POLITECNICO DI TORINO

Master of Science in Computer Engineering

Master Degree Thesis

Advancements in 'Happy Again', a web app to assess the neurological consequences of Long Covid. A Journey through Enhanced User Interaction, Administration, and Data Analysis.

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A chi ha visto infranti i propri sogni,
a chi ha sofferto in silenzio,
a chi non ha trovato la forza di chiedere aiuto:
questa tesi è dedicata a voi.
Non siete soli.

E, naturalmente, ai miei genitori.

Abstract

Long COVID, also known as long-term COVID-19, is a condition characterized by the persistence or onset of symptoms following an infection with COVID-19, even after the initial infection has resolved. These symptoms can vary widely in severity and type, impacting various bodily systems. Long COVID presents a significant challenge to public health, leading to a deterioration in patients' quality of life and necessitating long-term medical care and support. The comprehension of the underlying mechanisms and effective management of Long COVID remain active areas of research and are of paramount importance.

This study is dedicated to investigating the neurological consequences associated with Long COVID through the utilization of the website 'Happy Again,' which is accessible at https://happyagain.essex.ac.uk/. Developed as a comprehensive platform for data collection and analysis, 'Happy Again' forms an integral part of a research endeavor undertaken at the University of Essex.

During my contribution to the project, I effectively managed the collected data, optimizing their structure and utilization within the system through the management of databases and data manipulation within them. My responsibilities included the maintenance and implementation of new functionalities to enhance the flexibility and efficiency of the website. Among the introduced features is an administrative area enabling the monitoring of user-completed tasks, automated e-mail reminders to prompt task completion within a specific deadline, voucher management via an intuitive administrative interface, and the provision for users to repeat a specific task (Word Categorization Task) after completion.

These improvements not only optimize data collection but also contribute to a better understanding of the neurological implications of COVID-19 through the analysis of collected data.

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Introduction

Contextualization of the Topic

The global COVID-19 pandemic has shaken the entire world, posing unprecedented challenges to public health, the economy, and society as a whole. Beginning as a viral infection outbreak in the Chinese city of Wuhan in late 2019, the SARS-CoV-2 infection quickly spread worldwide, leading to a global health crisis of epic proportions. The World Health Organization declared COVID-19 a pandemic on March 11, 2020, highlighting the scope and urgency of the situation [1]. The emergence of the SARS-CoV-2 virus has deeply shaken our society, thrusting humanity into an unprecedented crisis that has impacted every aspect of daily life. The COVID-19 pandemic has brought with it a series of challenges and devastating impacts, straining healthcare systems, the global economy, and the mental and physical health of individuals. The need for drastic containment measures, such as national lockdowns and social distancing, has radically transformed our daily lives, imposing drastic changes in our behaviors and social interactions. In addition to the immediate effects of acute SARS-CoV-2 infection, increasing evidence is emerging regarding the persistence of symptoms and long-term complications for those who survive the infection. This phenomenon, known as Long COVID, manifests with the persistence of symptoms even after clinical recovery from the acute infection and represents a significant challenge for public health and healthcare systems worldwide, drawing the attention of the scientific and medical community due to its complexity and severity. Numerous studies have documented a wide range of persistent symptoms associated with Long COVID, including chronic fatigue, brain fog, and respiratory difficulties, which can persist for weeks or even months after the initial infection. Furthermore, an increased incidence of neuropathies, encephalopathies, and cognitive disorders has been highlighted in COVID-19 patients, suggesting a possible correlation between viral infection and these neurological complications.

Research Objective

The present study, initiated by the University of Essex, is part of the project titled 'Neurological Consequences of Covid-19: a web-based study for behavioral data analysis'. The main objective of this research is to investigate the impact of COVID-19, focusing specifically on the neurological consequences reported by patients who have had the virus in the past. Through the analysis of behavioral data collected via a dedicated web application, we aim to understand how COVID-19 influences the neurological health of patients and to identify any issues or neurological disorders associated with the disease. This approach will allow us to obtain a detailed overview of the long-term neurological consequences of COVID-19 and to develop targeted intervention strategies for their management and treatment. The web app is named 'Happy Again' and includes a series of small cognitive tasks for patients to complete. The data collected through this application will be subsequently analyzed by a team of experts, composed of psychologists, analysts, and designers, in order to identify any correlations between behavioral data and the neurological consequences of COVID-19. Through the collection and analysis of behavioral data, we aim to provide a solid knowledge base that contributes to the advancement of scientific research in the field of neurological consequences of COVID-19 and supports the efforts of the medical community in ensuring better care and treatment for patients affected by the disease.

During the course of the project, which lasted approximately one year, I actively collaborated with the team composed of psychologists and professors, offering my support in every phase of the process. I was always available to assist team members, responding to their requests and helping them solve any technical or maintenance issues on the site. In particular, we managed patient data within the databases together, taking responsibility for their management and organization. The team I was part of consisted of students from the University of Essex and Politecnico di Torino, with whom I collaborated closely to advance the project. This experience not only allowed me to contribute to the improvement of the web app through the development of new implementations, but was also extremely formative in other aspects. I had the opportunity to develop new skills in team management, communication, and organization, becoming aware of the importance of collaboration and coordination among group members.

Structure of the Thesis

This section provides an overview of the following dissertation, in particular of its six chapters.

- In **Chapter 1**, we will explore the description of the COVID-19 problem, including its symptoms and related issues, with particular attention to the phenomenon of Long COVID and its neurological effects.
- In **Chapter 2**, we will take a detailed look at the description of the 'Happy Again' project, focusing on its purpose, project evolution, and functional and non-functional requirements of the system.
- **Chapter 3** will focus on the design and implementation strategies of the solution.
- **Chapter 4** will examine the results obtained and the technologies employed in its realization.
- **Chapter 5** will present my personal contributions to the project, followed by conclusions.

Chapter 1

COVID-19 and Related Issues

1.1 Description of the problem

The COVID-19 pandemic, brought about by the novel coronavirus SARS-CoV-2, has presented a myriad of challenges across various spheres including public health, socio-economic, and psychological aspects. Recognizing the multifaceted nature of these challenges is pivotal in crafting effective strategies to mitigate the impact of the pandemic and fortify resilience against future threats.

The rapid spread of SARS-CoV-2 and subsequent onset of COVID-19 have placed unprecedented strain on healthcare systems worldwide, placing immense pressure on hospitals and healthcare workers. This strain has been exacerbated by shortages in medical supplies and personnel, with reports from frontline healthcare providers highlighting the overwhelming influx of cases, thereby compromising the quality of care provided to both COVID-19 patients and those with other medical conditions.

In addition to the physical health implications, the pandemic has taken a significant toll on mental health and well-being globally. Prolonged periods of social isolation, economic instability, and fear of infection have contributed to heightened levels of anxiety, depression, and stress across all age groups. Vulnerable populations, including frontline workers, the elderly, and individuals with pre-existing mental health conditions, are particularly susceptible to the adverse psychological effects of the pandemic [2][3].

Furthermore, the management and containment of the COVID-19 outbreak have posed considerable challenges for governments, public health authorities, and policymakers. The implementation of public health measures such as lockdowns, social distancing, and mask mandates has sparked debates surrounding individual liberties, civil rights, and governmental intervention. Additionally, the dissemination of accurate information and coordination of response efforts have been impeded by misinformation, conspiracy theories, and politicization of the crisis [4].

1.2 Symptoms of Covid-19

One of the most common symptoms of COVID-19 is fever, often accompanied by dry cough and fatigue. It has been found that 98% of hospitalized COVID-19 patients experienced fever [5]. Additionally, respiratory symptoms may include difficulty breathing, nasal congestion, sore throat, and loss of taste or smell.

Moreover, COVID-19 can present with gastrointestinal symptoms such as diarrhea, nausea, and vomiting, indeed it has been reported that approximately 15% of COVID-19 patients initially exhibited gastrointestinal symptoms [6].

The repercussions of COVID-19 extend beyond respiratory issues to include severe pulmonary complications like pneumonia and acute respiratory distress syndrome (ARDS), often necessitating intensive care and ventilatory support [7]. Furthermore, the virus can inflict multi-organ damage, affecting vital organs such as the heart, liver, kidneys, and central nervous system [8].
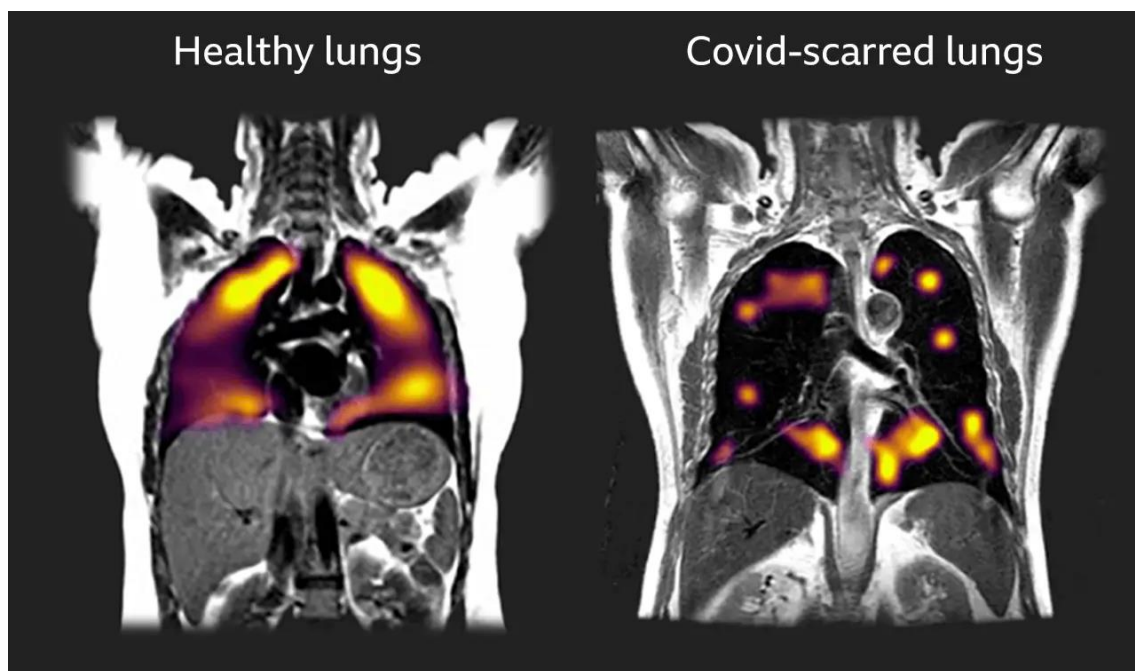
Figure 1 - BBC News. (2020, November 25). COVID-19: What does a severe case look like? Retrieved from https://www.bbc.com/news/health-55017301. In the scarred lungs, on the right, there are much larger areas of darkness, representing parts of the lungs that are having difficulty transporting oxygen into the blood stream.

It is crucial to underscore the significant mortality associated with COVID-19. Recent World Health Organization (WHO) data estimates a global mortality rate of approximately 2-3%, varying based on factors such as age, underlying health conditions, and access to medical care.

In addition to the physical toll, COVID-19 can profoundly impact mental health and psychological well-being. Social isolation, economic instability, and fear of contracting the virus contribute to heightened levels of anxiety, depression, and stress across populations [2][3].

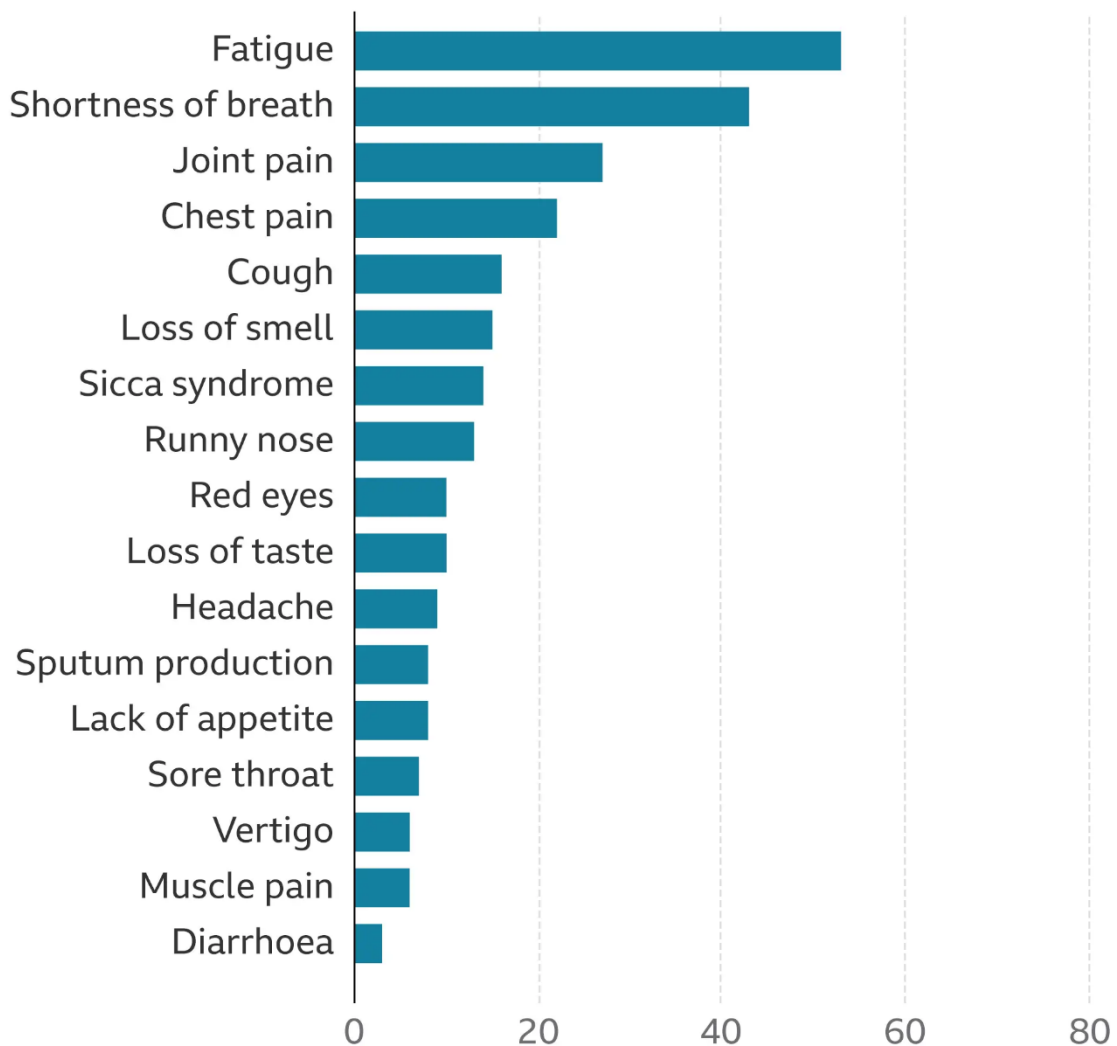# 1.3 Long COVID-19 and Persistent Neurological Manifestations

The 'Long COVID,' also known as long-term COVID-19, is a phenomenon involving the persistence of symptoms after the acute phase of COVID-19 infection. This condition presents a wide range of clinical manifestations, including numerous neurological issues that can persist even after the resolution of acute infection. Indeed, it has been highlighted that 'Long COVID' is associated with a high prevalence of persistent neurological symptoms [9].

The neurological manifestations associated with 'Long COVID' are extremely heterogeneous and can include a variety of symptoms such as headaches, brain fog, cognitive disturbances, fatigue, sleep disturbances, mood disorders, and loss of smell or taste. These symptoms can significantly impact the quality of life of patients and may persist for weeks or even months after the resolution of acute infection.

