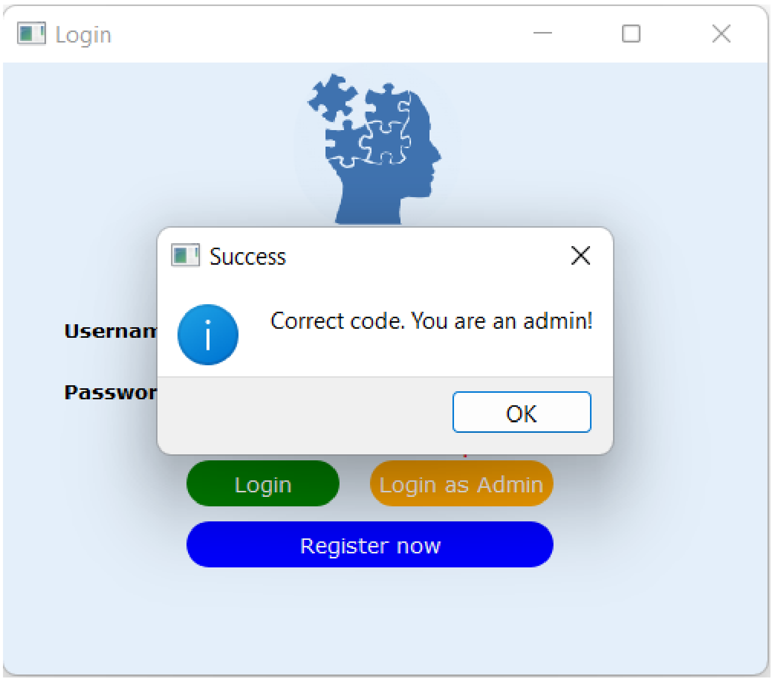


Figure 24: A success pop-up message appears when an admin's authentication process is successfully completed, confirming their access has been granted.

4.3.3 Home Page

After successfully completing the registration process and logging in, the patient will be directed to the Home Page of the application. The page displays the available neurorehabilitation tasks that the patient can perform and complete. Each activity is designed to target and enhance specific cognitive functions as part of their therapeutic journey.

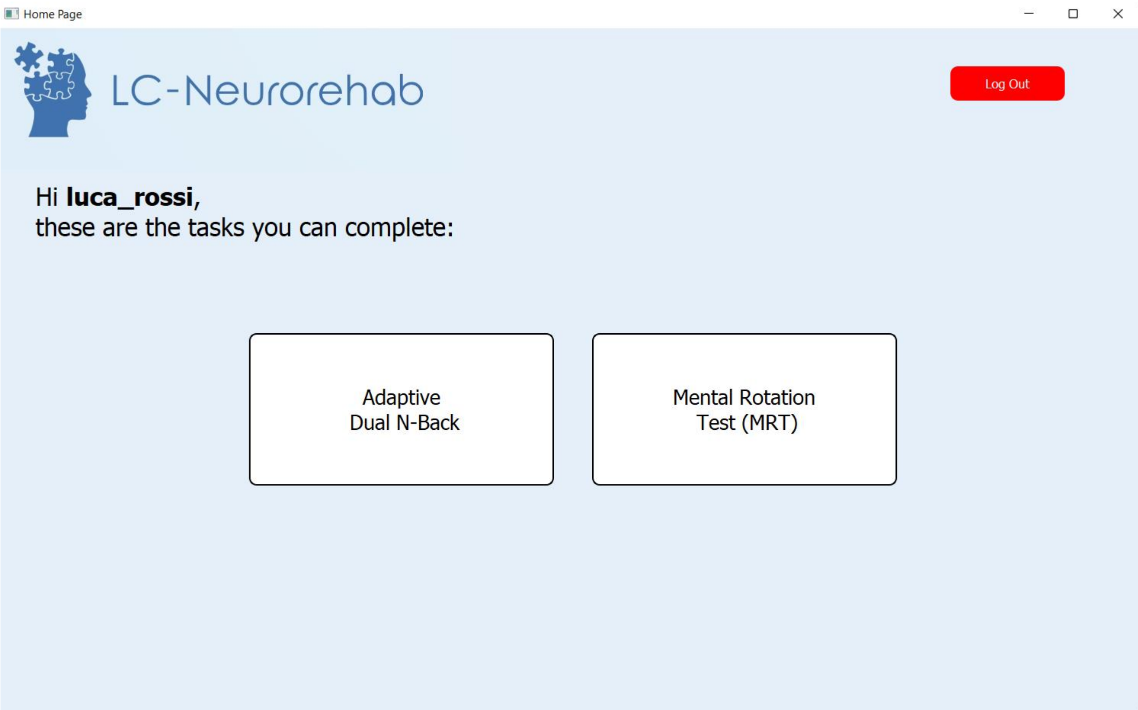


Figure 25: Home Page of the application from which the patient can select the available neurorehabilitation tasks for execution.

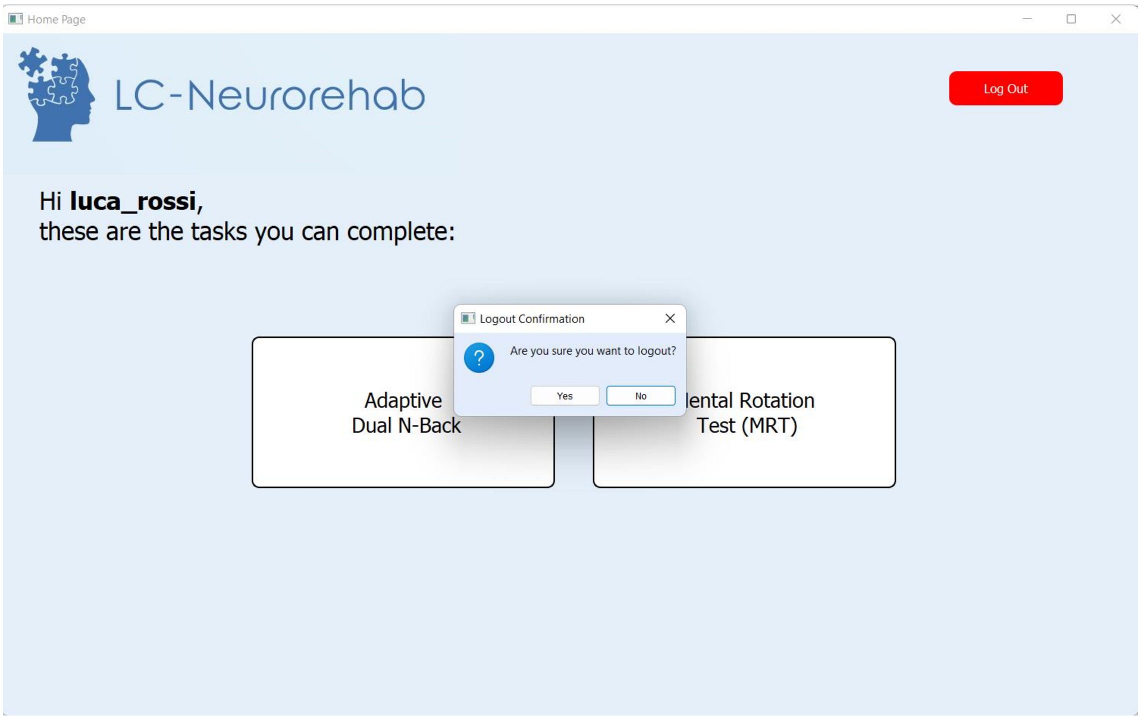


Figure 26: This confirmation pop-up message appears when the patient is in the process of logging out from the application. The "Yes" and "No" options serve as a safeguard against accidental logout, ensuring that such actions are intentional.

