UNIVERSIDAD DE GRANADA

End-of-degree project

Computer Sciences Degree

COGNIMOBILE: automatic detection of cognitive functioning from user-mobile interactions

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Granada, July 4, 2020

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Guillermo Bueno Vargas

Abstract

Cognitive diseases are affecting every day more people worlwide. The increased human life span is a consequence, among others, of more accessible and better health systems, which is favouring on the other hand the surge of ageing-related pathologies. This area needs more research based in innovative data obtention systems which can detect those in an early stage to help managing the raising number of patients that are expected in the following years. It is important to help discriminating what is a healthy ageing process from a pathological one in order to minimise the consequences of aging. This project tries to innovate in this field with an interactive free-access platform that allows the self-assessment to be conducted by users of mobile devices through a series of tests which can afterwards be remotely evaluated by an expert.

Keywords: *cognitive decline, cognitive process, platform, app, server, free software*

I, **Guillermo Bueno Vargas**, student of the **Computer Sciences Degree** of the **Escuela Técnica Superior de Ingenierías Informática y de Telecomunicación de la University of Granada**, declare that the present End of Degree work is original, having not used sources without being duly cited. If I do not comply with this commitment, I am aware that, in accordance with the Evaluation and Qualification Regulations of the students of the University of Granada of May 20, 2013, *this will automatically entail the numerical rating of zero [...] regardless of the rest of the qualifications that the student would have obtained. This consequence should be without prejudice to the disciplinary responsibilities that students who plagiar in plagiarism may incur.*

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license, giving permission to copy and redistribute it in any medium or format, also to adapt it in any way you want, but all this as long as the authorship is recognized and distributed with the same license as the original work. All source code as well as this document in LaTeX format can be found in the following *GitHub* repositories: `https://github.com/Guillergood/CogniMobilePlatform`. So, I hereby sign this document.

BUENO VARGAS GUILLERMO - 53733485B

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Granada, July 4, 2020

Mr. **Oresti Baños Legrán**, professor in the **Department of Computer Architecture and Computer Technology** at the **University of Granada**.

Advices:

That the present work, entitled ***COGNIMOBILE: automatic detection of cognitive functioning from user-mobile interactions***, has been carried out under his supervision by **Guillermo Bueno Vargas**, y and authorizes the defense of such work before the appropriate court.

Issues and signs this report in Granada July 4, 2020.

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Oresti Baños Legrán

Prologue

I remember the first contact I had with computer science in 1998, when I was just four years old. My parents brought a desktop computer that we installed in the study room, to serve as educational support for us and professional to my parents. The equipment was used for work in the evenings, but we also sat down to play together and discover the possibilities that technology was beginning to offer us. I was fascinated with that magic box that allowed me to see colored icons on a giant screen with a curved glass. Back then, the access to programs, IT contents and games was done through specialized magazines that we began to receive at home periodically. Among many other programs, the magazines incorporated children's pedagogical games, which immediately caught my childish attention. One of those first games was "Ven a jugar con Pipo"[1]became my favorite one and has been an educational reference for several generations of children.