It has been studied that 55% of patients with 'Long COVID' experienced at least one neurological symptom six months after recovering from acute infection [10]. Among the most reported symptoms are headaches, fatigue, cognitive difficulties, and sleep disturbances.

Long Covid symptoms

Percentage of patients with symptoms

Source: Agostino Gemelli University

Figure 2 - BBC News. (2020, September 29). Long Covid: Why are some people not recovering? Retrieved from https://www.bbc.com/news/health-54296223

The exact causes of persistent neurological symptoms in 'Long COVID' are not yet fully understood, but it is hypothesized that they may be linked to a combination of factors, including systemic inflammation, vascular damage, hypoxia, and immune system activation.

It is important to note that neurological symptoms of 'Long COVID' can be extremely debilitating and may require a multidisciplinary approach involving neurologists, psychiatrists, and rehabilitation therapists.

1.4 Behavioral Indicators of COVID-19 Neurological Implications

As previously mentioned, it has been observed that patients diagnosed with COVID-19 may experience neurological and cognitive implications. Consequently, there is now a pressing need to employ objective and systematic behavioral indicators to collect pertinent information about these repercussions.

Specifically, attention is focused on investigating various behavioral indicators, each shedding light on the multifaceted nature of these effects:

- **Responsiveness**: Assessing the speed and accuracy of responses to both visual and auditory stimuli, providing insights into cognitive agility and processing abilities.
- **Sensory integration's temporal binding period**: Examining the 'temporal binding window' in sensory integration, uncovering how sensory information merges over time.
- **Adaptive sensory responses**: Exploring adaptive responses exhibited by sensory functions, offering insights into the mechanisms of adaptation.
- **Verbal Information Retention**: Thoroughly examining the ability to retain and recall verbal information, revealing potential deficits in memory and cognition.

Each behavioral assessment employed within the 'Happy Again' web application is comprehensively described, outlining the specific indicators obtained through these assessments, in the subsequent sections.

1.4.1 Memory Experiment

The "Memory Experiment," comprising the Word Categorization and Word Recognition phases, aims to investigate implicit memory patterns in COVID-19 patients through Event-Related Potentials (ERPs).

1   In the **Word Categorization phase**, participants categorize words as living or artificial entities from the Medical Research Council Psycholinguistics Database. This phase consists of two blocks, with participants making binary choices for each word based on its association with living or artificial objects.

2   Moving to the **Word Recognition** phase, participants encounter a mix of 130 previously seen words and 70 new ones. Words are presented across four blocks, with participants rating their confidence in recognizing each word on a 5-point scale, ranging from 'I'm sure it's new' to 'I'm sure it's old'. If a word is recognized

as 'old,' participants categorize it further based on earlier distinctions of 'alive vs. not alive' or 'manmade vs. not man-made.' This categorization is carried out on a similar 5-point scale, ranging from 'I'm sure it's from alive list' to 'I'm sure it's from manmade list'.

This study provides a comprehensive exploration of memory and cognition in COVID-19 patients, offering insights into memory retrieval processes. Each phase is meticulously designed to unravel the cognitive repercussions of COVID-19 and contribute valuable insights to neuropsychology.

1.4.2 Flash Beep

This study aims to evaluate multisensory integrity by assessing participants' ability to perceive the order of auditory and visual stimuli. Participants are presented with an auditory stimulus (a beep) followed by a visual stimulus (a flash) and are asked to determine which stimulus occurred first. The timing between the flash and the beep, known as Stimulus Onset Asynchrony (SOA), varies across 15 intervals, including -400, -240, -200, -160, -120, -80, -40, 0, 40, 80, 120, 160, 200, 240, and 400 milliseconds. Positive values indicate instances where the visual flash preceded the auditory beep, while negative values indicate the opposite. A total of 120 trials are conducted to gather data on participants' temporal discrimination abilities.

1.4.3 Target Detection

This experimental task revolves around a widely recognized paradigm known as the Posner Task, which aims to investigate visual attention dynamics. Participants are tasked with swiftly detecting and responding to target stimuli, which are represented by circles with contrasting patterns. These circles are strategically positioned on either side of the screen, and participants must accurately identify the side displaying greater darkness. Crucially, participants are provided with directional cues before the appearance of stimuli, guiding their attention. These cues come in two forms: valid and invalid. A valid cue correctly directs attention toward the side where the target stimulus will appear, while an invalid cue intentionally misleads participants by pointing in the opposite direction.

To increase the cognitive challenge, some target stimuli are accompanied by white noise sounds, acting as distractors. This serves to test participants' ability to discern and respond to visual targets amidst competing sensory inputs.

The experiment comprises two blocks, each initially consisting of 128 trials. However, a unique feature of this task is the incorporation of a learning mechanism. After each block, incorrectly answered trials are reintroduced until participants achieve perfect accuracy, ensuring a thorough evaluation of visual attention capabilities.

1.4.4 Movement Perception

This experiment aims to explore the intricate realm of multisensory awareness by assessing individuals' ability to perceive and interpret the speed and trajectory of objects within a visual scene. It involves integrating sensory inputs from various sources, including visual cues, vestibular signals, and proprioceptive feedback.

The experiment begins with participants focusing their gaze on a central fixation point to establish a baseline for visual attention. They are then presented with a dynamic visual pattern on the screen, incorporating elements moving at different speeds and directions. After a brief interval, a test stimulus appears, characterized by motion in a specific direction.

Participants must accurately identify the perceived direction of motion, translating multisensory inputs into conscious perception. Importantly, the direction of motion may start randomly from either the left or right side, remaining consistent for half of the total trials, with the remaining trials involving motion in the opposite direction.

The experiment is systematically repeated to collect comprehensive data, with each participant undergoing 10 trials to capture the nuances of their multisensory perception capabilities.

1.4.5 Loudness Perception

This assessment aims to investigate the potential decline in sensory adaptation among individuals affected by Covid-19, particularly focusing on loudness perception and its evolution over time in response to auditory stimuli.

Participants are presented with a continuous auditory stimulus, typically a soft pure tone below 40 decibels SPL, setting the baseline for the assessment [11]. Intermittently, a high-pitched beep, accompanied by subtle white noise elements, is introduced into the auditory landscape, creating a dynamic challenge that unfolds over approximately 3 minutes.

At precise intervals of 20 seconds, participants are prompted nine times to compare the loudness of the current high-pitched beep with a predetermined reference beep, assessing whether it is equally loud or quieter. This perceptual exploration offers insights into the nuances of loudness perception and sensory adaptation among Covid-19 patients.

1.5 Questionnaires

In our studies, we use specialized questionnaires to obtain detailed information about participants. These questionnaires are different from traditional ones because they adapt to participants' responses in real-time, rather than having a fixed list of questions. This means that each participant receives personalized questions based on their previous answers, making the experience more engaging and useful.

Our goal is to gain a comprehensive understanding of participants' experiences, thoughts, and opinions. We want to make sure we ask the right questions to gather the most useful information. This method also helps us find the best participants for our study, as we can identify those whose profile best fits our research objectives.

In essence, these questionnaires are a practical and effective tool for collecting accurate and thorough data, which helps us better understand the people involved in our study and achieve more meaningful results.

1.5.1 Covid

The Covid-19 questionnaire adopts a dynamic approach, where each question is closely tied to the participant's previous response. Questions adapt based on the information provided, allowing for a comprehensive overview of individual experiences related to the virus.

For instance, the questionnaire might start by asking participants if they have contracted Covid-19 and if they have had it more than once, before delving into the severity of symptoms, specific symptoms experienced, and duration of recovery.

It then proceeds to inquire about participants' vaccination history and the presence of persistent symptoms or post-Covid-19 syndrome, asking for details on their impact on daily life.

Questions may also explore strategies used to manage Long Covid symptoms and provide space for any additional comments or experiences from participants.

This dynamic approach ensures that the questionnaire adjusts in a targeted manner to responses and specific needs of each participant, allowing for a thorough and personalized understanding of their experiences with Covid-19.

1.5.2 Demographic

The demographic questionnaire has been designed with the necessary flexibility to adapt to participants' responses, ensuring a personalized and targeted approach. Through a series of questions, it aims to gather crucial information to better understand the demographic profile of study participants.

The questions explore various areas, including age, gender, current country of residence, ethnic background, and level of education of the participants. This information is crucial for contextualizing responses and gaining a better understanding of participants' backgrounds.

Additionally, the questionnaire includes questions regarding participants' linguistic proficiency and employment status, providing further details about their individual characteristics.

Finally, any existing medical conditions and ongoing pharmacological therapies that may influence participants' responses are examined, contributing to a more comprehensive understanding of their demographic profile.

This flexibility allows the questionnaire to adapt to participants' responses, providing a detailed and comprehensive overview of their demographic profile without following a rigid temporal order.

1.5.2 Quality of Life

The quality of life questionnaire examines various aspects that influence an individual's overall well-being, with questions covering a wide range of dimensions, from health and personal relationships to work and social participation. The questions include topics such as material comfort, physical health, family relationships, parenting experience, romantic relationships, friendship, helping others, engagement in public activities, learning, self-understanding, work activity, creative expression, socializing, entertainment, participation in recreational activities, and independence.

The responses range from "1 – Terrible" to "7 – Delighted", with intermediate options reflecting various shades of satisfaction or dissatisfaction. This allows participants to

express their degree of satisfaction on each aspect of their life, enabling an overall assessment of their well-being.

Ultimately, the questionnaire aims to provide an in-depth view of an individual's quality of life, allowing respondents to reflect on different aspects of their existence and evaluate their level of satisfaction in each area.

1.5.3 Personality

The personality questionnaire explores a range of characteristics and beliefs that reflect an individual's attitudes and behaviors. The questions cover a wide array of topics, including feelings of social anxiety, beliefs in paranormal phenomena, communication habits, and levels of trust in interpersonal relationships.

The questions delve into subjective experiences, opinions, and behaviors that can vary greatly from person to person. They inquire about aspects such as social anxiety, tendency to believe in paranormal phenomena like telepathy and clairvoyance, perception of others' trustworthiness, degree of emotional openness, and tendency to feel observed or persecuted.

The responses provided by individuals to these questions can provide an indication of the dominant traits of their personality, including levels of introversion or extroversion, inclinations toward creative thinking, feelings of social discomfort, and beliefs in paranormal or mysterious phenomena.

Ultimately, the personality questionnaire provides a tool for exploring the complexity and variety of individual experiences and personal beliefs, contributing to a deeper understanding of the various facets of human personality.

1.5.2 Fatigue

The fatigue questionnaire explores a range of symptoms and sensations related to fatigue and an individual's energy level. The questions focus on various aspects, including problems with tiredness, daytime sleepiness, lack of energy, muscle weakness, concentration difficulties, and memory problems.

The questions may inquire about subjective experiences, such as the overall feeling of tiredness, the need for additional rest, and difficulties in concentrating or finding the right words during a conversation.

Responses range from "0 – Much worse than usual" to "3 – Much better than usual", allowing participants to express the level of fatigue and changes in their energy compared to their usual condition. This helps assess the degree of impact of fatigue on daily life and cognitive functions.

Ultimately, the fatigue questionnaire provides a tool to explore the symptoms and consequences of fatigue on different aspects of a person's life, contributing to a better understanding of their physical and mental conditions.

Chapter 2

Project Description

2.1 Introduction

Started in 2021, this research project has benefited from the continuous contributions of experts in psychology and computer science, who have consistently enhanced its development over time. The main objective is to better understand the relationship between Covid-19 and potential cognitive neurological issues, particularly within the context of the so-called long Covid.

Through ongoing research, we aim to keep our project abreast of the latest developments and recent discoveries in the fields of neurology and psychology. We want to ensure that we provide an up-to-date and relevant analysis that meets current and future needs.

A fundamental part of this process is opening our platform globally. We aim to engage individuals from around the world, of various ages and backgrounds, to gain a more comprehensive and accurate understanding of the situation.

Through access to a wide range of data and contributions, we are committed to better understanding the long-term impacts of Covid-19 on cognitive and neural functions. With a collaborative and multidisciplinary approach, we hope to provide valuable insights for managing and preventing neurological complications related to Covid-19, thereby contributing to the health and well-being of the global population.

2.1.1 Purpose of the Project

The purpose of the project is to investigate and understand the long-term effects of COVID-19 on individuals' neurological and cognitive functions, particularly focusing on those who have experienced lingering symptoms post-infection. Our mission is to uncover whether these changes correlate with the persistence of post-infection symptoms. To achieve this, after careful study by psychologists assisted by a team of skilled developers and computer engineers, a sophisticated web application platform has been meticulously crafted. This platform aims to facilitate seamless access and usability for users across various regions of the world, as it operates as a web app.

This study invites adults aged 18 years and older who have had COVID-19 and have encountered persistent symptoms to participate. Participants are required to engage with the platform, where they will find a series of tasks and questionnaires designed to assess cognitive functioning. Tasks vary from categorizing words to responding to different types of images and sounds. The platform ensures accessibility via the internet, accessible through personal computers or laptops, excluding mobile phones, and guides participants through the assessment process.

Upon completing the tasks and questionnaires, participants will receive a £20 Amazon UK voucher as a token of appreciation. The project consists of completing 10 tasks (tasks and questionnaires), and each participant can only complete them once. The data collected from this study will be instrumental in identifying markers of cognitive functioning and neurological integrity affected by COVID-19 and their correlation with the persistence and severity of symptoms. Ultimately, the findings aim to aid researchers, clinicians, and rehabilitation therapists in better assessing risk, monitoring recovery, and optimizing mental and physical functioning in individuals affected by COVID-19.

2.2 Evolution of the Project and Innovations Introduced

Throughout our development journey, we have significantly expanded the functionalities of our web platform to ensure an optimal user experience. Originally designed to adapt to a wide range of browsers, we now recommend using Google Chrome to maximize performance and stability. This update aims to ensure that users can fully enjoy all the features offered by the platform.

Furthermore, compared to the previous version, the supported languages have been extended to include not only English, Italian, and Spanish but also French, Portuguese, Hindi, and Greek. This expansion reflects our commitment to welcoming and serving a global community of users from diverse linguistic and cultural backgrounds.

In our endeavor to provide a superior quality service, we are currently conducting stress tests in preparation for the potential worldwide opening of the platform. This will enable us to identify and resolve any scalability and performance issues, ensuring a smooth experience for users worldwide.

Additionally, we are excited to introduce a new implementation that offers users the opportunity to repeat the word categorization task after a predetermined period of time. This functionality is made available exclusively on an individual basis, following the

suggestions and specific criteria established by psychologists to customize treatment in a personalized manner.

Through these updates and improvements, we are committed to ensuring that our platform continues to evolve to best meet the needs of our users, providing a welcoming, intuitive, and effective environment for data analysis and the assessment of Long-COVID severity.

2.2.1 Innovative Development Process

Our development process has distinguished itself through a cyclical approach, fueled by constant and detailed feedback. This iteration has been facilitated by feedback received from the Psychology Department at the University of Essex and individual research on neuropsychological tests for evaluating cognitive decline. The feedback has been periodically integrated into the document, giving rise to a dynamic process of continuous improvement.

To effectively manage the necessary interventions, received feedback has been organized according to priority levels: the most significant and challenging changes have been assigned high priority, while changes of lesser importance have been given a lower priority. This categorization has allowed for the concentration of resources on the most critical and complex tasks, ensuring effective progress in the development process.

Subsequently, the information regarding the required changes has been compiled into three separate tables, clearly displaying the necessary adjustments divided by task and category. These tables provide a comprehensive overview of the modification requests and serve as a guide for implementing the necessary corrections, maintaining clear traceability and an organized approach in the platform's development process.