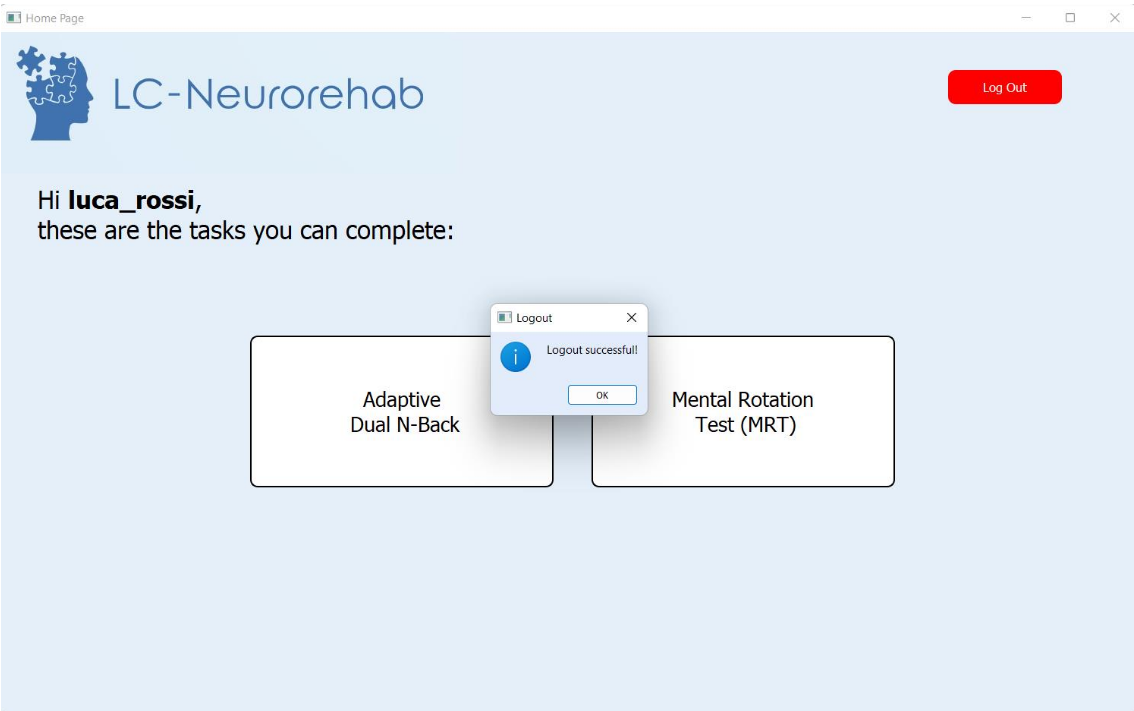


Figure 27: This pop-up message appears after the patient has successfully logged out from the application.

4.3.4 Adaptive Dual N-Back

After selecting the "Adaptive Dual N-Back" option, the patient will be directed to the specific page dedicated to this exercise. Before starting the exercise, the page provides a comprehensive overview of what the Adaptive Dual N-Back task entails. It is clearly communicated that this task is a cognitive exercise aimed at enhancing working memory and attention.

The instructions explain that the task consists of various levels, with each level containing a number of trials that challenge the patient to remember the position of a square that lights up and a letter that is spoken. As the difficulty level progresses, for example, at n=2, the patient must recall the position and the letter from two steps earlier in the sequence.

To interact with the task, the patient is informed about the specific keys on the keyboard that will be used: “C” for matches in the sound sequence and “M” for visual matches, and if the two stimuli match simultaneously, they should press the “SPACE” bar. This setup ensures that the patient is well-prepared to tackle the task, understanding the mental effort required and the motor responses needed to indicate successful recognition of the patterns.

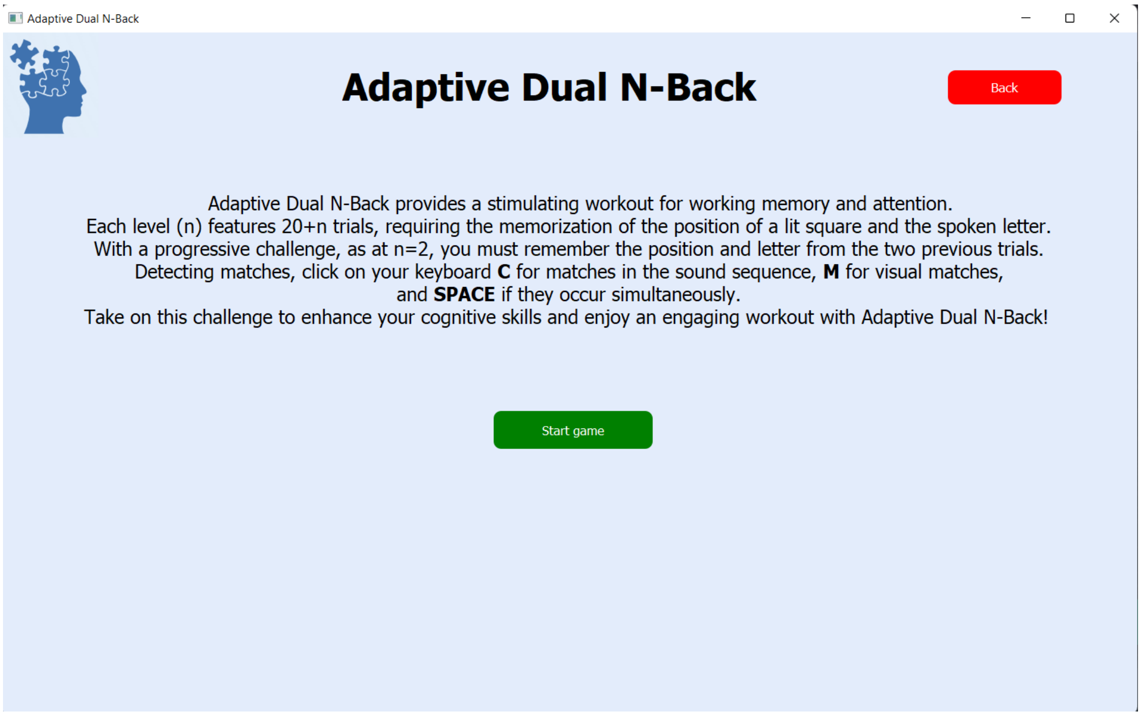


Figure 28: Comprehensive overview of what the Adaptive Dual N-Back task entails.