[1]For additional information, see: `http://www.pipoclub.com/`

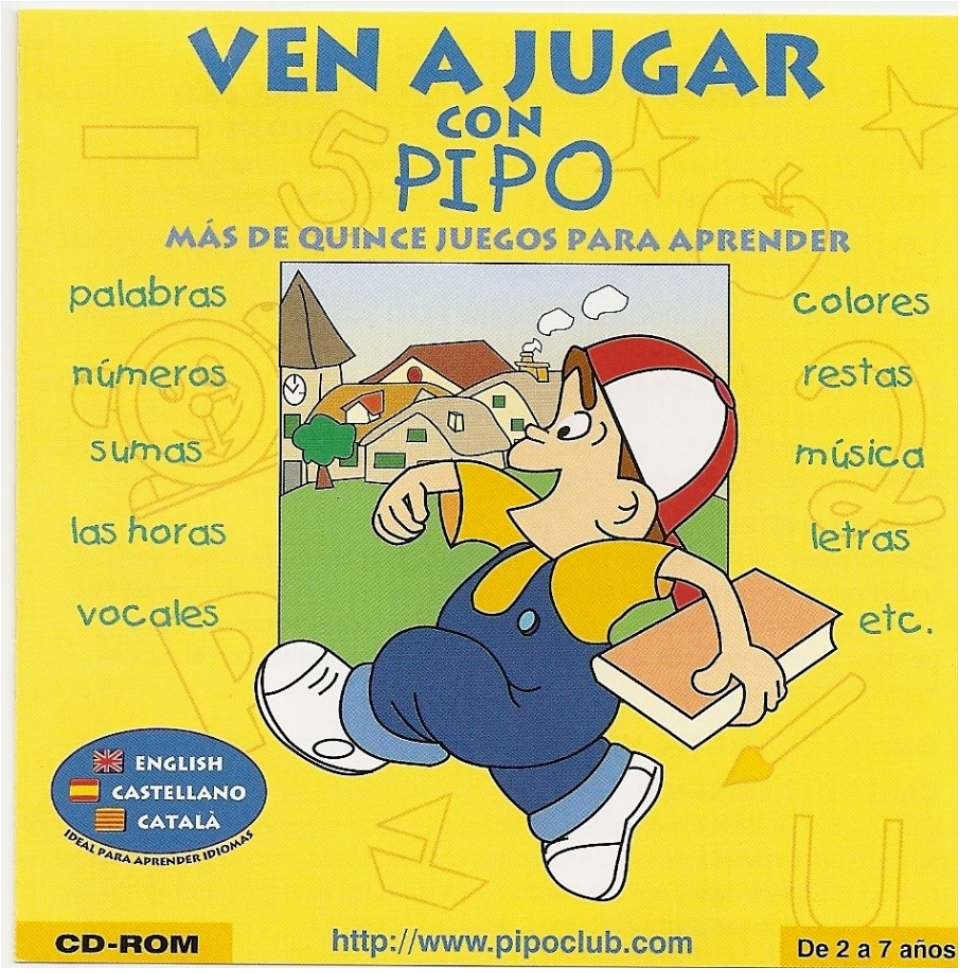


Figure 1: Cover of my first video game

It was an educational game that, among others, taught me to spell and read at an early age to the point that without having started to speak yet, one day I surprised my parents by spelling the name of the breakfast margarine without problem. Over time I understood how as a child I began to experience cognitive processes without being aware of it, and I also understood the importance of pedagogical resources in early stimulation of learning processes.

My IT knowledge and experience increased in time, and as part of my intellectual development, computer programs and computer games have always been an important element of curiosity, learning and progress. In my teens, I suddenly experienced certain problems that appeared unannounced. I suffered several epileptic seizures and once the first scare was over, instead of have been a once-off event, my life underwent a re-

markable change. The repetition of several of those episodes forced the onset of a treatment to reduce the excess of brain activity and thereby reduce and eliminate brain electrical abnormalities. Then a hard time began as taking the medication to block the attacks reduced my mental “agility“as a side effect. The medication managed to make those episodes disappear, but at the cost of a lower cognitive and intellectual performance.

In high school I realised that retaining knowledge and reasoning was harder, and I needed to make a bigger studying effort than before, as I could not concentrate well. Learning demanded more time and effort than what I was used to do previously. Headaches, mood swings, tendency to depression, memory loss... All this allowed me to discover at an early age the impact that the reduction of cognitive abilities can have on our live and gave me a new perspective that other people do not usually have at that age. Suffering the impact of reduced cognitive functions helped me to empathize and understand the potential difficulties people with reduced cognitive and intellectual abilities can face in their day by day activities. Based on my own experience, helping others became the purpose and a strong motivation which inspired me to start this project.

Contents

Chapter 1

Introduction

1.1 Context

The United Nations has accounted for 703 million people who are 65 years of age or older in 2019 [1]. The World Health Organization's forecasts show that from 2015 to 2050, the figure of over-60s representing 12% (900 million) was estimated to be 22% (2 billion) an increase of 10%. Most health-related problems in this sector are from diseases that are not transmitted [2].