Task	To fix or to implement
General	- Add a new implementation: a user who has completed all the tasks has the possibility to re-register with the same e-mail and to complete again the word categorization task, while the other tasks are disabled. - Implement email reminder for user: API implementation after a user registers, defining a

	time interval in which reminder emails will be sent divided into several days, to remind the user that he must complete the tasks within a certain amount of time. ● Add a cronjob to the server that calls the email reminder function every day and the function that checks the voucher checkbox every five seconds
Admin Area	● Implement get task data by type API
Charlie Download	● Update the excel file adding the information of users who registered the second time, with the second data of word categorization task
Word Categorization	● Modify excel file adding the information related to the users who registered the second time
Flash Beep	● Create file with statistics information ● Create a zip folder to download with the flash beep data and statistics inside

Database	● Create new tables in *userdb*:
	
	- **NotifiedUsers**, for the e-mail reminder
	
	- **CheckedUsers**, for the checkbox voucher
	
	- **SubjectUniqueId**, with the new user_id composed by:
	
	   if *admin*: '-' + voucher + language + 1
	
	   if *not admin*: voucher + language + subject_id

Table 1. High priority requests categorized by task

Task	To fix or to implement
General	● Conduct stress tests to identify and address any scalability and performance issues, ensuring a seamless experience for users globally
Admin Area	● Add 'data by task' table

	● Add checkbox for voucher
Login Page	● Add message error when the login doesn't works (credentials expired)
Covid Survey	● Add count of remaining characters
Registration Page	● Update the form adding the 'security code' field

Table 2. Medium priority requests categorized by task

Task	To fix or to implement
General	● Update italian, spanish, language translations ● Modify the maximum dimension of user_id from 32 to 64
Admin Area	● Update graphic of the users info button ● Fix the checkbox for voucher after the new implementation (users who registered a second time using the same email)
Homepage	● Add recommendation to access only via computer using Google Chrome

Table 3. Low priority requests categorized by task

2.3 Functional Requirements

In the world of software development, requirements serve as the pillars upon which the success of a project is built. They act as an essential guide, clearly and precisely delineating what a software application must do and how it should behave to meet the needs of users and the goals of the project itself.

Among the requirements, two main categories emerge with relevance: functional requirements and non-functional requirements.

Functional Requirements represent a comprehensive set of directives that delineate the specific actions a software system must undertake to fulfill its intended purpose. These requirements meticulously define the system's functionalities, capabilities, and behaviors, thereby providing a roadmap for its development. They elucidate how the software interacts with users, responds to inputs, and navigates through different

scenarios, effectively addressing the fundamental question: "What tasks and objectives should the software accomplish?"

Throughout the project, we expanded and enriched our existing set of requirements with new needs emerging during subsequent development. This process involved adding new requirements reflecting the project's evolution and implementing new functionalities, ensuring that the application fully meets user needs.

Identifier	Description
FR-1	The application must initiate with a welcoming window displaying study information for participants.
FR-2	The system is accountable for overseeing the registration process for all participants.
FR-3	The system is obligated to furnish participants with study information and a consent form.
FR-4	The system must enable user registration only after participants accept the consent.
FR-5	The system must transmit an email to the participant for email address confirmation and account validation.
FR-6	The system must offer the option of resending the confirmation email should it go undelivered or become untraceable for the participant.
FR-7	The system must grant access to all registered participants for signing in.
FR-8	The system is mandated to differentiate between participant-users and administrator-users.
FR-9	The system must incorporate a mechanism for password reset.
FR-10	The system must afford participants the ability to log in and log out at their discretion.
FR-11	The system is required to detect and retain metadata concerning the device(s) utilized by participants.
FR-12	The system must present the tasks and questionnaires in an intuitive and user-friendly manner.
FR-13	The system must facilitate participants' return to the home page at any point.
FR-14	The system must display the estimated time required to complete each task and questionnaire.

FR-15	The system must permit participants to complete the "Demographics" questionnaire only once and store the results.
FR-16	The system must display only the current question of the "Demographics" questionnaire.
FR-17	The system must enable scrolling between questions of the "Demographics" questionnaire using "PREV" and "NEXT" buttons, which are activated only when the current question has been answered.
FR-18	The system must allow participants to complete the "Covid" survey only once and store the results.
FR-19	The system must show solely the current question of the "Covid" survey.
FR-20	The system must facilitate scrolling between questions of the "Covid" survey using "PREV" and "NEXT" buttons, which are activated only when the current question has been answered.
FR-21	The system must block participants who declare not having had Covid-19 so they are not able to proceed.
FR-22	The system must permit participants to complete the "Personality" survey only once and store the results.
FR-23	The system is responsible for presenting a comprehensive instructional description before participants can initiate the initial part of the "Word Categorisation" task.
FR-24	The system must afford participants a practice trial for the initial segment of the "Word Categorisation" task.
FR-25	The system shall enable participants to complete the initial part of the "Word Categorization" task following the demo and save the results.
FR-26	The system is mandated to present an extensive instructional description before participants can commence the second part of the "Word Categorisation" task.
FR-27	The system is authorized to allow participants to complete the second part of the "Word Categorisation" task and accurately store the results.
FR-28	The system must display a detailed instructional description for the "Flash Beep" task and prompt participants to select an audio device before they can start.
FR-29	The system must provide participants with a practice trial for the "Flash Beep" task.
FR-30	The system must permit participants to undertake the "Flash Beep" task following the demo and save the results.

FR-31	The system must present a detailed instructional description for the "Loudness Perception" task and prompt participants to select an audio device before allowing them to start.
FR-32	The system must provide participants with a practice trial for the "Loudness Perception" task.
FR-33	The system will allow participants to undertake the "Loudness Perception" task following the demo and save the results.
FR-34	The system will display a detailed instructional description for the "Target Detection" task and prompt participants to select an audio device before allowing them to start.
FR-35	The system must provide participants with a practice trial for the "Target Detection" task
FR-36	The system will enable participants to undertake the "Target Detection" task following the demo and save the results.
FR-37	The system must present a detailed instructional description for the "Movement Perception" task before participants can initiate.
FR-38	The system will request participants to configure the screen through a size matching exercise before allowing them to start the "Movement Perception" task.
FR-39	The system must provide participants with a practice trial for the "Movement Perception" task.
FR-40	The system shall permit participants to undertake the "Movement Perception" task following the demo and save the results.
FR-42	The system must allow participants to complete the "Quality Of Life" questionnaire only once and store the results.
FR-43	The system must display only the current question of the "Quality Of Life" questionnaire.
FR-44	The system shall facilitate scrolling between questions of the "Quality Of Life" questionnaire using "PREV" and "NEXT" buttons, which are activated only when the current question has been answered.
FR-45	The system must allow participants to complete the "Fatigue" questionnaire only once and store the results.
FR-46	The system must exhibit solely the current question of the "Fatigue" questionnaire.
FR-47	The system shall enable scrolling between questions of the "Fatigue" questionnaire using "PREV" and "NEXT" buttons, which are activated only when the current question has been answered.

FR-48	The system is mandated to clearly indicate to participants which tasks they have already completed and which ones are available.
FR-49	The system must notify researchers through an automated email mechanism as soon as a participant completes all the tasks and questionnaires.
FR-50	The system must enable admin-users to access the dedicated Admin Area.
FR-51	The system must enable admin-users to view the list of active users, the number of tasks they have completed, and the timestamp for each completed task.
FR-52	The system must enable admin-users to download participants' gathered data, both individually and collectively.
FR-53	The system must enable admin-users to search for specific participant information.
FR-54	The system is required to notify admin-users through a web app notification when new data becomes available.
FR-55	The system must send reminder emails to all the users that successfully registered but didn't complete all the tasks after one week
FR-56	The application must inform participants, prior to registration, whether they are eligible for a voucher and provide them with a registration code in case they do not meet the voucher requirements.
FR-57	The application must save the information if the user can have or not the voucher
FR-58	The application must show the captcha before the participant perform the tasks
FR-59	The application must allow a registration only with a valid otp code
FR-60	The application must guarantee a filter for the admins to navigate through different types of users
FR-61	The application must show in the admin area for each participant in the admin area if he can have or not the voucher and a check box to remind if it has been sent or not
FR-62	The application must allow the admins to extend a partecipant
FR-63	The system must show in all downloads the information about the users, if is valid, if can have the voucher and his uid
FR-64	The application must insert in the "Word Categorization Task" download additional informations: statistics and word frequency
FR-65	The application must add a download called "Charlie" with all data regard the Covid, Fatigue and Quality questionnaires and Word Categorization statistics

FR-66	The system must perform the factor analysis and show the results in the "Charlie" download
FR-67	The system must calculate the LCSI severity indexes and show them in the "Charlie" download
FR-68	The system must accept and handle user_ids up to 64 characters in length
FR-69	Users must be able to view all labels, messages, and text on the website correctly translated into Italian, Spanish, French, Portuguese, Hindi, and Greek
FR-70	The system must ensure that users who have completed all tasks must have the possibility to re-register with the same email and complete the word categorization task again
FR-71	The system must guarantee the functioning of the voucher checkbox also for users who have registered a second time with the same email
FR-72	The system must undergo rigorous testing to ensure that it can handle a high volume of users without compromising performance
FR-73	The application must show in real time the number of characters remaining while answering the open question in the covid questionnaire
FR-74	The system must guarantee the functioning of the cronjobs in the server (one every day and one every 5 seconds) which manage the sending of the reminder via email and the management of the voucher checkbox
FR-75	The application must insert in the "Flash-Beep Task" download (in data by task) an additional file: FB_statistics.csv
FR-76	The application must show on the homepage all tasks that are inaccessible apart from the word categorization for users registered a second time

Table 4. Functional Requirements

2.4 Non-Functional Requirements

Non-functional requirements represent the characteristics of a software system that define its overall quality, performance, and behavior, rather than the specific actions it must perform. Unlike functional requirements, which focus on "what" the system does, non-functional requirements focus on "how" it does it and on which quality criteria must be met.

These requirements define aspects such as security, reliability, performance, usability, and scalability of the system. For example, a non-functional requirement might specify

that the system must be able to handle a certain number of simultaneous users without compromising performance, or it might establish security criteria regarding access and management of sensitive data.

Non-functional requirements are often measurable and must be specified clearly and concisely to enable an objective evaluation of the system. They play a fundamental role in ensuring that the software is robust, reliable, and able to meet users' expectations in terms of user experience and overall performance.

2.4.1 Performance

The Performance requirement refers to the system's ability to execute its functions efficiently and timely, maintaining acceptable performance even under high workloads.

Attribute	Description
Identifier	NFR-01
Name	Throughput
Description	The system's capacity to handle incoming requests within a specific timeframe.
Metric Target	30,000 requests/minute
Priority	Medium

Table 5. Non-Functional Requirement 1

Attribute	Description
Identifier	NFR-02
Name	Front-end response time
Description	The duration required to execute a task that doesn't require interaction with the backend.

Metric Target	1 second
Priority	Medium

Table 6. Non-Functional Requirement 2

2.4.2 Reliability

Reliability concerns the system's ability to maintain stable and reliable operation over time, ensuring that operations are performed correctly and without unwanted interruptions.

Attribute	Description
Identifier	NFR-03
Name	Connection Interruption Tolerance
Description	The system remains operational with on-site interactions even following a brief disruption in internet connection.
Metric Target	Availability percentage of 99.5%.
Priority	High

Table 7. Non-Functional Requirement 3

2.4.3 Security

The Security requirement refers to the system's ability to protect data and resources from unauthorized access, unwanted manipulations, or external threats, ensuring the confidentiality, integrity, and availability of information.

Attribute	Description
Identifier	NFR-04
Name	Secure authentication token
Description	A robust encryption method is utilized to create the authentication token for user verification.
Metric Target	None
Priority	High

Table 8. Non-Functional Requirement 4

Attribute	Description
Identifier	NFR-05
Name	Secure connection to the backend
Description	All requests to the backend must employ the HTTPS security protocol, and any HTTP requests should be automatically redirected to use HTTPS.
Metric Target	None
Priority	High

Table 9. Non-Functional Requirement 5

2.4.4 Usability

Usability indicates how easily users can interact with the system, assessing the intuitiveness of the user interface, clarity of instructions, and ease of learning the offered functionalities.

Attribute	Description
Identifier	NFR-06
Name	Participant-friendly interface
Description	The application must guarantee that all interfaces and activities accessible to users are intuitive and easy to navigate.
Metric Target	None
Priority	High

Table 10. Non-Functional Requirement 6

Attribute	Description
Identifier	NFR-7
Name	User-friendly interface for the administrators
Description	The application must ensure that all interfaces and activities available to administrative users are user-friendly and intuitive, facilitating straightforward usage.
Metric Target	None
Priority	Medium

Table 11. Non-Functional Requirement 7

2.4.5 Scalability

Scalability refers to the system's ability to adapt and handle an increase in demand or workload without compromising performance or the quality of service provided to users.

Attribute	Description
Identifier	NFR-08
Name	Auto Scaling
Description	The server must have the capability to adjust dynamically when there is an increase in client-side requests.
Metric Target	Configuration in order to support 1000 requests/minute and scale up to 30,000 requests per minute.
Priority	High

Table 12. Non-Functional Requirement 8

2.4.6 Maintainability

The Maintainability requirement indicates how easily the system can be modified, updated, repaired, or improved over time, ensuring efficient and sustainable management of maintenance operations.

Attribute	Description
Identifier	NFR-9
Name	Logs
Description	The system must retain a comprehensive log of every action and operation executed, enabling the transmission of this information in case of any errors or issues.

Metric Target	None
Priority	High

Table 13. Non-Functional Requirement 9

Attribute	Description
Identifier	NFR-10
Name	Version Support
Description	The system must ensure continuous operation even when undergoing system upgrades or modifications.
Metric Target	None
Priority	High

Table 14. Non-Functional Requirement 10

2.4.7 Interoperability

Interoperability concerns the system's ability to cooperate and interact with other systems or software components, allowing seamless data exchange and interconnection.

Attribute	Description
Identifier	NFR-11
Name	Backend Server API Connectivity

Description	The server should be able to perform queries on the backend server and possess the required permissions to make alterations to the existing database.
Metric Target	None
Priority	High

Table 15. Non-Functional Requirement 11

2.4.8 Availability

Availability refers to the system's ability to be available and accessible to users when needed, ensuring a high degree of operational availability and minimizing downtime.

Attribute	Description
Identifier	NFR-12
Name	Server availability
Description	The server should maintain high availability, minimizing downtimes and ensuring uninterrupted service for most of the time.
Metric Target	Availability percentage of 99.5%
Priority	High

Table 16. Non-Functional Requirement 12

2.4.9 Resource Management

The Resource Management requirement indicates the system's ability to efficiently manage available resources, such as memory, CPU, network, and storage, to ensure optimal utilization of available resources

Attribute	Description
Identifier	NFR-13
Name	Memory Limits
Description	This requirement sets the maximum allowable memory usage for the client-side operations of the web application.
Metric Target	2 GB of RAM
Priority	High

Table 17. Non-Functional Requirement 13

2.4.10 Portability

Portability concerns the ease with which the system can be transferred or adapted to different hardware or software platforms, ensuring its compatibility and interoperability across different runtime environments.

Attribute	Description
Identifier	NFR-14
Name	Timestamps In International Format

Description	It is crucial to ensure that all timestamps gathered within the application are standardized and formatted according to the Coordinated Universal Time (UTC).
Metric Target	None
Priority	High

Table 18. Non-Functional Requirement 14

Attribute	Description
Identifier	NFR-15
Name	Multi-platform
Description	The system must exhibit platform agnosticism and be compatible with widely used web browsers like Chrome, Firefox, Microsoft Edge, and Safari.
Metric Target	None
Priority	High

Table 19. Non-Functional Requirement 15

Chapter 3

Solution Design and Deployment Strategies

In this chapter, we will examine three key elements for success in ideating and implementing innovative solutions: methodology, use cases, and architectural design. We will analyze the methodological process, explore concrete use cases, and discuss the architectural design of our solutions. This overview will help us understand how we design and implement our solutions to maximize their effectiveness and scalability.