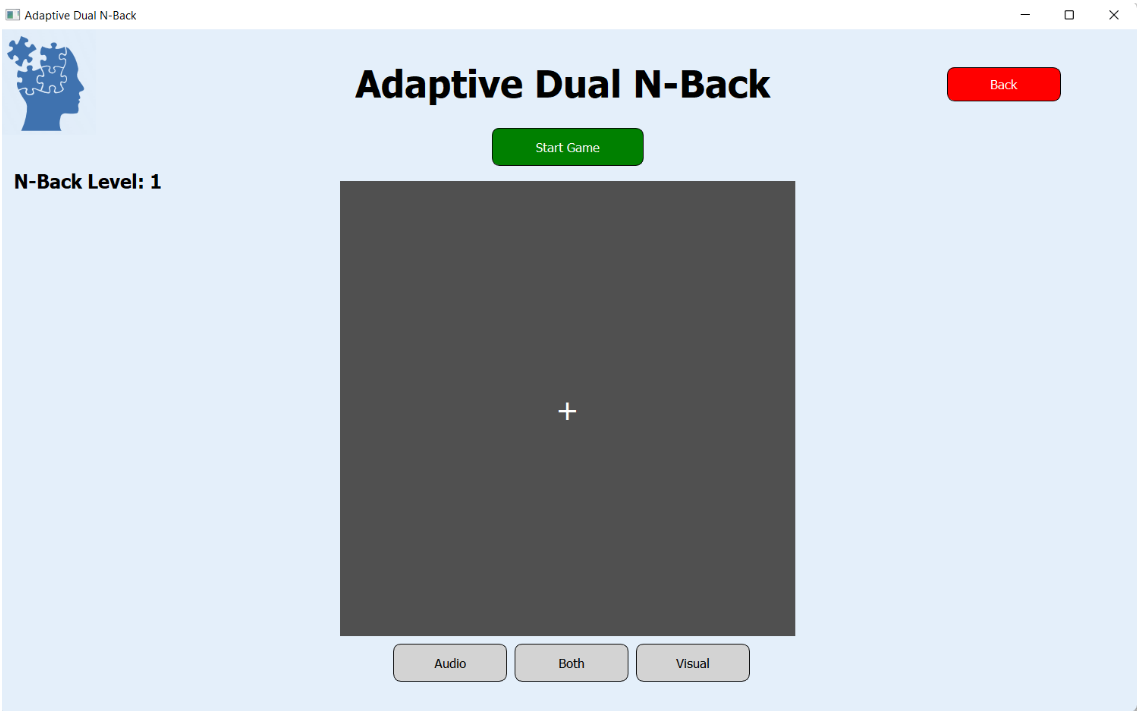


Figure 29: User interface of the Adaptive Dual N-Back Task.

The figure 30 displays the user interface of the Adaptive Dual N-Back task. At the centre of the screen, the game grid is highlighted where a blue square appears in a specific position, central to the game mechanism that challenges the patient to remember a sequence of positions or sounds. Above the grid, a green progress bar indicates the current level of completion, while the label "N-Back Level: n" informs that the player is at level n, in this case level 1. At the bottom of the interface, the buttons "Audio," "Both," "Visual" correspond to the input modes the player will use, responding to the presented stimuli. These buttons will light up in response to the patient pressing the corresponding keys on the keyboard, providing immediate visual feedback of the executed action.

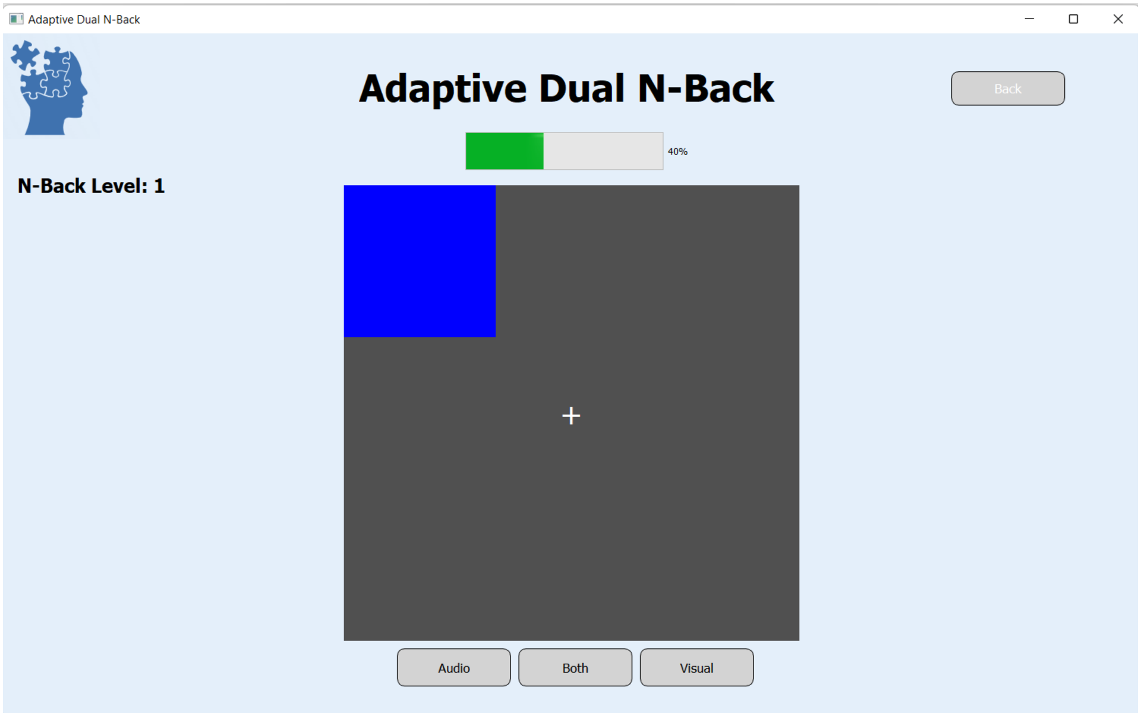


Figure 30: User interface of the Adaptive Dual N-Back task when it is started.