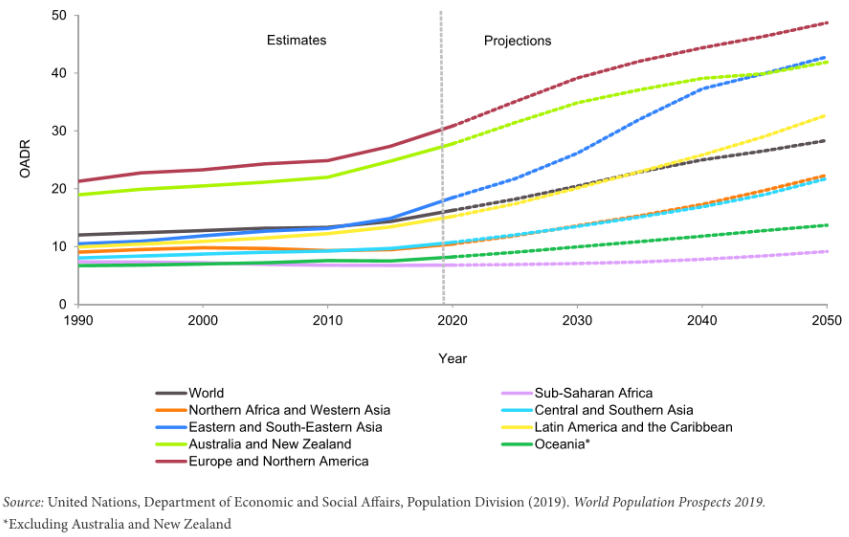


Figure 1.1: Estimation and projection of population dependency rate over 60 by region, 1990-2050, 1990-2050 [1].

It is predicted that by 2050 approximately 7% of this population will suffer from dementia. Diagnosing the disease early allows the patient

to have a better quality of life. It is a disease with a high public health priority, which needs more research and innovation to improve current treatments [3].

1.2 Approaching the problem

The main limitation of the MoCA [4] test is its face-to-face nature, and that it is performed in the form of a physical questionnaire in front of an interviewer. This has been identified as one of the main limiting factors for the extension of these evaluations. In order to be diagnosed with this method, the candidate must be evaluated externally, making an appointment and going to the clinic is therefore a pre-requirement without which the diagnosis cannot be made. That is the reason why the main objective of this work and method is to eliminate the face-to-face factor and the external evaluation as limiting factors in the diagnosis of certain mental pathologies. Also, the project will aim to facilitate and extend its use to many more people through the creation of a network-based computer application, with an easy access, understanding and use.
The proposed solution is a platform that will allow tests to be conducted remotely, from any location with Internet access and without the need of the intervention of a specialist. In addition, the different types of user data which will be used to improve the accuracy of the diagnostic method and to develop new lines of research.
The tests provided could be created dynamically so that the mental health specialist will have access to them in real time enabling with it an early diagnosis so that an eventual therapeutic response can be initiated accordingly. The data collected will be hosted on a secure server of the entity that manages the patients' information and will then be analysed from a web interface by the specialists in the field. Obviously, the privacy of the data obtained and their use will be guaranteed at all times for the exclusive purposes of improving the life of the patient. Also, the data will be used for the development and improvement of complementary diagnostic methods through the analysis and statistical treatment.

1.3 Motivation

In an increasingly complex society, the generation and compilation of data is currently ramping up exponentially along with the evolution of the devices we usually manage, allowing us to know things about ourselves, through patterns which we do not even realise about.

If those data are used correctly, the opportunities to generate diagnosis are unimaginable. As exposed previously the pressing problem of cognitive diseases is becoming more and more concerning and demands appropriate responses.
One way to innovate in this area is combining both clinical and technical approaches by collecting contextual data and test results remotely, being able to automate processes thus, speeding them up and trying to discover potential pathological patterns during the diagnosis. That will enable to simplify and automate processes, and as a consequence of that time and effort needed to diagnose patients will be reduced accordingly.

1.4 Goals

To achieve these objectives we will perform the following tasks, where the main objective is:

- Develop a mobile platform that allows cognitive tests to be administered to patients remotely and evaluated by an expert. This goal will be achieved through the following specific objectives:

  Design a system architecture that includes all the requirements needed for a mobile cognitive platform.

  Implement a mobile app for end users to realise the cognitive tests remotely a front-end so that the expert can introduce new tests and verify the score of these finally implement a back-end to host the front-end and handle all the data.

  Evaluate the usability of the system that has been developed.

1.5 Project structure

The project documentation proposal as follows:

- *Chapter 1* (**Introduction**) provides a brief introduction to the idea, as well as the motivations that have led us to realize it.
- *Chapter 2* (**State-of-the-art**) describes the most innovative technologies and projects regarding the subject and how this project seeks to push forward this field.
- *Chapter 3* (**Design**) describes how the project was designed, using software engineering and agile development methodology.