3.1 Methodology

The software release life cycle (SRLC) has been a journey of continuous improvement since the release of the first Alpha version in 2021. From that moment on, the team has worked tirelessly to make significant enhancements and changes to the website. My contribution has played a crucial role in refining the user experience, both for site administrators (psychologists and developers) and for end users.

The improvements and changes have been driven by detailed and focused feedback from the psychology team, which identified user needs and challenges. Thanks to this feedback-driven approach, we have been able to implement targeted solutions that have greatly improved website usability.

From then until now, our steadfast commitment to pursuing excellence has led to a significant increase in website functionality and usability. We are confident that the improvements made will continue to ensure an optimal user experience for all site users.

In this project, we have embraced the Design Thinking methodology as our guiding framework to develop and enhance our web application.

Design thinking is a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test [12].

The Design Thinking process, characterized by its five key phases, forms the backbone of our approach. These phases include Empathize, Define, Ideate, Prototype, and Test

(Figure 3). Each phase plays a crucial role in our journey toward innovation and user-centric design.

Now, let's delve into each phase in detail to understand how they have shaped our project and contributed to the development of our web application.
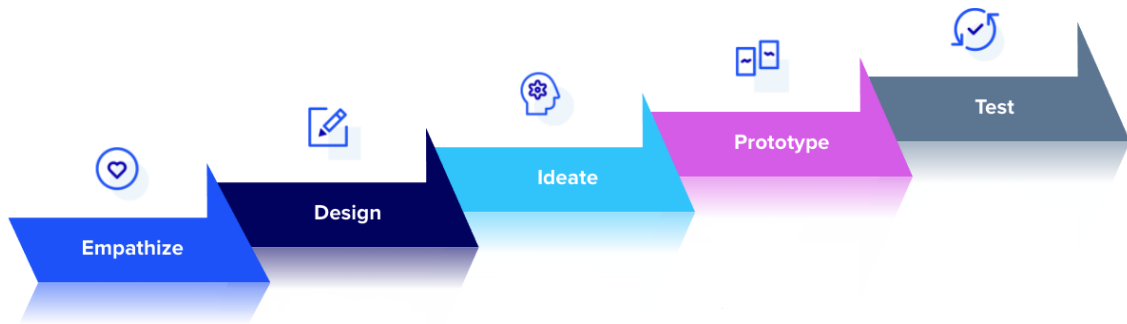
Figure 3 - Example of design thinking process templates. Image source: UserTesting. Retrieved from https://help.usertesting.com/hc/en-us/articles/11880355855773-Choosing-Templates-for-Your-Design-and-Development-Process

1. **Empathize**: Our journey began with empathizing with the project, gaining a theoretical understanding of its goals and objectives. Through detailed explanations, we comprehended the essence of the study and the functionalities of the web app. This initial phase allowed us to immerse ourselves in the users' world and understand their needs deeply.

2. **Design**: With a solid foundation laid during the empathize phase, we transitioned into the design phase, where we delved into the web app to explore its components and functionalities. This hands-on exploration provided us with a practical understanding of user needs, enabling us to design solutions that were tailored to meet their requirements effectively.

3. **Ideate**: As we progressed, we encountered requests from the psychology team and received feedback from users. In response, we organized brainstorming sessions to generate a wide range of possible solutions. These collaborative ideation sessions sparked creativity and innovation, allowing us to explore diverse approaches to address the identified challenges.

4. **Prototype**: With a plethora of ideas at hand, we moved on to the prototype phase. Here, we evaluated various proposals and selected the most promising ones to be transformed into prototypes. These prototypes served as tangible representations of our solutions, enabling us to test them and collect preliminary feedback from users and stakeholders.

5. **Test**: The final phase of our Design Thinking process involved thorough testing of the prototypes. We conducted extensive testing on the new implementations and changes, involving both the psychology team and web app users. Through rigorous testing, we assessed the effectiveness and acceptance of our solutions, ensuring that they met the needs of our users and aligned with the project objectives.

By following the Design Thinking methodology and embracing each of its phases, we were able to develop a robust and user-centric web application that addressed the challenges identified in the project. This iterative approach allowed us to continuously refine our solutions and achieve our goals effectively.

3.2 Use Cases

A use case is a written description of how users will perform tasks on your website. It outlines, from a user's point of view, a system's behavior as it responds to a request. Each use case is represented as a sequence of simple steps, beginning with a user's goal and ending when that goal is fulfilled [13].

Use cases are, therefore, a technique used in the analysis and design of information systems to describe specific interactions between a system and the external actors that interact with it. Actors are the stakeholders who interact with the system and can be people, other systems, or external entities.

The ultimate goals of use cases are to understand the functional requirements of the system and guide software development, ensuring that the system meets user needs and functions correctly in an operational environment.

In previous versions of the project, numerous use cases were defined to represent the various interactions and usage scenarios of the system. However, in order to maintain the clarity and conciseness of this thesis, not all previous use cases will be presented. Rather, we will focus on some of them, selected based on their relevance and importance for the objectives of this research.

Furthermore, new use cases that have emerged during the development of the project or that have been identified as necessary to satisfy the new functional requirements defined previously will be included.

ID	UC1
Name	Register
Functional requirement	FR-1, FR-2, FR-3, FR-4, FR-5, FR-6.
Goal	The participant is able to register for the study.
Pre-condition	The participant was shown a Welcome page.
Post-condition	The system records the participant's data in a secure stand-alone database under a pseudo-nym.
Main success scenario	1. The participant clicks on the "Register" button. 2. The information sheet on the study is presented. 3. The participant reads the consent form and agrees to participate in the study. 4. The participant clicks again on the "Register" button. 5. The registration screen is shown. 6. The participant fills all the entries, name, email, password and OTP code with valid data clicks on the "Confirm" button. 7. The system stores the entered user data into a secure database. 8. The application informs the participant that an email was sent to the provided address to verify their account. 9. The participant clicks on the link and validates their account. 10. The redirected page informs the participant about their successful registration.
Includes/Extends	Validation: 6.a.1. The participant's email has already been used and it's recorded in the database. The application informs the participant about their existing account. 8.a.1. The participant is unable to find the email sent. The application offers to click on "Resend email".

Table 20. UC1 - Register.

ID	UC2A
Name	Log in
Functional requirement	FR-6, FR-7, FR-8, FR-9.
Goal	The participant is able to log into the application.
Pre-condition	The participant is successfully registered.

Post-condition	The system records the active session of the participant and redirects them to the Home page.
Main success scenario	1. The participant clicks on the "Log On" button. 2. The log on screen is shown. 3. The participant fills all the entries, email and password. 4. The system authenticates the participant's entered data. 5. The participant is logged in and presented the Home page.
Includes/Extends	Password recovery: 3.a.1. The participant does not remember their password. The application shows a "Forgot password" button to click on. 3.a.2 The application presents a screen where the participant can enter their email and establish a new password in case they need to. Authentication: 4.a.1. The system is unable to find the participant's data. The application displays a "No user created with the inserted email" message. 4.a.2. The entered password does not match the one registered. The application displays a "No user created with the inserted email" message.

Table 21. UC2A – Login.

ID	UC2B
Name	Log Out
Functional requirement	FR-10.
Goal	The participant is able to log out from the application.
Pre-condition	The participant is logged in.
Post-condition	The system records the ending of the session, and the participant is redirected to the Log on page.
Main success scenario	1. The participant clicks on the "Log Out" button. 2. The system stores the ending session time. 3. The application shows the "Log On" screen.
Includes/Extends	None

Table 22: UC2B – Log Out.

ID	UC3
Name	Home
Functional requirement	FR-11, FR-12, FR-13, FR-14.
Goal	Users who have completed all tasks are allowed to re-register using the same email address, granting them access to complete the word categorization task again.
Pre-condition	The participant is logged in.
Post-condition	None
Main success scenario	1. The application presents the first instructions of the study, including recommendations for completing tasks. 2. The application displays 10 task options in the form of buttons, which each show the estimated time it requires to complete them.
Includes/Extends	None

Table 23: UC3 - Home.

ID	UC4
Name	Admin
Functional requirement	FR-8, FR-50, FR-51, FR-52, FR-53.
Goal	The admin is able to see all the participant and the tasks they did and has the possibility to download the data
Pre-condition	The admin is logged in.
Post-condition	None
Main success scenario	1. The application presents the homepage. 2. The user cliks on "Admin-area" in the top bar menu. 3. The application shows all the users the tasks they completed. 4. The user select one user. 5. The application shows the tasks of that specific user and a download button. 6. The admin clicks on the download button for the tasks he need the informations about. 7. The application start the download of the file.
Includes/Extends	None

Table 24: UC4 - Admin.

ID	UC5
Name	Re-registration and Word Categorization Task Completion
Functional requirement	FR-10, FR-48, FR-70, FR-71, FR-76.
Goal	Users who have completed all tasks are allowed to re-register using the same email address, granting them access to complete the word categorization task again.
Pre-condition	The user has completed all tasks
Post-condition	The user has successfully re-registered with the same email address. The user has completed the word categorization task again, and the system has recorded the completion status.
Main success scenario	1. User completes all tasks. 2. User logs out and initiates a new registration process. 3. User enters the same email used for the first account, provides additional information, and proceeds with registration. 4. The system verifies the user's email and checks if all tasks have been previously completed. 5. The system allows the user to proceed with the second registration. 6. User views the homepage with only the "word categorization" task active and others deactivated. 7. User completes the "word categorization" task. 8. System saves the data related to this second completion of the "word categorization" task.
Includes/Extends	If the user has not completed all tasks during the first registration attempt, the system prevents them from proceeding with the second registration until all tasks are completed.

Table 24: UC5 – Re-registration for memory experiment.

3.3 Architecture

In the context of this project, the architecture adopted represents a crucial element to ensure correct functioning and effective data management. This is an approach that has been previously outlined and implemented in previous work, providing a robust and established framework for system development and management. This architecture is based on a three-tier model, known as a tri-tier architecture, which includes the presentation, application, and data tier.

The presentation layer, or frontend, constitutes the user interface of the system, through which users interact with the application. This layer is responsible for displaying data and responding to user inputs, ensuring an intuitive and user-friendly experience. It also includes both non-logged and logged-in user interfaces, providing a clear distinction between anonymous and authenticated users.

In the presentation layer, new implementations have been introduced to enhance the overall user experience and provide advanced functionalities. One of the main additions is the introduction of the administrative area interface, designed to allow administrators, including psychologists and developers, to access participant data. This administrative area provides a dedicated and secure interface for managing participant data, enabling administrators to view and analyze data related to tasks completed by users. With this functionality, administrators can closely monitor user progress and performance, as well as identify any issues or anomalies in the system.

The application layer, commonly referred to as the backend, functions as the operational core of the system, handling data processing and overall functionality. Positioned between the presentation and data layers, it orchestrates business logic and facilitates cohesive communication across system components. Within this layer, data models are structured to organize information for experiments and questionnaires, ensuring coherent data management (Figure 4). Additionally, APIs play a pivotal role in this layer, managing connections and enabling seamless data transactions between different system modules (Figure 5). With its robust architecture and defined functionalities, the application layer optimizes system operations, enhancing overall performance and user experiences.
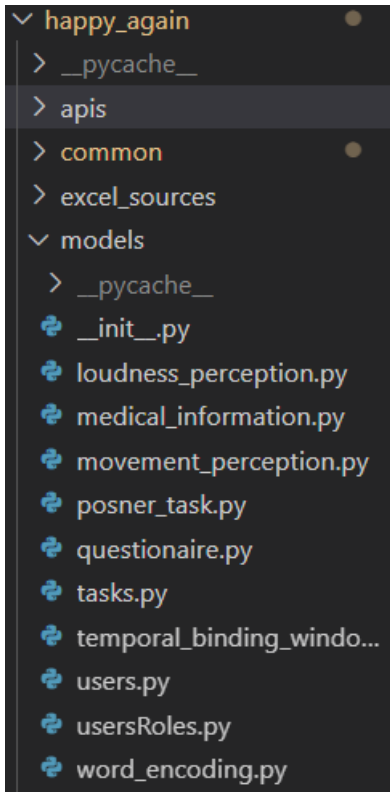
Figure 4 – 'models' folder in happy-again-backend repository. Retrieved from VisualStudioCode
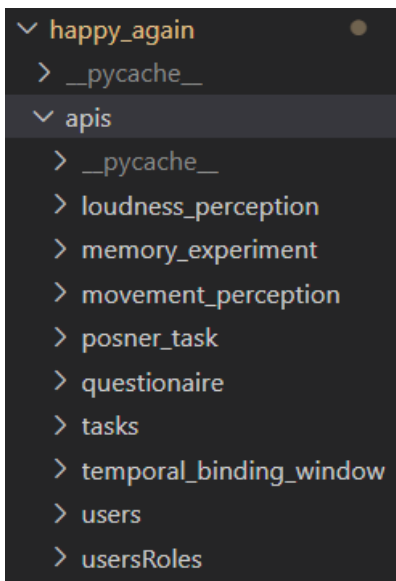
Figure 5 – 'apis' folder in happy-again-backend repository. Retrieved from VisualStudioCode

The data layer, also known as the database, serves as the backbone of the system, handling the storage and management of all essential data. Within this layer, two primary databases play pivotal roles: Userdb and Happyagaindb (Figure 6,7).

- **Userdb** serves as a repository for user-related information, encompassing registration details and administrative data. This database ensures the secure and organized storage of user credentials, registration timestamps, and exclusion statuses. Additionally, it maintains essential metadata, such as user sessions and access logs, facilitating efficient user management and system administration.
- **Happyagaindb** functions as the repository for task-related data and analytical insights. It stores survey responses, experiment results, and associated metadata, all linked to user IDs for seamless data retrieval and analysis. This database plays a crucial role in tracking user interactions, storing experiment outcomes, and generating actionable insights to drive system improvements and user engagement.
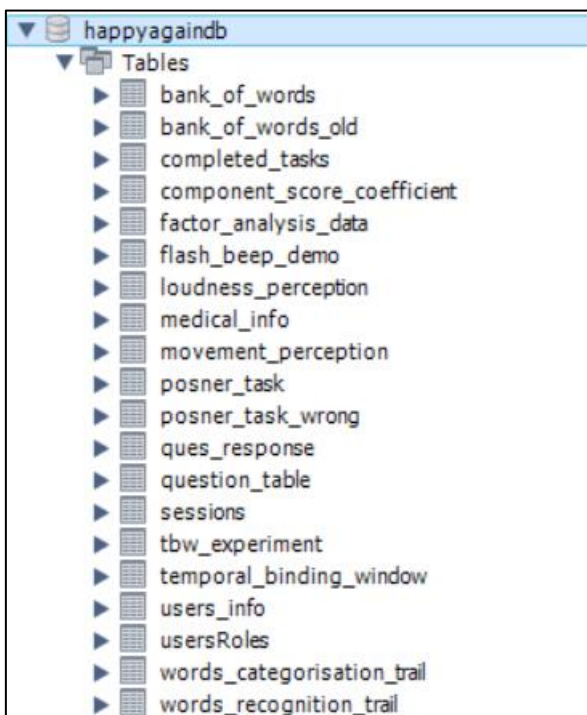
Figure 6 – 'happyagaindb' database. Retrieved from MySQL Workbench
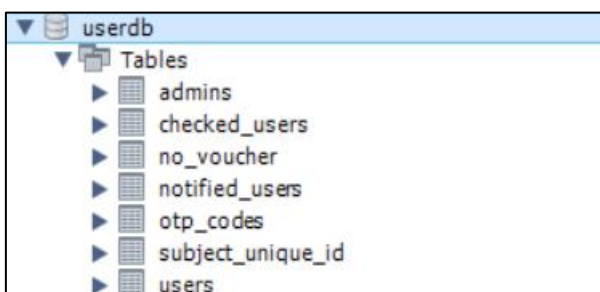
Figure 7 – 'userdb' database. Retrieved from MySQL Workbench

Together, these databases form a robust and scalable infrastructure for system data management, ensuring data integrity, accessibility, and performance across various user interactions and analytical processes.