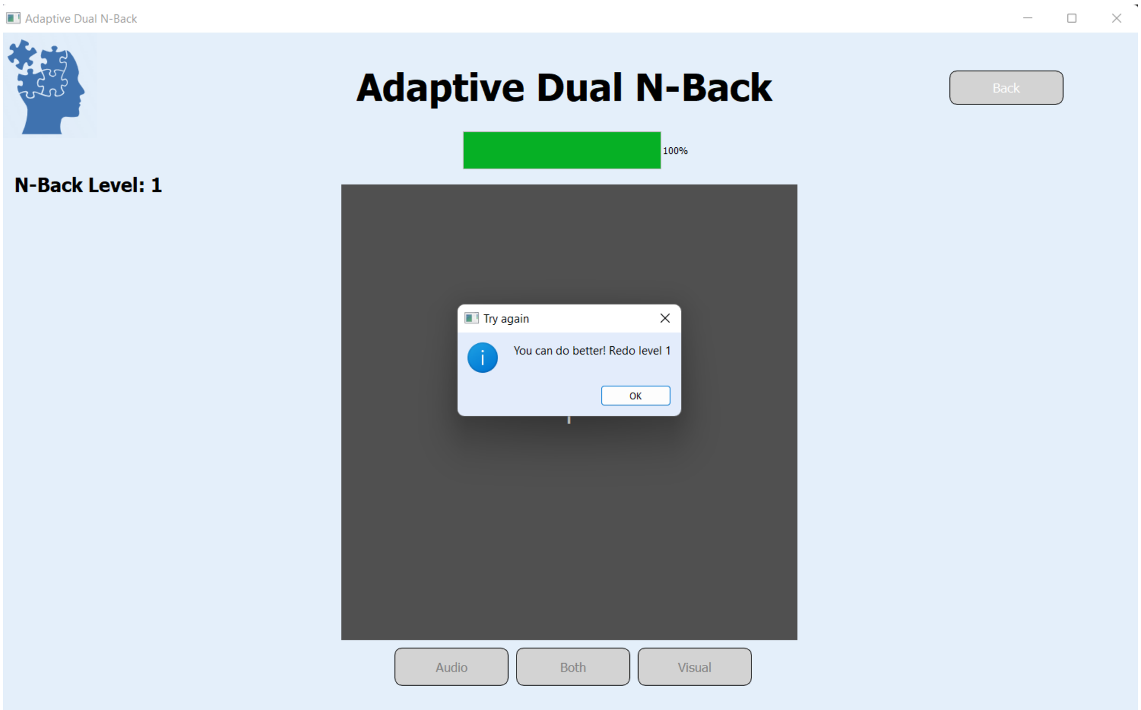


Figure 31: An encouraging pop-up message saying, "You can do better! Redo level "N-Back Level"!" appears to motivate the patient to attempt the level once more. This alert shows up when the user has not yet achieved sufficient accuracy (<95%) to advance to the next level.

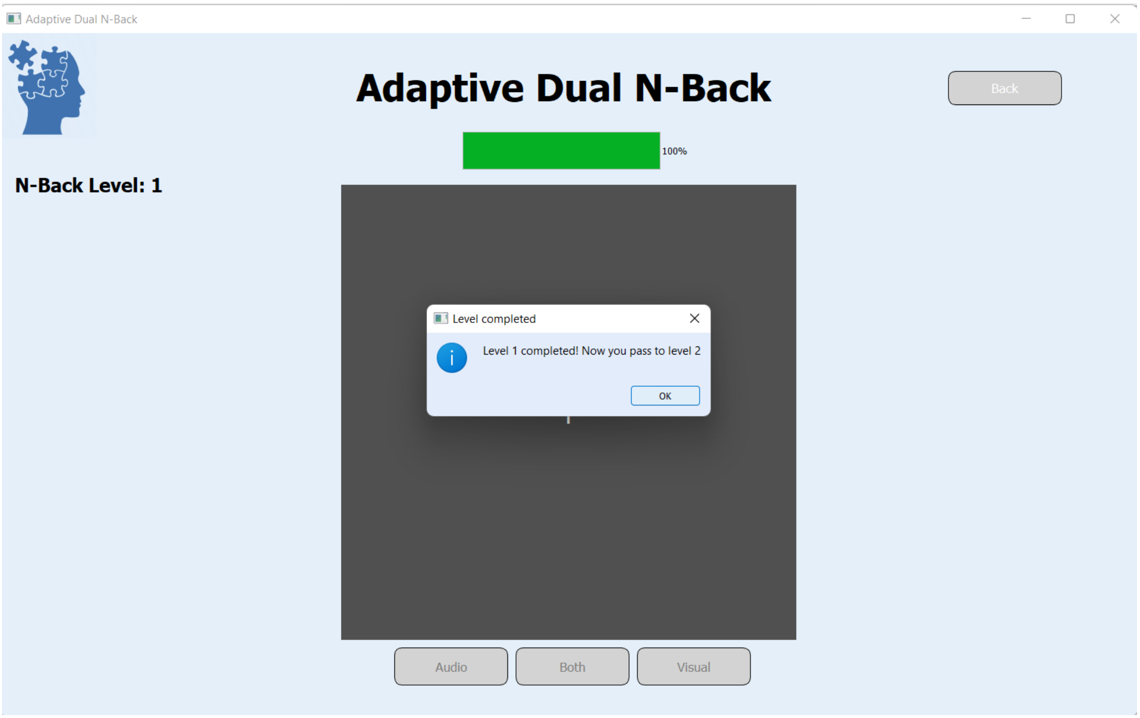


Figure 32: A congratulatory pop-up message saying, "Level 1 completed! Now you pass to level 2!" appears after successfully completing level 1, in this case. This alert shows up when the patient has achieved sufficient accuracy (>95%) to advance to the next level.

Figure 33: A pop-up message "Game completed!" indicates that the patient has finished the game session.

4.3.5 Admin Area

In the administrative area of the application, administrators have access to a range of tools and functionalities designed to effectively manage patient profiles and monitor their progress in cognitive rehabilitation programs. In this area, administrators can view patients' personal information, including relevant notes, and have the ability to insert, modify, or delete such notes as needed. Additionally, they have access to information regarding the activities performed by patients, such as the results of two cognitive tasks, the Dual N-Back and the Mental Rotation Test (MRT).

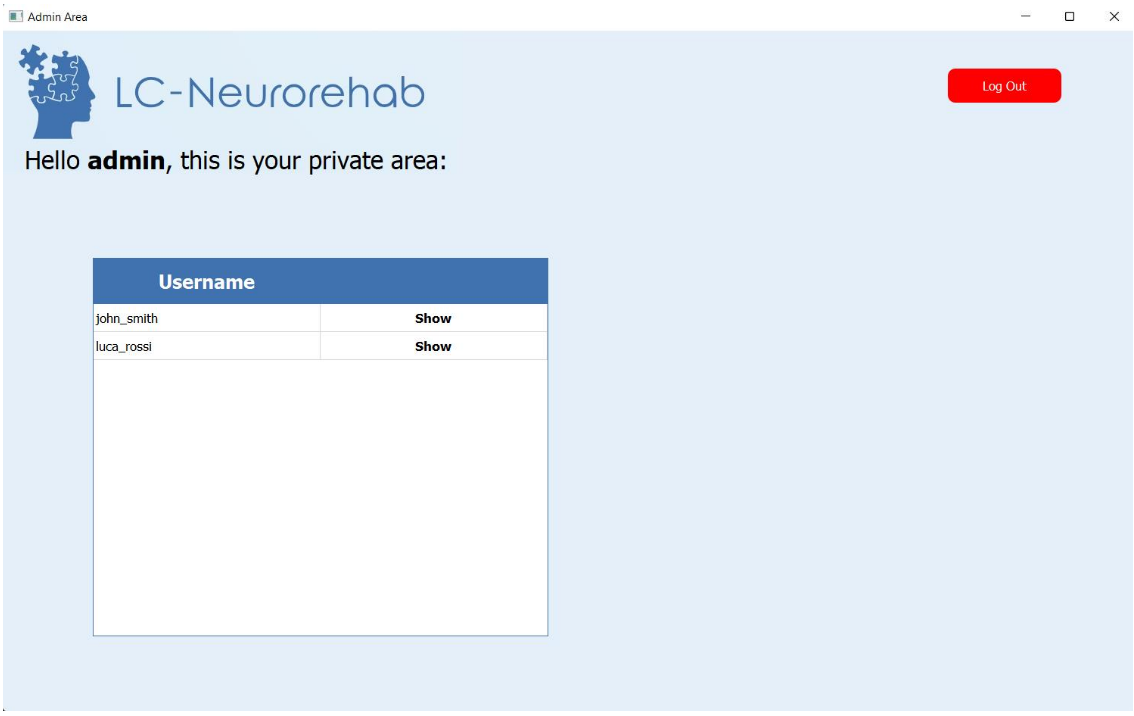


Figure 34: The image displays the interface of the administrative area of the application, where a table listing usernames corresponding to patient profiles is shown. Next to each username, the "Show" button, once clicked, allows access to more detailed information about each patient.