- *Chapter 4* (**Implementation**) presents how the project has been planned and implemented, following the planning and diagrams previously made.
- *Chapter 5* (**Results**) defines all the results obtained from the usability test, performing a statistical study.
- *Chapter 6* (**Conclusions**) shows the final conclusions as well as recommendations for future work.

Finally, an attachment with the source code developed and released under the MIT free license [5] is included. This source code can also be found in the url: `https://github.com/Guillergood/CogniMobilePlatform`.

Chapter 2

State-of-the-art

In this chapter we present and analyse the advanced technology that we are going to use to achieve the objectives presented in the previous chapter. For the detection of mild cognitive impairment and dementia, several tests are already available. A cognitive test is a set of cognitive tasks that evaluates the user abilities.

2.1 Cognitive assessment techniques

The Mini-mental State Examination (MMSE) is a set of cognitive tasks that enables the evaluation and detection of cognitive impairment. It was created by Folstein et al. in 1975 [6].

The MoCA (Montreal Cognitive Assessment) test is a set of cognitive tasks that allows to evaluate and detect cognitive impairment. It was created by Ziad Nasreddine in Montreal in 1996 [4].

Both tests are currently being used to perform cognitive evaluations on patients. Both tests have been studied in detail and tasks that are usually performed have been evaluated and are presented here:

Alternating Trail Making

This task has been introduced in the MoCA test to add an assessment of mental agility and flexibility. It assess executive abilities requiring different mental capabilities such as letter and number recognition, visual processing and coordination. [7]

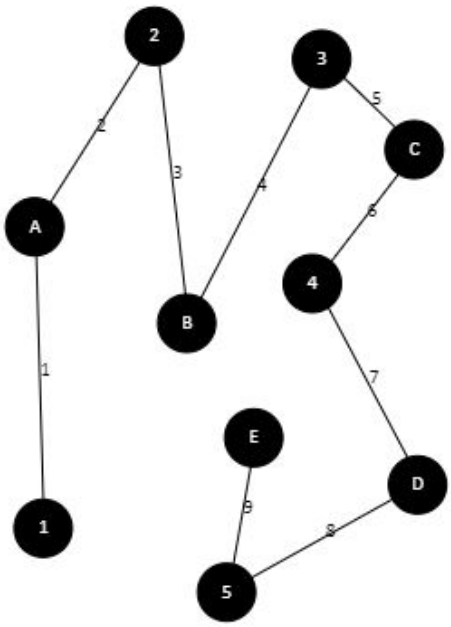


Figure 2.1: Sample of Alternating Trail Making

Drawing of overlapped infinities, wire cube and clock

These tasks are commonly used in different tests for their ability to accurately diagnose dementia. A shape is administered and the patients have to draw the figure as faithfully as they can. This task uses visuospatial constructional abilities and executive functions to evaluate the patient's capabilities.

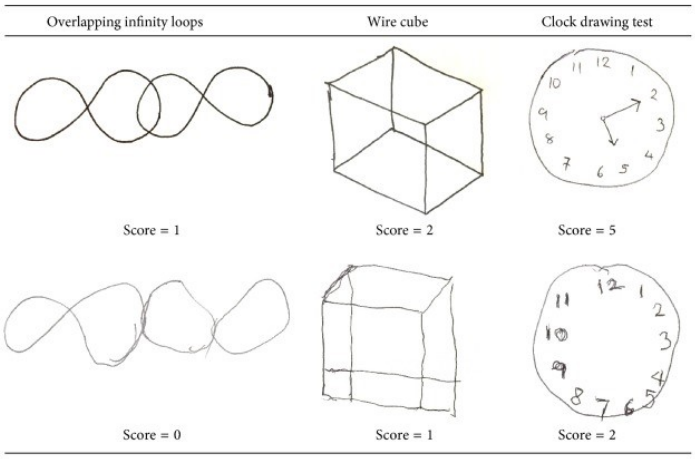


Figure 2.2: Samples of the tasks of overlapped infinities, wire cube and clock [8]

Memorization

This task tests the patients' memory. There are several types of memorization tasks, the most important ones of them presents pictures of different animal species and the patient is expected to name them. Studies conclude that this type of task has excellent reliability [9] [10].