In addition to the two main databases, it is worth noting that there are also two additional databases, called **userdbdev** and **happyagaindbdev**. These databases are used exclusively in the local development environment and are not distributed during deployment. They serve the same role as core databases, but are specifically intended for system development and testing before deployment to a production environment. This practice is common in software development and helps maintain separation between production and development data, ensuring data integrity and security during the software development process.

Chapter 4

Results and Technological Implementation

This chapter delves into the critical aspects of our research on the neurological consequences of Long COVID. We begin by examining the employed technologies, including the frontend, backend, and database, pivotal for the functionality of 'Happy Again.' Additionally, we present new implementations, such as the Admin Area, enriching the site with advanced management and supervision features. Through a detailed analysis of these implementations, we underscore the pivotal role of 'Happy Again' in our research process and data analysis concerning Long COVID.

4.1 Tecnhnologies employed

4.1.1 Frontend

For the frontend, we employed Angular as the primary framework, harnessing its extensive capabilities to craft dynamic and engaging web experiences. Angular is a frontend web application framework developed by Google, known for its robust features and comprehensive tools for building dynamic and scalable single-page applications. This framework serves as a cornerstone in modern web development, offering a structured approach that seamlessly integrates with TypeScript, HTML, and CSS. This combination of technologies enables us to create robust, maintainable, and scalable frontend applications that cater to the diverse needs of our users.

At the heart of our frontend architecture lies TypeScript, a superset of JavaScript. TypeScript serves as the primary language in our frontend development, offering static typing and advanced features that enhance code quality and maintainability. Unlike JavaScript, TypeScript provides compile-time type checking, helping to catch errors early in the development process and facilitating smoother collaboration among team members. This integration of TypeScript with HTML and CSS empowers developers to construct visually stunning interfaces while ensuring clarity and consistency in the underlying logic.

Central to our frontend architecture is Angular's Model-View-ViewModel (MVVM) pattern, which is a software architecture model (Figure 8).

MVVM provides a division between the **View** and the **Model**, with an intermediate level for managing the interconnections between View and Model called **ViewModel**.

- The View is the set of visible elements, such as user interfaces (UI), animations and text.
- The Model hosts the logic for the program and data manipulation.
- The ViewModel contains the controls for interacting with the View, and the binder, used to connect and synchronize the View's user interface elements to the ViewModel's controls. [14]
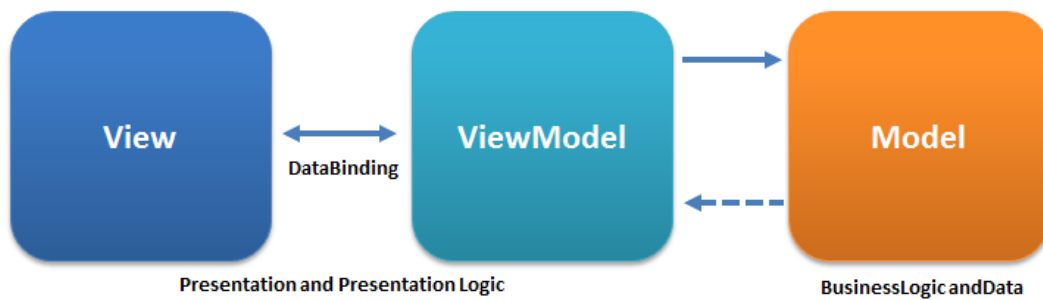
Figure 8 Model-View-ViewModel Schema – Retrieved from https://it.wikipedia.org/wiki/Model-view-viewmodel

4.1.2 Backend

For the backend, Python served as the primary programming language, with the Flask framework as the backbone of our development stack. Python is a high-level, interpreted programming language known for its simplicity and readability. It boasts a vast ecosystem of libraries and frameworks, making it a popular choice for web development, data analysis, machine learning, and more.

Flask, a lightweight and versatile web framework for Python, provided the foundation for building our backend infrastructure. It offers essential tools and features for developing web applications, including routing, request handling, and template rendering. Flask follows a minimalist design philosophy, allowing developers to extend its functionality through various extensions and packages tailored to specific use cases.

In our project, we leveraged several Flask extensions to enhance the functionality and efficiency of our backend. These are the Flask extensions utilized:

- Flask-MySQLdb: This extension facilitates seamless connectivity between Flask and MySQL databases, enabling efficient interaction and data retrieval.
- Flask-SQLAlchemy: It empowers the creation of data models and simplifies connectivity with MySQL databases, facilitating efficient data management and manipulation.
- Flask-Mail: This extension simplifies the configuration of the Simple Mail Transfer Protocol (SMTP), allowing easy delivery of registration emails to participants, enhancing communication capabilities within the application.
- Flask-CORS: CORS, or Cross-Origin Resource Sharing, is essential for configuring the server and managing access rights to specific server resources. Flask-CORS serves as a gatekeeper for requests from other domains, ensuring secure and controlled access to resources.
- Flask-JWT-Extended: This extension provides robust features for user authentication, along with secure storage and retrieval of security tokens for each user, enhancing the application's security measures and user management capabilities.
- Passlib: Leveraging Passlib, the application supports a wide array of hash algorithms, ensuring secure password storage. Specifically, the pbkdf2 sha256 library class is employed for hashing user passwords, enhancing data security and integrity within the application.

Within the backend of our system, we implemented task automation using crontab, a task scheduling system under Unix/Linux. Crontab allows you to schedule scripts, commands, or programs to run at predefined regular intervals, such as every day, week, or month. Specific details about the created crontabs, including the tasks performed and their schedules, will be explored in more detail in the next chapter, Chapter 5.

4.1.3 Database

In our project, we adopted MySQL as the primary relational database management system (RDBMS). MySQL is widely recognized for its reliability, scalability, and ease of use, and was the ideal choice for our application given its compatibility with a large ecosystem of applications and tools.

Using MySQL, we were able to create a robust and performant database environment. We took advantage of the flexibility of MySQL to model data into tables and define relationships between them. Thanks to the power of SQL (Structured Query Language), we were able to execute complex queries and obtain fast and efficient results.

Additionally, integrating MySQL with other tools and frameworks was critical to our development process. We used tools like MySQL Workbench for visual database design and SQL query management, streamlining our workflow and improving the team's overall productivity.

4.1.4 REST API

In our project, we have implemented a REST API to facilitate communication between the frontend and backend of the application. This API, which follows the client-server paradigm, consists of a set of endpoints through which the frontend sends HTTP requests to the backend and receives responses in a structured format, usually JSON or XML.

Once a request is received, the backend processes the information and interacts with the database to obtain or modify the requested data. Next, it generates a structured response in JSON format and sends it to the frontend via the same REST API using the HTTP protocol (Figure 9).

The introduction of a REST API in our project significantly simplified the communication between frontend and backend, allowing a clear and modular separation between the two components of the application. This allows the frontend to focus on data presentation and user interaction, while the backend handles request processing and data management in the database.

The stateless nature of REST APIs ensures that each request sent from the frontend to the backend is independent of the previous ones, which contributes to greater scalability and reliability of the application. Furthermore, the use of open standards such as HTTP and JSON makes our REST API interoperable and easily integrated with other external platforms and services.
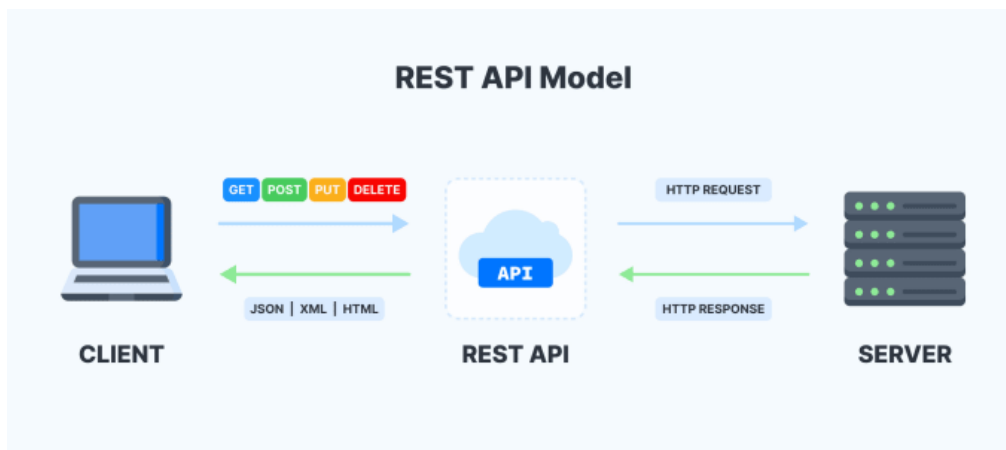
Figure 9 – REST API Model - Perera, Ramith. "Tap into the world of REST APIs." *Medium*, 14 maggio 2022. Retrieved from https://medium.com/@ramith_perera/tap-into-the-world-of-rest-apis-1cc172830abf

4.2 Interfaces

In this section, we will present screenshots taken directly from our website, showing the main interfaces of our application: the homepage, the registration page, and the administrative area (admin area). These screens provide a visual preview of the user and administrative experience offered by our application, focusing on the parts most relevant to users and administrators. Since my work has mainly been focused on improving the user and especially administrative experience, we will not focus on the tasks in this section, since the interfaces have remained the same in previous versions.

4.2.1 Homepage
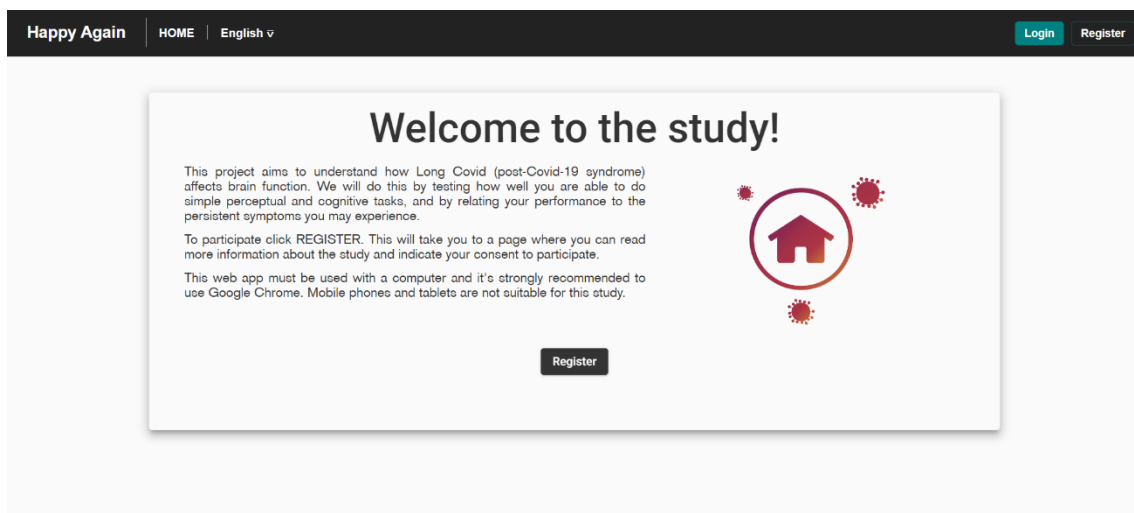
Figure 10 – Homepage view without login
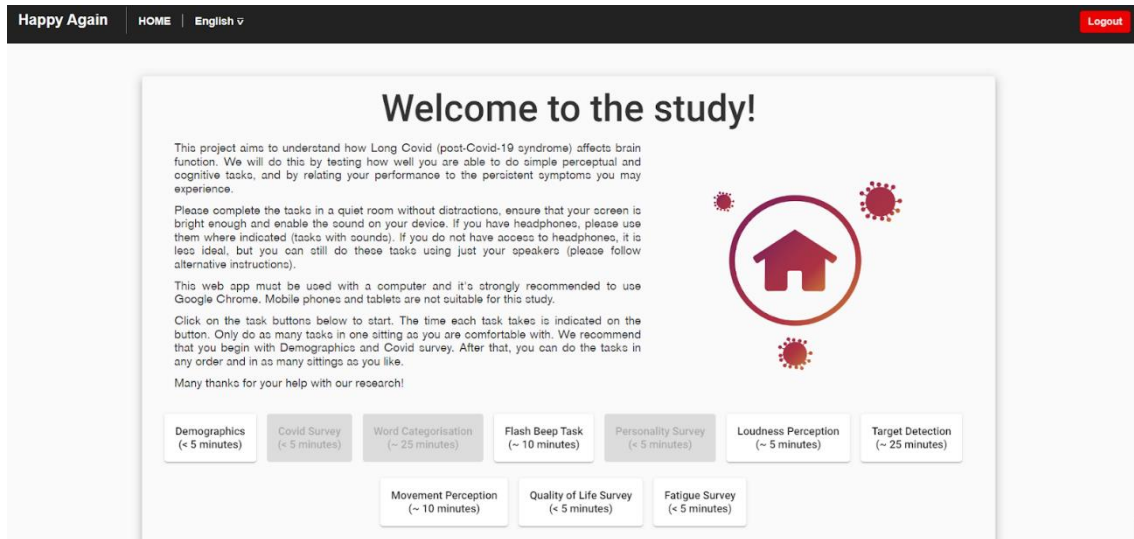
Figure 11 – Homepage view after user login
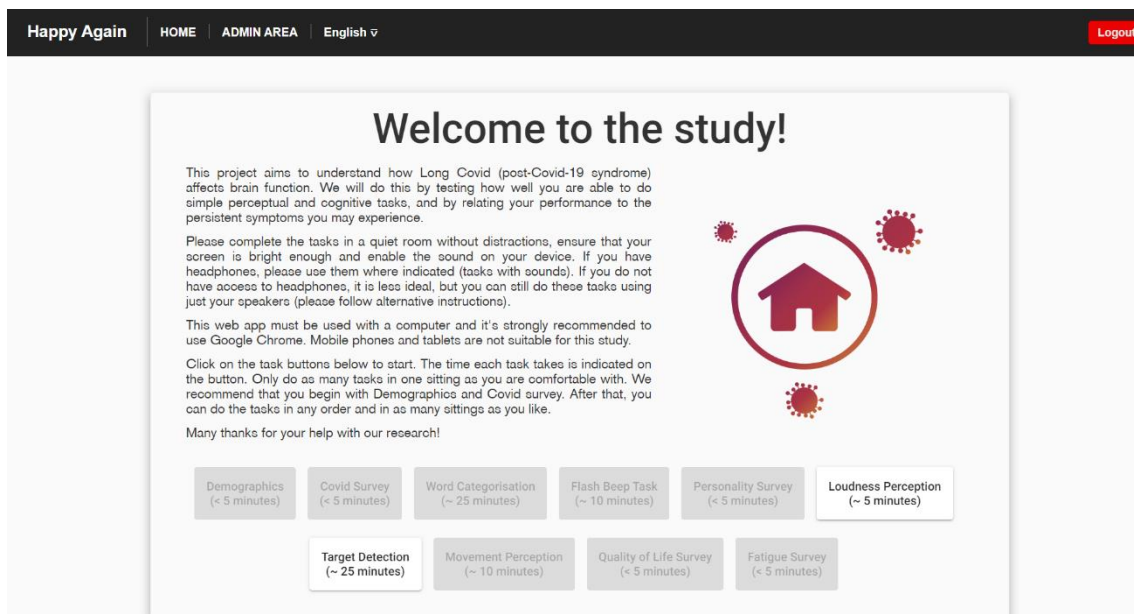
Figure 12 – Homepage view after admin login

The homepage of our website is designed to provide an engaging and intuitive experience for users. It is the first thing a user sees when accessing the site after completing the CAPTCHA verification to ensure security.