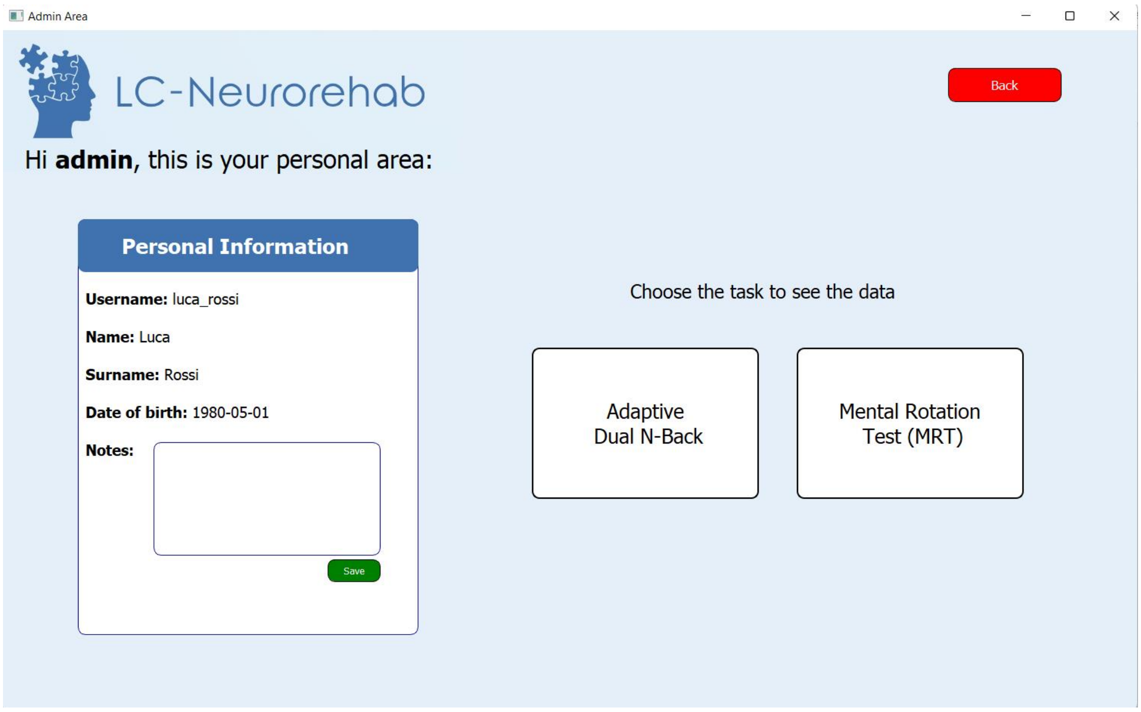


Figure 35: The image displays the administrative area of the application, specifically the personal information section pertaining to a specific patient selected by the admin. In this section, the admin has the ability to insert, delete, or modify information via the "Notes" field. The buttons "Adaptive Dual N-Back" and "Mental Rotation Test (MRT)" can be used to navigate to the corresponding task data for the patient.

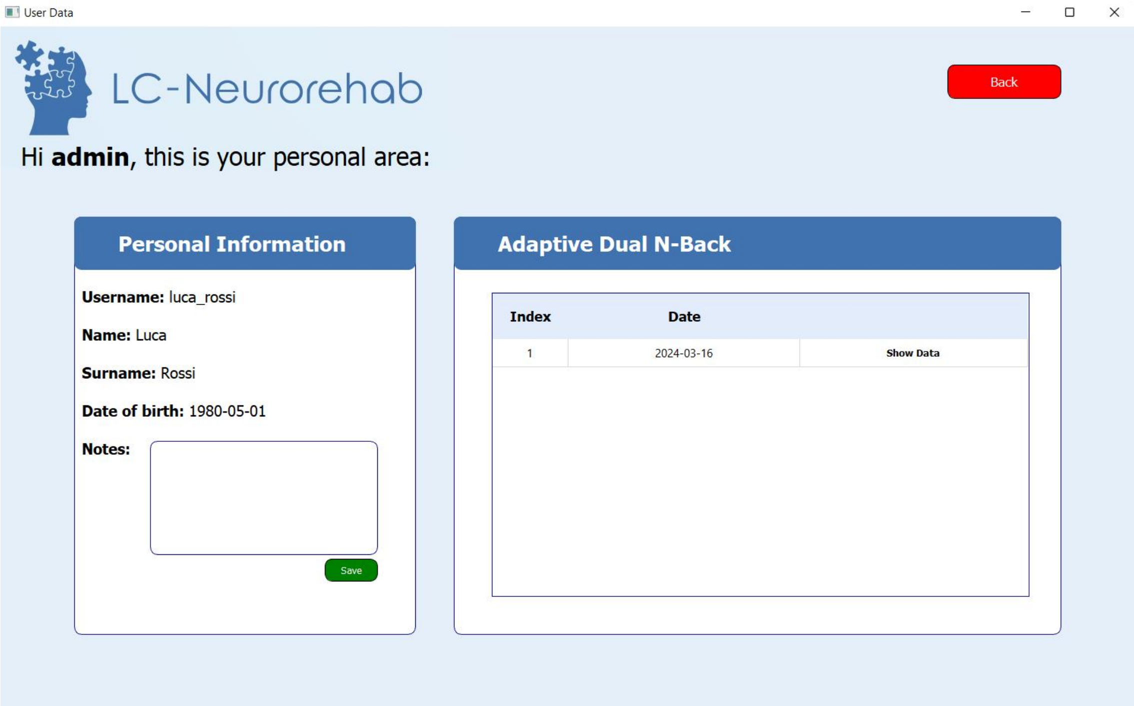


Figure 36: After selecting the "Adaptive Dual N-Back" button, the administrative interface of the application displays a detailed table concerning the task performed by the specific patient. The table includes an index, the date of task completion, and a “Show Data" button that allows the administrator to access the patient's data related to that specific activity session.