Figure 2.3: Sample of a drawing of an animal used to be named by a patient [1]

Other tasks ask the user to memorize words or numbers and then requests them to be repeated o memorized in a certain way.

Serial subtraction

This task asks the patient to repeat various arithmetic subtraction. It usually starts with the number 100 and the patient subtracts 7 to that amount several times. The results are taking into account to the assessment. Various studies show that it is useful for evidencing cognitive deficiencies in attention and memory [11].

Abstraction

This task asks to specify some properties that share two subjects. The MoCA test sets an example of an apple and an orange, to which the subject could respond that both are fruits or that they are round. This exercise evaluates the patient's abstract reasoning by figuring out the link between to entities.

[1] Cambridge Cognition. Graded Naming Test (GNT). Retrieved `https://www.cambridgecognition.com/cantab/cognitive-tests/graded-naming-test-gnt/`

Orientation

This task asks the subject about issues related to dates and locations. This exercise evaluates the patients' orientation and memory abilities by asking them where they are, what day is today in different formats, number and word.

2.2 Mobile apps to measure cognitive status

Over the last few years several mobile applications have been developed to reinforce cognitive functions, by practising the same cognitive tasks or similar to the previous ones. Some examples are:

- **Brain Test** [12]: A game where puzzles have to be solved, by tapping on the screen or by dragging elements into their right position. Examples of these tasks are: put certain objects into others, swipe items to the left of the screen with a picture of an arrow indicating the opposite direction, forcing the patient not to follow the instructions of the screen, slide objects so that others are visible, etc. It has not a scientific or research purpose, its purpose is for entertainment.

- **NeuroNation** [13]: A mental skill trainer, that includes exercises similar to those described above. Its rating is based on 4 parameters, "Memory", "Attention", "Reasoning", "Speed". Several examples of these tasks are: "Conceptual Alternation", where several circles are arranged and the app shows a sequence that the patient has to memorize. These circles have the possibility to move, use exercises of additions and subtractions, compare figures. This application was created with a scientific purpose, by the Free University of Berlin where they continue to test the effectiveness of this application and a commercial purpose, since this application contains advertising and also offers a paying subscription that gives access to a routine of mental exercises.

- **Lumosity** [14]: A mobile application that allows the user to practice cognitive tasks. The app starts by asking the user the kind of exercises they want to practice from the following options: "Memory", "Attention", "Flexibility", "Problem Solving", "Speed", "Mathematics". After registering the user level is pre-tested with a speed task, where the user is asked to check similarities between two different figures, the goal being to get the highest number of points. The second exercise is an attention related task in which the user

needs to perform a series of chain decisions to plan in advance certain movements. The game consists of changing train tracks to get certain trains to their corresponding station. Just like the previous one, the user has to get the highest number of in a minute. The last exercise is about memory, in which the user has to repeat a sequence of colours in a square matrix to achieve the largest number over fifteen arrays that have more and more components. At the end of this test, the user gets a training program. Games rotate depending on the day, more games can be unlocked only if the user subscribes to a premium version. This application has proven to be a tool that improves certain cognitive processes, such as decision-making and concentration, among others [15].

- **mindLAMP** [16]: A tool that allows both to obtain data for research and its clinical use in the diagnostic stage. It incorporates a series of cognitive games that allow users to test themselves with it. There are different examples, like the version of the "Conceptual Alternative", where the user is asked to form with his finger a path alternating letters and numbers. There is another version of this exercise that involves identifying gem figures, in which the user is requested to select the gem with the next number of a series that starts with the one. Other exercises are: the memorization of colour patterns in a matrix and its repetition; five consecutive subtractions of seven units, starting at one hundred to finish in the number sixty-five; drawing figures during a time interval; and image memorization of missing figures. The app also collects user's context data such as their GPS position, calls or exercise information, to give a complete understanding of the context under which the test has taken place and introduce them as factors that could influence the results obtained. All of those data are analysed and sent to a server where the expert can view the data through a web interface.

- **MobileCogniTracker** [17]: A smartphone based assessment for cognitive functioning with clinical questionnaires that are sent by an expert. Then the data obtained in the questionnaires are compiled by the medical entity to be processed. It uses AWARE [18], an open source context instrumentation framework that allows capturing information from the phone's sensors; the user is able to create their own extensions in order to capture elaborate data. This app gives an expert the ability to manage the Mini-Mental State Examination (MMSE) remotely by eliminating the face-to-face fac-

tor.