In the no-login view, users find a brief but incisive explanation of our study, inviting them to register to actively participate (Figure 10). The clean and attractive layout includes a navigation menu with language options and buttons for login or registration.

After logging in as a registered user, the homepage offers a detailed explanation on how to properly participate in the study, along with buttons to perform 10 specific tasks

(Figure 11). These tasks are easily identifiable and, once completed, their button becomes disabled and colored grey.

In the case of access as an administrator, in addition to the detailed explanation of the study, access to the "Admin Area" is offered for managing user data and tasks (Figure 12). Also in this case, the homepage presents the 10 buttons for the tasks, with the same enabling/disabling functionality based on completion.
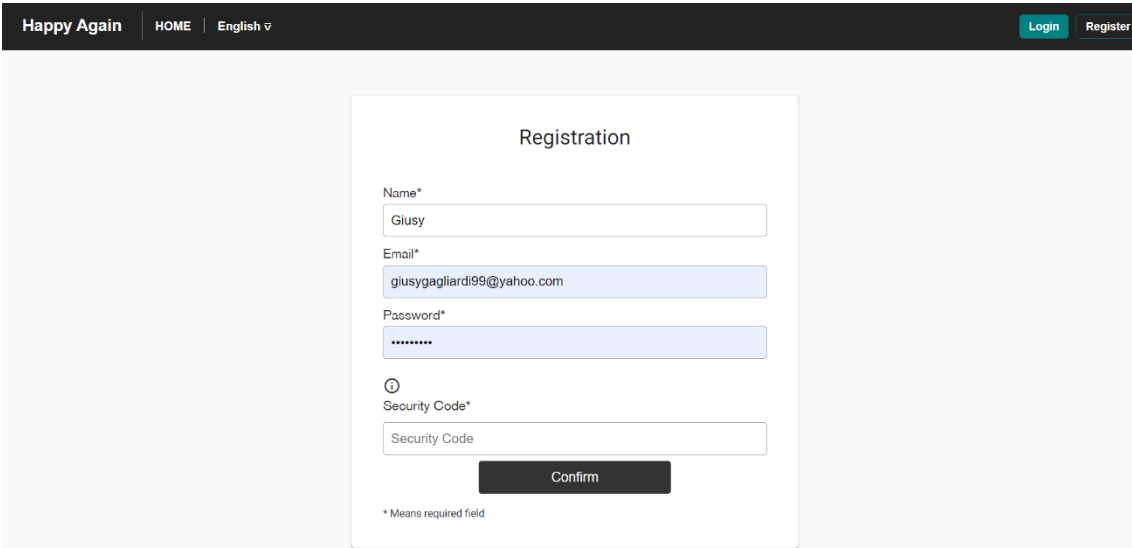
4.2.2 Registration

Figure 13 – Information Sheet and Consent Form for Registration

Figure 13 shows the Information Sheet and Consent Form for our research study. This document provides complete details about the study and participation procedures. It is essential that users carefully read and accept this document before registering to participate in the study.

The Information Sheet begins with an "Invitation to Our Study," which explains the focus of the research regarding the short- and long-term effects of Covid-19 on neurological and cognitive functioning. Participation is requested from adults who have had Covid-19 and experienced persistent symptoms.

The Consent Form is an essential part of the registration process. Users must agree to the terms and conditions set out in the document before they can register and participate in the study. The Consent Form also includes confirmation that the data collected will be anonymized and may be shared in publicly accessible archives.

Figure 14 – Registration

The registration form in Figure 14 is designed to allow users to register to participate in the research study.

The Security Code field is a new implementation compared to previous versions, it is an additional security measure to prevent multiple registrations by malicious users who may attempt to exploit the system to receive undeserved thank you vouchers. Legitimate users must request the security code from the psychology team to complete the registration.

In addition to the OTPs (security codes) that must be given to users who want to participate in the study, three other different codes have been created: one for the developer team, and two for users who reside outside the UK and therefore cannot receive the Amazon voucher of thanks.

4.2.3 Admin Area

"The "Data By User" section (Figure 15), provides a comprehensive overview of all users who have completed at least one task, also indicating the total number of tasks completed. Administrators can search for specific users using the search field or filter the list by selecting from various options such as "All Users", "Voucher", "No Voucher", "Italian", "Spanish", as shown in Figure 17.
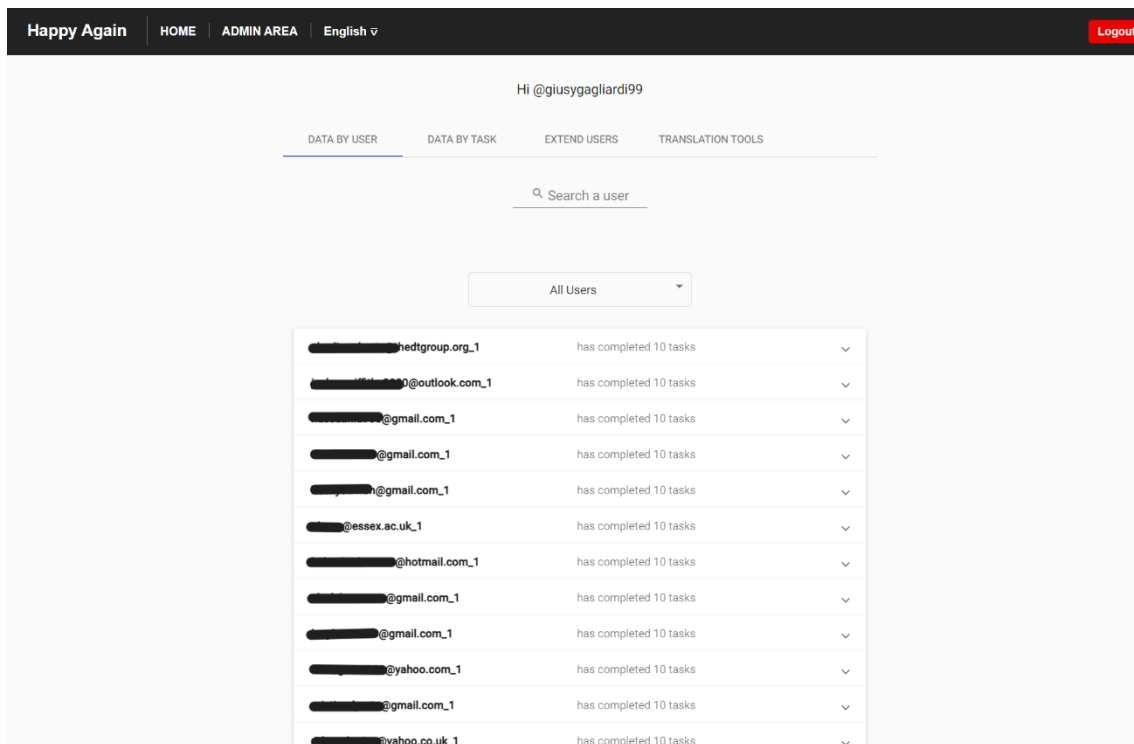
Figure 15 – 'Data By User' section in Admin Area

When a user is selected from the list, a second section is displayed, as illustrated in Figure 16. Here, users can examine the list of tasks completed by the user, along with the respective completion dates. For each task, there is a "Download" button that allows users to download a .csv file containing the data related to that specific task for that user. Additionally, there is a "Voucher Sent" checkbox, used by psychologists to track users who have already been sent the voucher.

Figure 16 – List of downloadble tasks to download and checkbox for voucher in 'Data By User' section

Figure 17 shows the use of filters, an additional tool that allows for greater organization and facilitates user search. The filters include options such as:

- All Users
- Voucher: Users who have already received the voucher.
- No Voucher: Users who have completed all tasks but cannot receive the voucher, for example, because they are administrators.
- Italian/Spanish: Users who cannot receive the voucher because they do not reside in the United Kingdom."
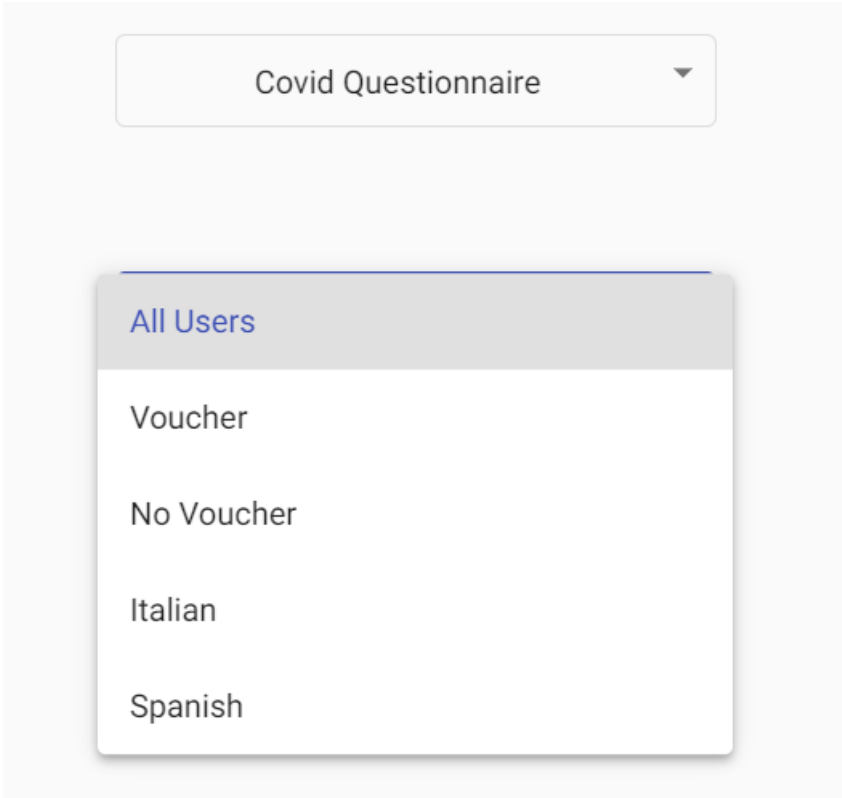
Figure 17 – Filter for users in 'Data By Task' section

Figure 18 illustrates the scenario where a user completes a task. A notification appears with a button labeled 'New Data Available'. Clicking this button allows admins to update the view of completed tasks.
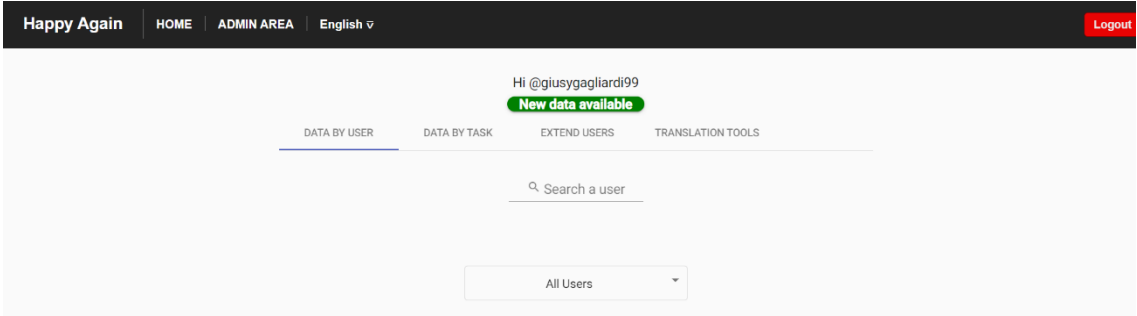
Figure 18 – New data available in Admin Area

The 'Data By Task' section shown in Figure 19 provides administrators with a detailed analysis of data related to individual tasks in our system.

Within this section, there are two drop-down menus and a download button. The first drop-down menu allows administrators to select the task of their interest, as highlighted

in Figures 20, 21, and 22, while the second drop-down menu corresponds to the filter previously illustrated in Figure 17.
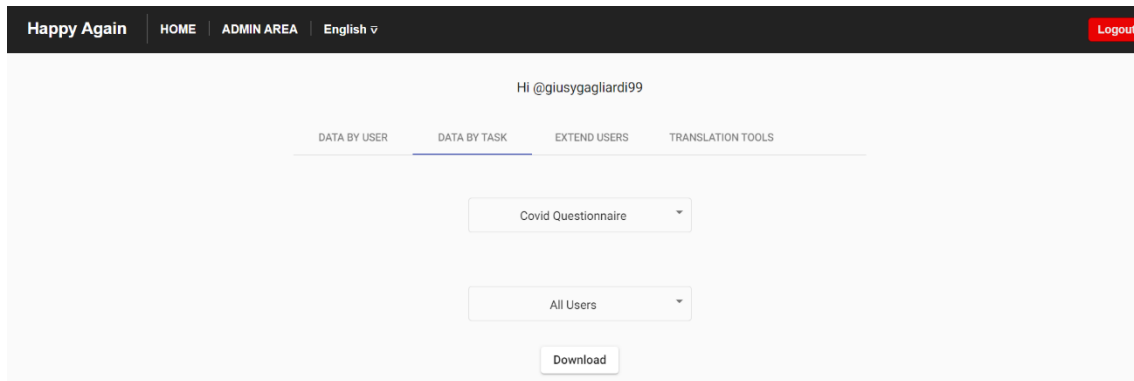
Figure 19 – 'Data By Task' section in Admin Area

Using the task drop-down menu, administrators can select the specific task they wish to download all relevant data for. Once the task is selected, simply pressing the download button will retrieve a file containing all information related to that task for all users.