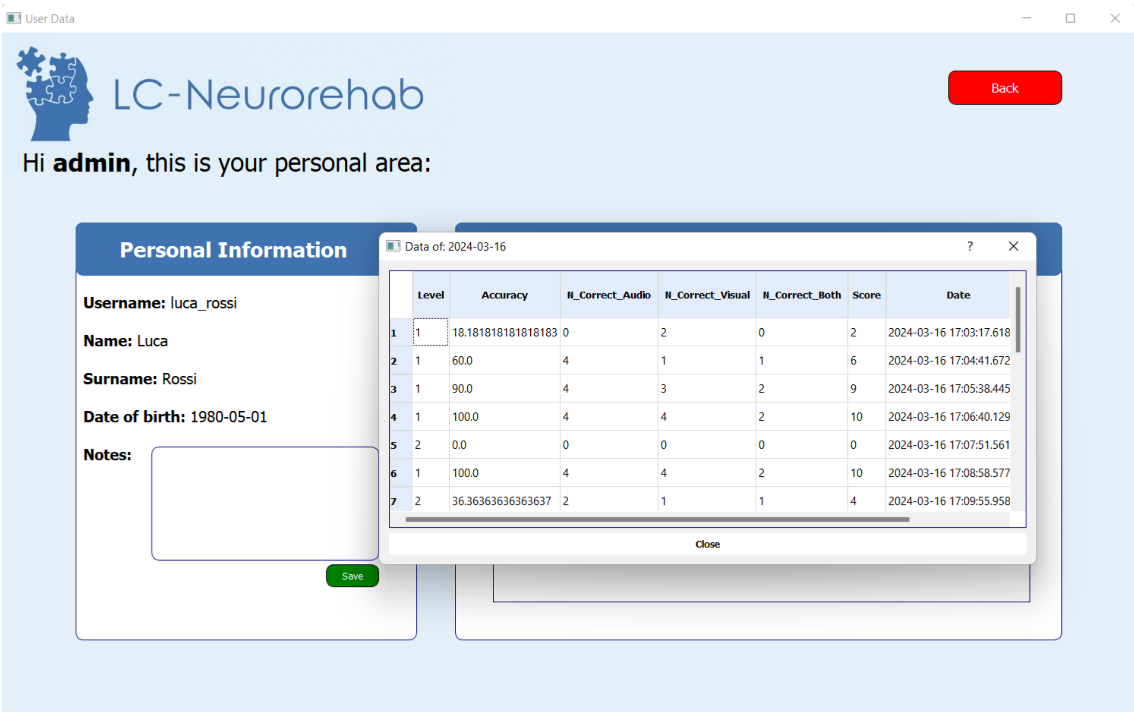


Figure 37: After clicking the "Show Data" button, the application provides the administrator with an in-depth view of all the recorded information for that specific task (Level, Accuracy, N_Correct_Audio, N_Correct_Visual, N_Correct_Both, Score, Date), thus allowing a detailed analysis of the patient's results and progress.

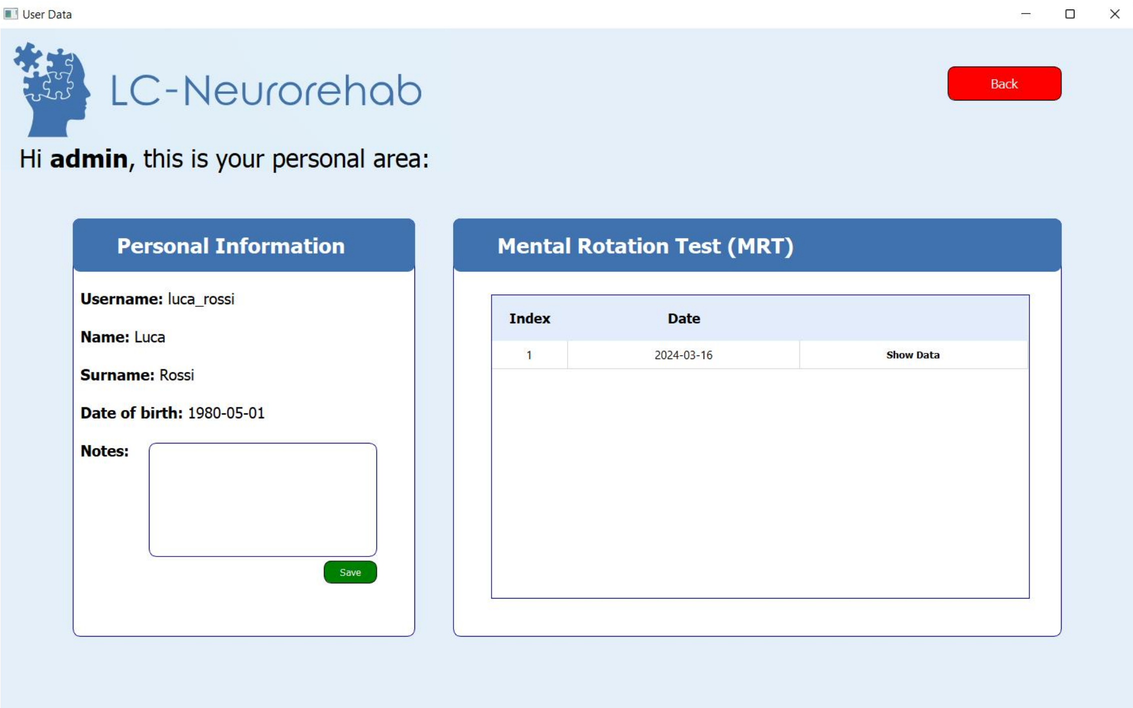


Figure 38: After selecting the "Mental Rotation Test (MRT)" button, the administrative interface of the application displays a detailed table concerning the task performed by the specific patient. The table includes an index, the date of task completion, and a "Show Data" button that allows the administrator to access the patient's data related to that specific activity session.

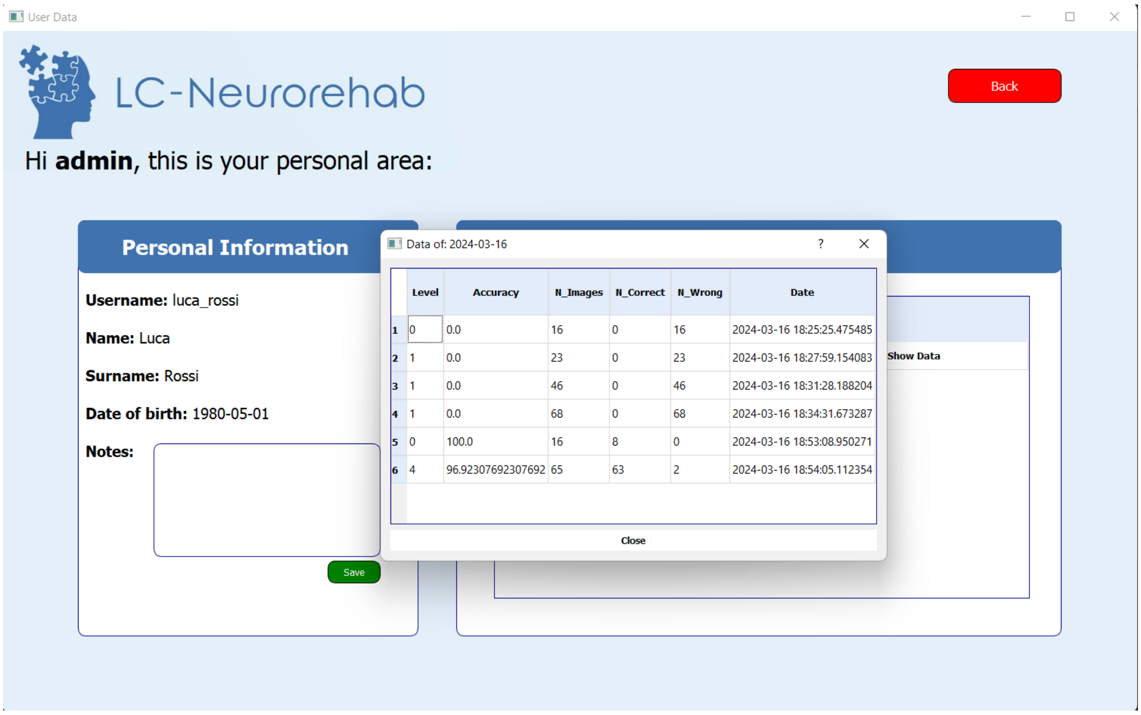


Figure 39: After clicking the "Show Data" button, the application provides the administrator with an in-depth view of all the recorded information for that specific task (Level, Accuracy, N_Images, N_Correct, N_Wrong, Date), thus allowing a detailed analysis of the patient's results and progress.

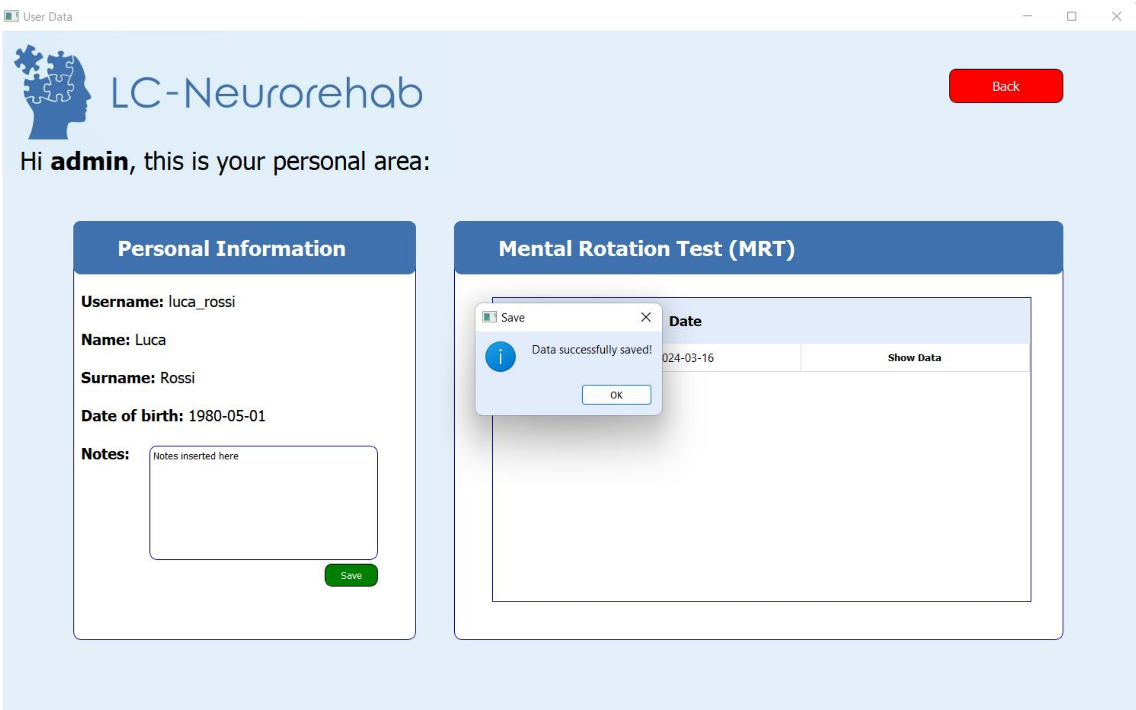


Figure 40: This pop-up message appears after the admin has entered or updated notes in the "Personal Information" section of a specific patient.

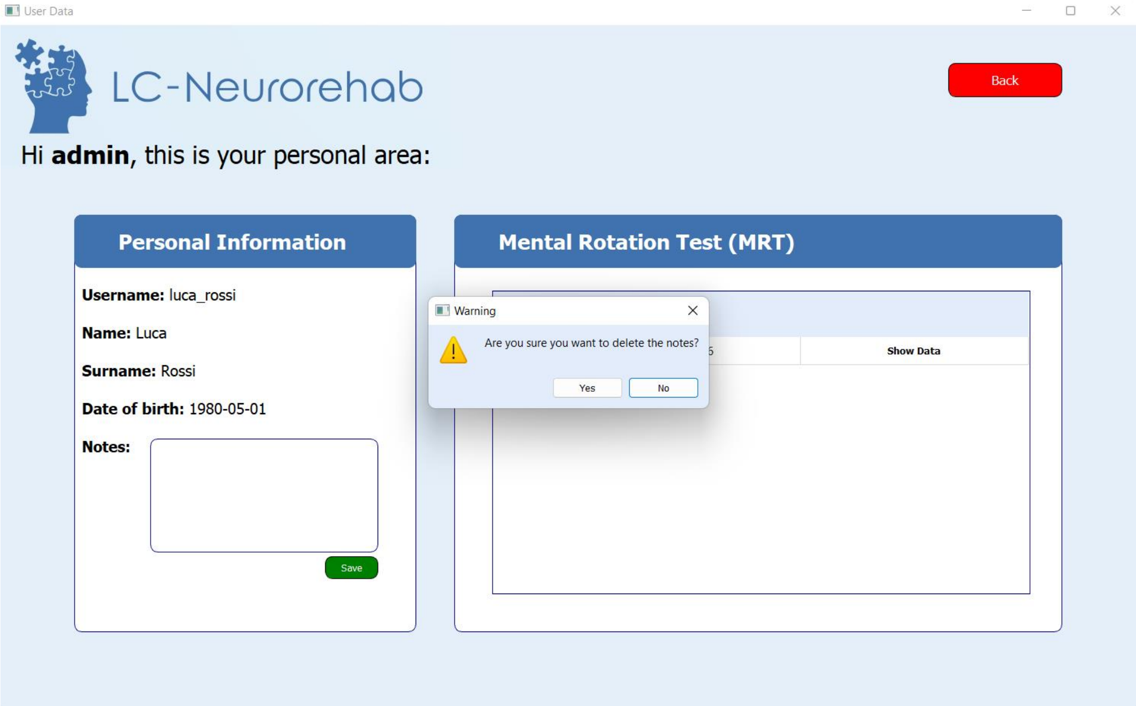


Figure 41: This confirmation pop-up message appears when admin is in the process of removing notes from the "Personal Information" section of a specific patient profile. The "Yes" and "No" options provide a safeguard against accidental deletion, ensuring that such actions are deliberate.