A specific file named 'Charlie' was created at the request of our team's psychologist. This file was designed for data analysis purposes and includes user responses to all questionnaire items, including total scores for Quality of Life and Fatigue questionnaires, along with statistical data related to Word Categorization Task and the Long Covid Severity Index.
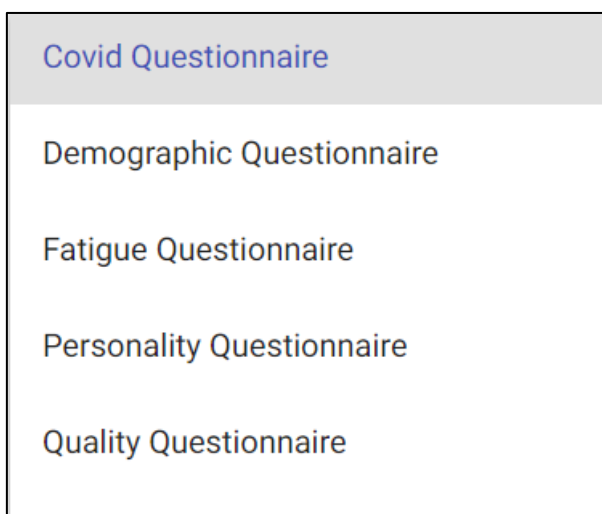
Figure 20 – Tasks list in 'Data By Task' section pt.1

Flash-Beep Task

Loudness Perception Task

Movement Perception Task

Target Detection Task

Word Categorization Task
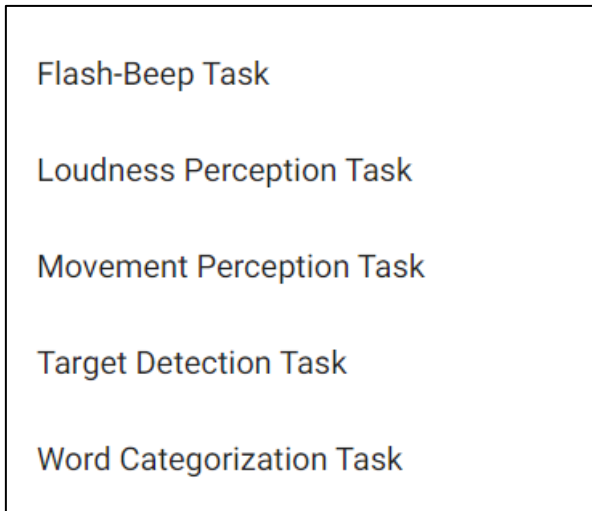
Figure 21 – Tasks list in 'Data By Task' section pt.2

Target Detection Task

Word Categorization Task

Users Info

Charlie

Factor Analysis
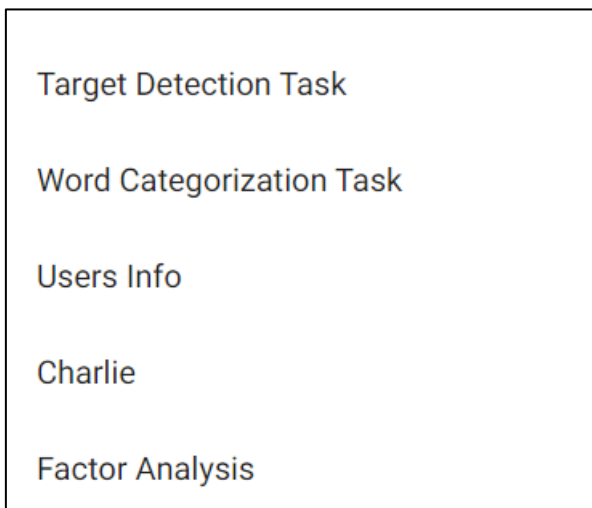
Figure 22 – Tasks list in 'Data By Task' section pt.3

The 'Extend Users' section in the Admin Area, shown in Figure 23, allows administrators to extend the usage time of the web app for specific users. Administrators have the option to extend a user's usage time by 1 week or 2 weeks. Also in this case there is the possibility of searching for a user, or choosing him from the list.

This is particularly useful because each user has a limited time period (typically 2 weeks) from the moment they confirm their email to complete all assigned tasks. If a user fails to complete the tasks within the designated period, their profile will be automatically blocked. However, administrators have the authority to extend this time period,

allowing the user to continue accessing and completing tasks even after the initial deadline.
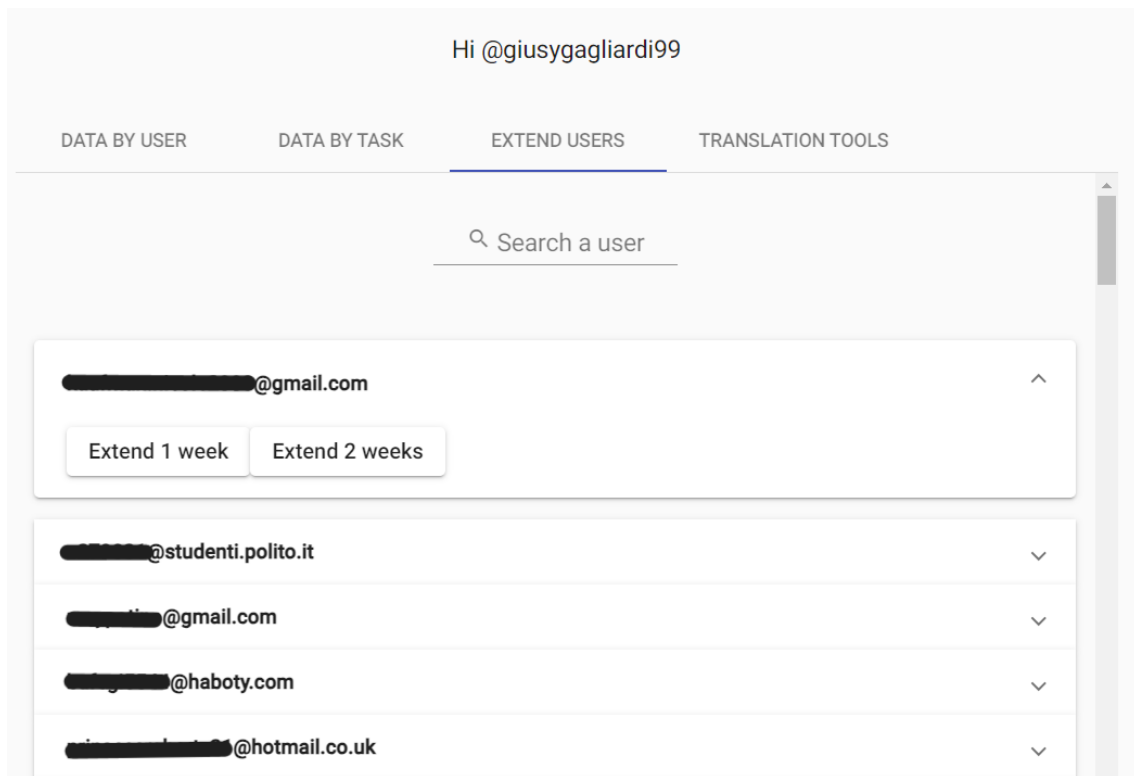
Figure 23 – 'Extend Users' section in Admin Area

The "Translation Tools" section in the Admin Area (Figure 24) facilitates the management of translations within the web application. It serves as a centralized platform for developers to streamline the conversion process of the General_Translations.xlsx file, which is regularly updated by translators on the project's shared Drive, into .JSON files.

Translators collaborate on the General_Translations.xlsx file to provide translations for various sections or components of the website in different languages. Once the file is updated with new translations, developers can utilize the Translation Tools section to convert the General_Translations.xlsx file into .JSON format.

Before converting the .xlsx file, developers are prompted to select the language for which they want to download the .json file. After downloading this .JSON file, it must be uploaded to the Frontend folder, typically located in the "src/assets/i18n" directory (Figure 25). Subsequently, the updated translations need to be deployed to ensure that the changes take effect within the web application.
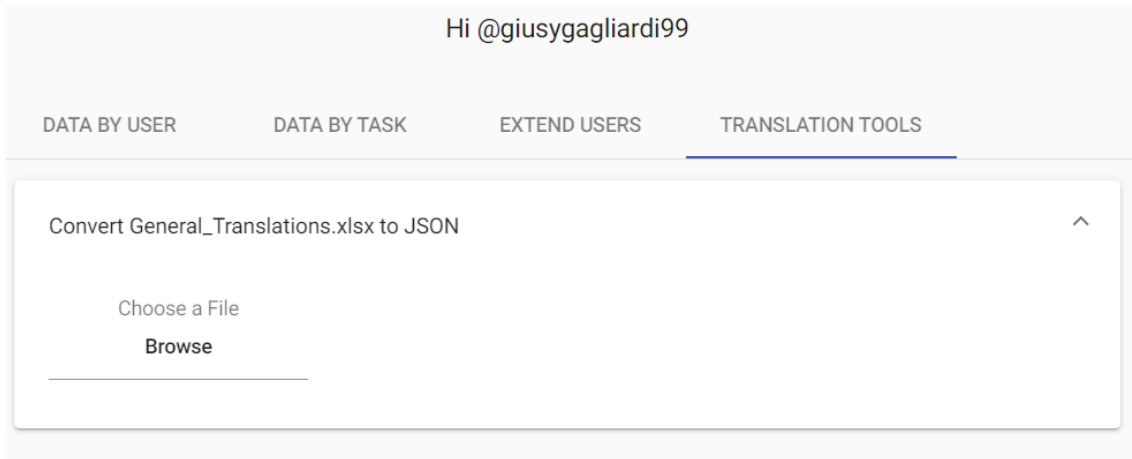
Figure 24 – 'Translation Tools' section in Admin Area
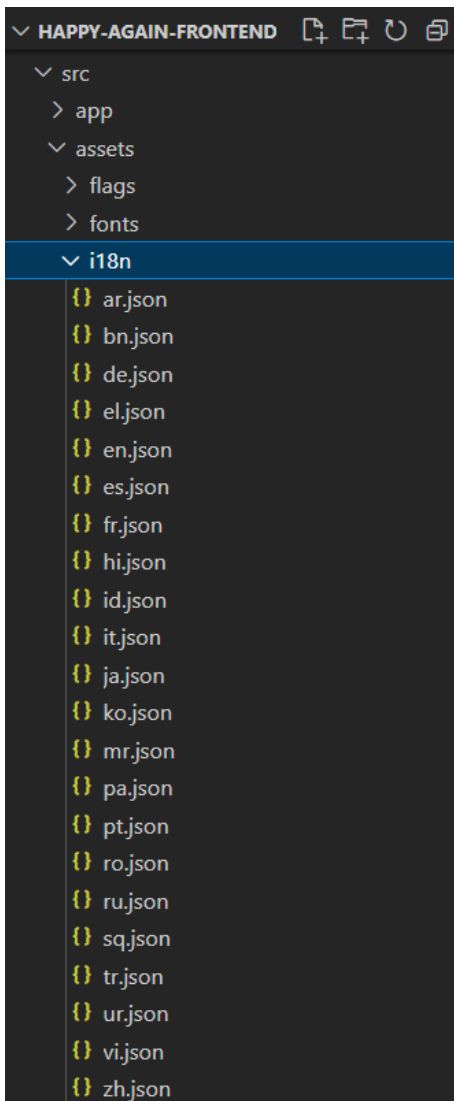
Figure 24 – 'i18n' folder in happy-again-frontend repository. Retrieved from VisualStudioCode

Chapter 5

Technical Developments and Site Optimization

In this chapter, we will examine the new implementations and updates made to the 'Happy Again' website aimed at enhancing its functionality and user experience. We will explore the new features introduced to streamline site management, such as voucher management through an intuitive administrative interface and the addition of statistics in data downloads, which is crucial for future data analysis. Additionally, we will analyze the new features designed for users, such as email reminders to encourage task completion. We will also examine the new feature allowing users to repeat the word categorization task after initially completing it.

5.1 Admin experience enhancements

5.1.1 Voucher Management in Admin Area

In the administrative area of the 'Happy Again' website, a voucher management system has been implemented to track whether a voucher has been sent to users upon completing tasks. This system is designed to assist psychologists in efficiently managing user vouchers. To ensure the persistence of this information even after the site is closed, a new table called `checked_users` was created in the database, through the creation of a corresponding model in the backend.

When a user first appears in the administrative area, indicating that they have completed at least one task, they are automatically inserted into the `checked_users` table. This table stores the user's email address and a integer state (basically acts as a boolean value) to determine whether the voucher has been sent or not.

Additionally, to automate the process of updating the checkbox status for eligible users, a Python script called `job_checked_users.py` was developed. This script periodically checks for new users who have completed tasks but have not yet received a voucher, updating the `checked_users` table accordingly with the appropriate checkbox status for these users.

Figure 26 – Terminal screenshot showing access to the Happy Again server crontab

To schedule the execution of the `job_checked_users.py` script at regular intervals, a crontab has been configured. The crontab is a Linux tool that allows scheduling the execution of scripts or commands at specific times or predefined intervals. In Figure 26, you can observe the definition of the crontab settings through a screenshot of the terminal once logged into the Happy Again server. Referring to the management of the checkbox, che crontab is the second one, and the syntax "* * * * *" means that the command will run every minute. The first crontab will be analyze subsequently.

5.1.2 Added statistics in flash beep download

Another new implementation on the website was the creation of a file concerning the statistics of the Flash Beep Task data, the 'FB_statistics.csv'. Initially, the site only contained the 'flash_beep.csv' file, but to provide users with additional data and useful information, work similar to that of the Word Categorization Task was developed, resulting in this new file containing Flash Beep Task statistics.

To further facilitate access and download of data related to both the Flash Beep and Word Categorization tasks, another implementation was introduced. In addition to creating the file dedicated to Flash Beep Task statistics, a mechanism was developed to allow admins to easily download both files simultaneously. For this purpose, a zip file was created containing both the 'flash_beep.csv' file and the 'FB_statistics' file (Figure 27). This solution optimizes admin experience by enabling them to quickly and conveniently access both necessary data for analysis and performance evaluation.
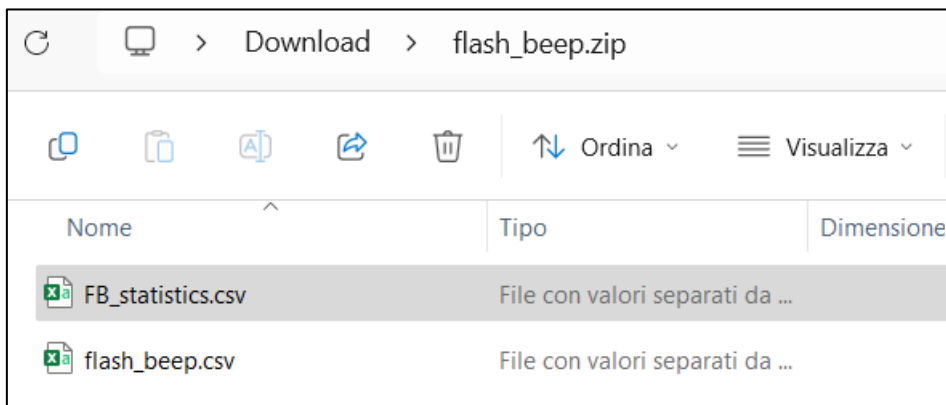
Figure 27 – 'flash_beep.zip' download file from the 'Data By Task' section in Admin Area

I created this statistics file (Figure 28) that, based on the answers provided by each user, computes several variables:

- **user_id** (short): This field represents a unique identifier for each user and is structured differently depending on whether the user is an administrator or a standard user. If the user is an administrator, the user_id starts with "-" followed by the voucher status, language selection, and "1". If the user is not an administrator, the user_id includes the voucher status, language selection, and subject_id.
- **voucher:** Indicates whether a user is eligible to receive a voucher (1) or not (0).
- **valid**: Determines if the user is considered valid and if their data are useful for our research.
- **language:** Each language is assigned a corresponding number, with 0 representing English.
- **subId_language_voucher:** This identifier consists of the subject_id (if admin = -1), language (EN/IT/SP), and voucher status (0/1).
- **SOA** (Stimulus Onset Asynchrony): Introduces a variable representing temporal intervals ranging from -400 to 400 milliseconds. These intervals indicate the timing relationship between visual flashes and auditory beeps, with positive

values indicating visual flashes preceding auditory beeps and negative values denoting the opposite.

- **n_trial**: Represents the number of trials conducted for each Stimulus Onset Asynchrony (SOA), typically set to 8 for each interval.
- **accuracy**: Indicates the accuracy of user responses for each SOA, calculated based on the trials conducted. If a specific SOA is presented in only one trial, accuracy is either 0 or 1. For multiple trials, accuracy is computed as the average accuracy across trials for that SOA.
- **average_reaction_time**: is calculated by summing the response times of all participants for a specific SOA and dividing it by the total number of attempts for that SOA. This provides us with a measure of the average time it took participants to correctly respond to visual and auditory stimuli presented in relation to a given SOA.
- **information**: measures the amount of information contained in a response, based on the probability of success or failure. A positive value indicates an amount of information greater than chance, while a negative value indicates the opposite.
- **information_rate:** quantifies the speed with which information is processed by a system. It is calculated as the ratio between the information and the total number of attempts. A positive value indicates fast information processing, while a negative value indicates less efficiency.

	Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11
1	user_id	voucher	valid	language	subid_language_voucher	SOA	n_trial	average_reaction_time	accuracy	information	information_rate
2	-001	0	0	0	-1_EN_0	-400	8	849.125	0.625	0.04556599707503506	0.00005366229598119836
3	-001	0	0	0	-1_EN_0	-240	8	1020.625	0.75	0.18872187554086717	0.00018490814504922687
4	-001	0	0	0	-1_EN_0	-200	8	332.375	0.875	0.4564355568004036	0.0013732547778876377
5	-001	0	0	0	-1_EN_0	-160	8	491.375	0.875	0.4564355568004036	0.000928894544493317
6	-001	0	0	0	-1_EN_0	-120	8	465.625	1	1	0.002147651006711409
7	-001	0	0	0	-1_EN_0	-80	8	899.375	0.75	0.18872187554086717	0.00020983669274870568
8	-001	0	0	0	-1_EN_0	-40	8	1050	0.75	0.18872187554086717	0.00017973511956273063
9	-001	0	0	0	-1_EN_0	0	8	1002.75	0.375	-0.04556599707503506	-0.000045441034230900084
10	-001	0	0	0	-1_EN_0	40	8	1030.75	0.5	0	0
11	-001	0	0	0	-1_EN_0	80	8	15242.375	0.25	-0.18872187554086717	-0.000012381395651325149
12	-001	0	0	0	-1_EN_0	120	8	405.375	0.25	-0.18872187554086717	-0.00046554887583315983
13	-001	0	0	0	-1_EN_0	160	8	759.375	0	-1	-0.0013168724279835392
14	-001	0	0	0	-1_EN_0	200	8	988.375	0.5	0	0
15	-001	0	0	0	-1_EN_0	240	8	248.25	0.25	-0.18872187554086717	-0.0007602089649178939
16	-001	0	0	0	-1_EN_0	400	8	831.75	0.375	-0.04556599707503506	-0.00005478328473103103
17	-001	0	0	0	-1_EN_0	-400	8	361.375	0.875	0.4564355568004036	0.0012630523882404803
18	-001	0	0	0	-1_EN_0	-240	8	682.125	0.75	0.18872187554086717	0.00027666758371393393
19	-001	0	0	0	-1_EN_0	-200	8	620.625	1	1	0.0016112789526686808
20	-001	0	0	0	-1_EN_0	-160	8	567.125	1	1	0.001763279700242451
21	-001	0	0	0	-1_EN_0	-120	8	893.125	0.875	0.4564355568004036	0.0005110545072642727
22	-001	0	0	0	-1_EN_0	-80	8	615	1	1	0.0016260162601626016
23	-001	0	0	0	-1_EN_0	-40	8	578.375	1	1	0.0017289820618111088
24	-001	0	0	0	-1_EN_0	0	8	617.375	0.25	-0.18872187554086717	-0.0003056843499345847
25	-001	0	0	0	-1_EN_0	40	8	778.875	0.375	-0.04556599707503506	-0.000058502323318934434

Figure 28 – A part of 'FB_statistics.csv' file.

5.2 User experience enhancements

5.2.1 Sendind automatic reminders email for inactive users

One of the new implementations created to support the user experience is the email reminder for completing tasks. These reminders have been created to provide support to users in completing assigned tasks and to maximize their engagement in the project.

The reminders are sent via email to users who have confirmed their account after registration but have not yet completed all assigned tasks. The first reminder is sent 7 days after the account confirmation and informs users that they have 7 days remaining to complete all tasks. Additionally, it specifies that another reminder will be sent later. It is shown in Figure 29. The second reminder, shown in Figure 30, is sent when there are 4 days left until the deadline and informs users that no further reminders will be sent.
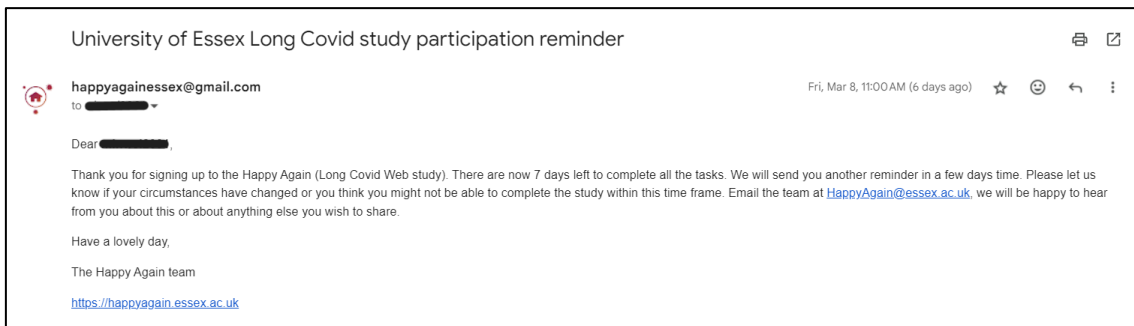

Figure 29 – First automatic reminder email sended to a user.
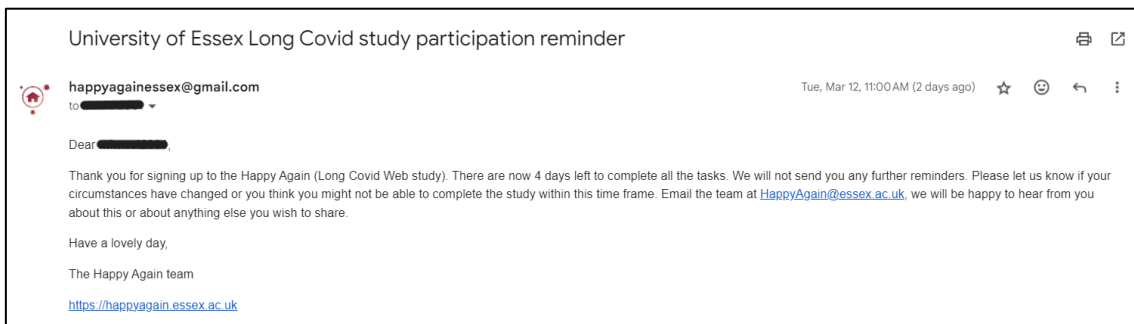

Figure 30 – Second automatic reminder email sended to a user.

Both messages include an invitation to contact the Happy Again team at the email address happyagain@essex.ac.uk if users have changed circumstances or need assistance. The team is available to answer any questions or provide necessary support.

This new feature has been implemented to ensure that users are consistently informed about the status of their involvement in the study and to actively encourage them to complete remaining tasks. Additionally, the system automatically manages timestamp updates in the database and user blocking if tasks are not completed by the deadline. It is noted that users, after being blocked, can request administrators to extend the time period for completing tasks.

To enable email reminders, a specific email address for the project, "happyagainessex@gmail.com," has been configured using Gmail's SMTP server to ensure reliable delivery of messages to registered users.

To facilitate the sending of reminder emails, a new table named **notified_users** was created in the **userdb** database. This table stores user-specific information related to reminder emails sent, including the email address, the number of emails sent (n_mail_sended), and the timestamp of the last reminder email.

The reminder email functionality was integrated into the existing backend system using Python scripting and MySQL database queries. Scheduled jobs, executed via the crontab utility, trigger the reminder email process daily at a specified time (10 AM UTC, 11 AM UK time). The first crontab in Figure 26 is used for this purpose. The script job_check_inactive_users orchestrate the user activity check and initiates the sending of reminder emails as needed.

5.2.1 Possility to complete the 'Word Categorization Task' a second time

In response to a request from our team of psychologists, we have implemented a feature to allow users to redo the 'Word Categorization Task,' also known as the Memory Task. This enhancement aims to provide users with the opportunity for additional engagement and potentially improve their performance on the task.

To facilitate users in retaking the memory task, we developed a solution allowing individuals who have completed all tasks to register again using the same email address. However, it's worth noting that users must have completed all 10 tasks in their initial registration to qualify for this feature. If a user has not completed all the tasks, they will not be able to register again using the same email address and in this case an error message will be shown (Figure 31).
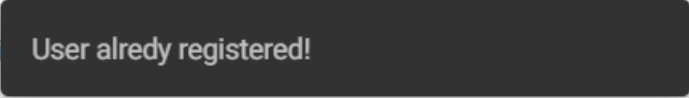
Figure 31 – Error message shown when a user who has not completed all tasks tries to re-register with the same previous email, in Registration form.

To ensure smooth integration and prevent any potential database conflicts, an initial step was taken to modify all existing user_id entries in the database by appending "_1" to them. Subsequently, when a user registers for the second time using the same email address, their original user_id is retained from their initial registration (thanks to the used email), but with a "_2" appended to differentiate it (Figure 32). This sequential labeling system helps maintain data integrity and ensures clarity in user identification, especially in instances where users opt to retake the memory task.

Figure 32 – Example of user record in userdbdev/users table with user_id suffixes '_1' and '_2'

In the admin area, we've introduced a visual enhancement to differentiate between the two user types within the "Data by User" section. Now, when viewing the list of users, the admin will notice that email addresses are accompanied by suffixes "_1" and "_2". We can see an example of it in Figure 33. These suffixes serve as visual cues to distinguish between users who registered the first time and those who have registered the second time and completed the word categorization task twice. It's important to clarify that these suffixes are purely for visual representation and do not alter the actual email addresses stored in the database.

Figure 33 – Example of user who registered the second time in 'Data by User' section in Admin Area

In the section related to tasks completed by users with the "_2" suffix, the "covid", "fatigue", and "quality" questionnaires will also appear as we can see in Figure 30. However, it's important to note that these questionnaires were not actually completed by the user upon their second registration. The user only has the option to complete the Word Categorization Task at this stage. The presence of the additional questionnaires is necessary solely to ensure that the data of users registered for the second time are included in the "charlie" file.

After the introduction of this new feature in our system, we felt the need to make some changes to the files downloaded from the "data by task " section of the admin area, in particular to the "WC_MT_statistics.csv" file in Word Categorization Task and the "Charlie" download file. This update was key to improving data management and enabling more accurate and detailed viewing of the information collected.

Previously, the "WC_MT_statistics.csv" file contained a series of standard fields, such as WC_CorrAns_RT_SD, WC_correct_answers_percentage, WC_information, and more, that represented the results of the word categorization task for each user. However, with the introduction of the ability for users to complete the task more than once, it was necessary to find a way to display both attempts in a clear and orderly manner.

To solve this challenge, we decided to change the file format, introducing new fields identified by the suffixes "_1" and "_2". Each original field has been duplicated, one to represent the user's first attempt and the other for the second attempt. For example,

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the WC_CorrAns_RT_SD field has been replaced by the new fields WC_CorrAns_RT_SD_1 and WC_CorrAns_RT_SD_2, which represent the value of the first and second attempts to correct answers, respectively. The same approach was adopted for the other fields related to the word categorization task. We can see an example of it in Figure 34 and Figure 35.

Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14	Column15
WC_CorrAns_RT_mean_1	WC_CorrAns_RT_SD_1	WC_correct_answers_percentage_1	WC_information_1	WC_information_rate_1	MT_IC_1	MT_EC_1	MT_IW_1	MT_EW_1	MT_NG_1	MT_C_1
212.84057971014494	113.7302457047805	53.07692307692308	0.002733457041004937	0.01067403848880003	15.5	33	9.5	17	25	48.5
174.8	116.4738597282669	46.15384615384615	-0.004272547915074532	-0.02133811866921587	59.5	0	31.5	0	9	59.5
180.22727272727272	66.62327272297242	50.76923076923077	0.0001707398766064675 8	0.0007260060824531707	56.00000000000001	3	39.5	1.5	0	59.00000000000001
138.23214285714286	73.000487051073	43.07692307692308	-0.01387391536976175	-0.07249232307351397	16.5	2.5	28.000000000000004	5	48	19
213.578125	762.9071209174052	49.23076923076923	-0.00017073987660646758	-0.0009215388175222447	19.5	0	46	0	34.5	19.5

Figure 34 – A part of WC_MT_statistics.csv file

Column16	Column17	Column18	Column19	Column20	Column21	Column22	Column23	Column24	Column25	Column26
WC_CorrAns_RT_mean_2	WC_CorrAns_RT_SD_2	WC_correct_answers_percentage_2	WC_information_2	WC_information_rate_2	MT_IC_2	MT_EC_2	MT_IW_2	MT_EW_2	MT_NG_2	MT_C_2
216.16666666666666	127.88436814623444	50.76923076923077	0.00017073987660646758	0.0006990043446129869	46.5	15.5	23.5	11	3.5000000000000004	62
247.83076923076922	728.4138631137736	50	0	0	0	0	0	0	100	0
159.77272727272728	56.26231729237108	50.76923076923077	0.00017073987660646758	0.0008676145862033688	39	0	59	0	2	39
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 35 – Example of user who registered the second time in 'Data by User' section in Admin Area

If a user has completed the task only once, new fields with the suffix "_2" will simply contain the value NULL. This ensures that each line of the file uniformly and completely represents the results of the task, regardless of the number of attempts made by the user.

In the "charlie" task file, like the "WC_MT_statistics" file, there is a duplication of columns, distinguished by the suffixes "_1" and "_2", to differentiate between the two attempts made by the same user. The columns with suffix "_2" relating to the questionnaire data will be NULL, while there will be values only for the columns with suffix "_2" relating to the data of the Word Categorization Task.

This new data structure now allows admins to easily view and compare the results obtained by users in different attempts to complete the task. Each row of the file represents a single user, with information relating to their attempts divided into distinct columns to ensure clear and complete data analysis.

Chapter 6

Conclusions

In conclusion, this study has provided valuable insights into the neurological consequences associated with Long COVID, a condition that emerged as a significant concern in the aftermath of the COVID-19 pandemic. With the 'Happy Again' platform, we aimed to understand the persistent or emerging symptoms experienced by individuals even after the resolution of the initial COVID-19 infection. The comprehensive analysis of behavioral data collected through this platform has shed light on the various neurological manifestations of Long COVID, contributing to our understanding of the long-term impacts of the virus on neurological health.

During this research endeavor, we demonstrated the importance of interdisciplinary collaboration and the use of innovative technological solutions in addressing complex challenges in the healthcare sector. By leveraging the expertise of psychologists, analysts, and designers, we were able to develop a robust framework for data collection and analysis, facilitating the identification of correlations between behavioral data and neurological outcomes.

The improvements made to the 'Happy Again' platform, including the implementation of new features such as task repetition for users and an intuitive administrative interface, have not only optimized data collection but also laid the groundwork for future research in this field. These enhancements have positioned the platform as a valuable tool for ongoing studies on Long COVID and other neurological consequences of COVID-19.

Looking ahead, further research efforts are needed to deepen our understanding of Long COVID and develop effective intervention strategies for affected individuals. By refining data collection methodologies and expanding collaborative networks, we can continue to advance scientific knowledge and support the medical community in addressing the complex challenges posed by COVID-19 and its consequences.

It is also worth mentioning that the implemented improvements have addressed various aspects, enhancing both user and administrator experiences. The administrative area has undergone significant improvements, aiding administrators in visualizing user data and developing a translation assistance system to make the site accessible to users from different countries. As we plan to make the site accessible globally, it is imperative to ensure that the server can effectively handle increased traffic and requests. Currently, we are conducting specific stress tests to assess the scalability of the site and ensure it can meet the needs of a broader audience. Additionally, we anticipate conducting

further tests on the activities available on the platform, like those already conducted for word categorization, to evaluate any improvements over time. Finally, we are developing a new software called LC-Neurorehab, which will offer specific activities for neurorehabilitation and can be used by specific users following the analysis of data from the Happy Again website.

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