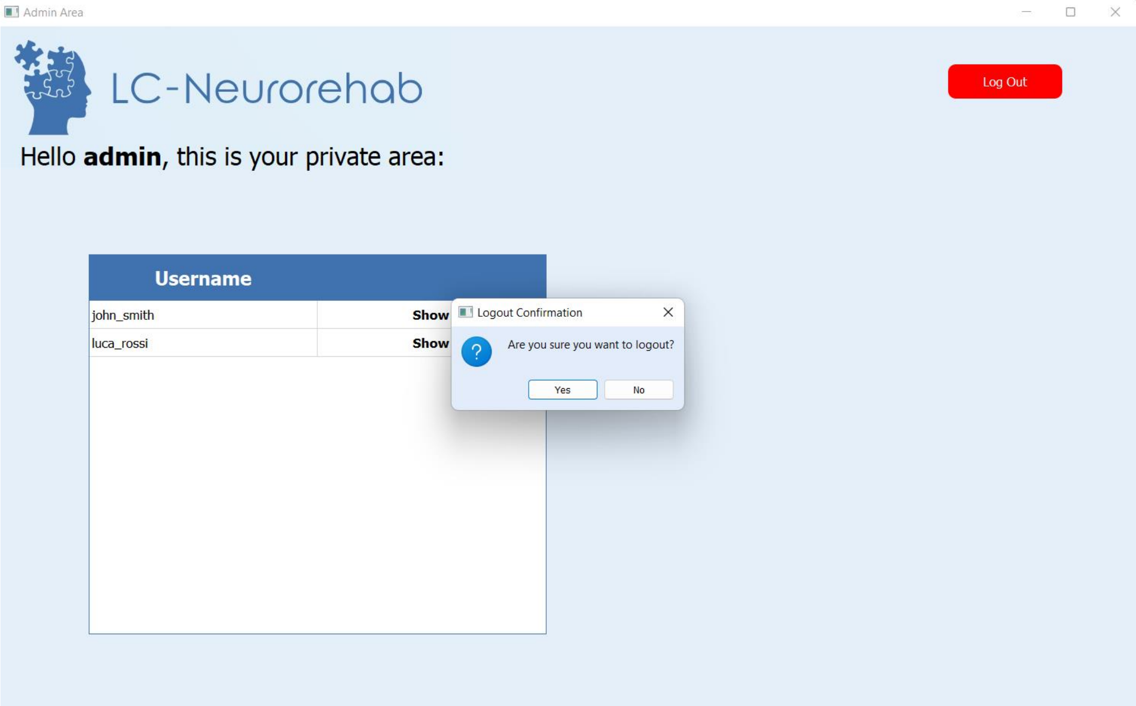


Figure 42: This confirmation pop-up message appears when the admin is in the process of logging out from the application. The "Yes" and "No" options serve as a safeguard against accidental logout, ensuring that such actions are intentional.

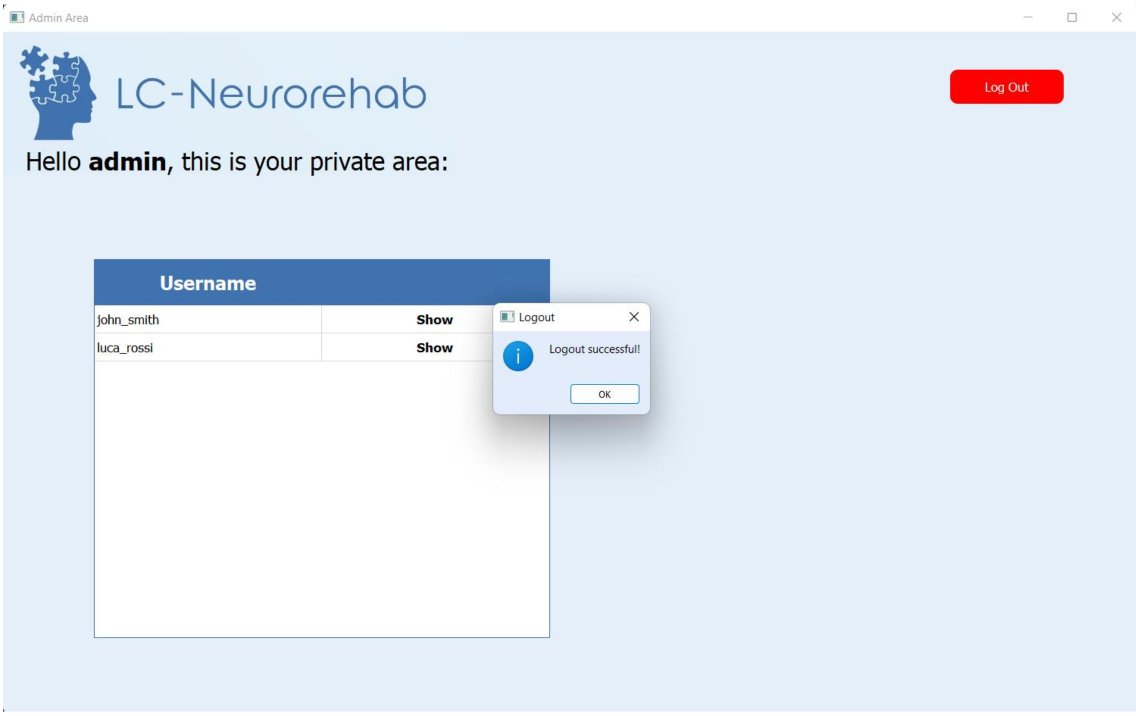


Figure 43: This pop-up message appears after the admin has successfully logged out from the application.

Chapter V

Future steps and Conclusion

5.1 Future steps

During the drafting of this thesis, despite the application having already reached an advanced stage of development and being ready for use, it has become apparent that further improvements can be made. Initially, it is crucial to complete some minor adjustments, including optimizing the application to make it responsive, ensuring proper display on devices of various sizes.

Looking ahead, a key step will be the introduction of specific protocols for the implementation of advanced sensors, such as electroencephalogram (EEG) and optical trackers. This functional expansion aims to equip the application with tools capable of providing precise biometric measurements, essential for accurately monitoring the physical and neurological conditions of patients. The inclusion of such sensors will enable obtaining more detailed data on the effects of Long Covid on cognitive abilities and overall well-being, thereby providing valuable insights for further optimizing neurorehabilitation strategies.

Other future steps may involve integrating artificial intelligence (AI) into the application. AI could be employed to analyze data collected from advanced sensors, providing a more thorough and precise interpretation of patients' biometric information. This analysis could help identify significant patterns and trends in the data, allowing healthcare professionals to more precisely tailor rehabilitation strategies and develop predictive algorithms to monitor the trajectory of cognitive recovery over time and anticipate any risks or complications.
Finally, AI could contribute to optimizing the user experience of the application by personalizing cognitive tasks based on each patient's specific abilities and needs and developing decision support systems for healthcare professionals, providing data-driven recommendations for planning and adapting neurorehabilitation treatments.

This multidisciplinary approach, combining computer and medical expertise, lays the foundation for an innovative and highly personalized neurological rehabilitation platform, capable of dynamically responding to patients' needs and effectively supporting healthcare professionals in developing targeted therapeutic pathways. The implementation of these technological advancements represents a promising field of research and development, the outcome of which could have a significant impact on the quality of life of patients affected by Long Covid, opening new frontiers in cognitive rehabilitation.

5.2 Conclusions

Concluding the work on "LC-Neurorehab," we find ourselves facing a significant milestone in the field of post-COVID neurorehabilitation. This desktop application embodies the intersection of advanced technology and the clinical needs emerging from the pandemic, providing a dedicated tool for the recovery of patients suffering from Long Covid.

"LC-Neurorehab" represents a notable advancement in cognitive rehabilitation, offering researchers and healthcare professionals a dynamic platform to explore and address the neurological complexities resulting from COVID-19. Through the integration of direct feedback, the project evolves into a highly adaptable and patient-centered tool aimed at improving the cognitive abilities and overall well-being of affected individuals.

The contribution of future developments, such as the implementation of sensors for biometric monitoring and the integration of artificial intelligence (AI), will open new avenues for the collection of valuable clinical data and the customization of rehabilitation.

At this point, despite having already achieved significant milestones, "LC-Neurorehab" remains an ongoing project. The goal is to further expand its capabilities, making it an increasingly effective and inclusive tool for the global scientific and medical community. The journey undertaken with "LC-Neurorehab" underscores the importance of technological innovation applied to health and opens promising scenarios for the future of neurorehabilitation.

In conclusion, "LC-Neurorehab" is not just a testament to the commitment to research and improving the quality of life for patients but is also a symbol of hope, a reminder that through interdisciplinary collaboration and innovation, we can face and overcome the challenges posed by complex conditions like Long Covid.

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