2.3 Conclusion

There are already a variety of cognitive exercises available that are being used to help in the diagnosis of mental health pathologies. To innovate various authors have developed digital tools to perform simple tasks or cognitive tests. The test results can be compared with their analogue paper-based tests.
With the use of this type of mobile applications there will be new opportunities to open up extensive research possibilities. A new more simple and friendly approach to patient self-diagnosis, the increased and enhancement of multiple data obtention and the capture of context parameters, together with the immediate access to all them for complex analyses, will change the perspective about our understanding of cognitive diseases.

Chapter 3

Design

In this chapter the necessary tools and processes used to resolve the challenges and objectives presented in the Introduction and the State-of-the-art chapters, will be defined.

3.1 Introduction

The objective of this project is to develop a platform that allows the realization of a remote cognitive assessment of mental health patients, in addition to the collection of more context data which could be relevant to the diagnosis. Currently, most evaluation tests are performed in clinics, using pen and paper, and demanding the physical presence of the patient; however, there is not yet a standardised process to digitalize these tests. The way those are performed does not allow the obtention of additional valuable information which an electronic device could collect and provide with, such as on-screen taps or other sensor-related information.

The MoCA test has been chosen as the basis to develop this platform, due to its popularity in recent years and its apparent effectiveness in detecting indicators of cognitive diseases. This chapter explains how it has been designed, planned, and implemented.

3.2 Requirements

The software version of a cognitive test has to be as close as possible to the original. It is not intended to modify or alter the user's responses, as it could interfere with the purpose of the project, which is to provide greater flexibility and scope to the test on a different platform,

but with the requirement of maintaining its original reliability. As an added bonus, the user will get help from the application itself to carry out the tests. This requirement creates additional challenges, added to those inherent to the development of a specific software. This section presents and discusses the decisions made to overcome and resolve the challenges encountered in translating a pen-and-paper cognitive test into a digital version and the requirements to consider during the development phase. We have used the *MoSCoW* methodology [19] to help in the definition of such requirements.

Must have: These are the features that the application must incorporate to meet the minimum functionality requirements. The platform to be developed must have capabilities to capture data from the user's context and be able to send test data to a server. The researcher should be able to define a diagnostic based on that evidence. It also has to be scalable and modular and as an essential requirement it must be comparable in its parameters and diagnostic qualities to the physical support version (on paper) of the original MoCA test. Its similarity, performance and reliability with respect to the original must be the highest possible for obvious reasons. It should also contain specific accessibility elements, such as button labels and colours that are contrasted for a better understanding. Finally, the data must be managed and stored securely by the entity that will use the evidence.

Should have: These are aspects that, although optional, it is recommended that the application incorporates to offer improvements that technology can offer when compared with the original paper version. The application to be developed should have Text-to-Speech and Speech-to-Text functionalities, which basically allow to transform written text to speech and vice-versa, to facilitate the information process for the user. The application should contain animations to make it easier to understand its functionalities and be visually appealing and easy to handle. The platform should be able to provide the answers to the tests.

Could have: These are some features that would be ideal for the application to incorporate and would be geared towards improving its usability, improving data collection, notifications and accessibility. The user could enter explanations and/or responses to the tasks through the microphone and the app could eventually show scores of the tests performed. The platform to be designed would allow creation of tests to be included in the study, which should be displayed with a notification when it occurs. Tests created by experts should be able to have preferred language selection in order to facilitate their listening and reading for a better understanding in the user's native language.

Will not have: Those items that should not be incorporated into the application for different reasons. The only aspect included in this section is that the platform will not have any elements for example, to automatically recognise user drawing patterns, as that element would exceed the scope of this project. It will be considered for future developments.

3.3 Design choices

As described in the previous section, the application will communicate with a server containing a centralized database, where the platform will store the information to be consulted by the expert. With the web interface the expert will be able to store as many tests as required. Each test may contain different exercises, randomly chosen, with different information.

3.4 MoCA test

The MoCA cognitive test has been chosen to be implemented and be compared with its original version, since it appears to be more effective than the other most popular cognitive test, the Mini Mental State Examination (MMSE) [20].

The architecture of the Cognimobile is presented below, at high and low level.

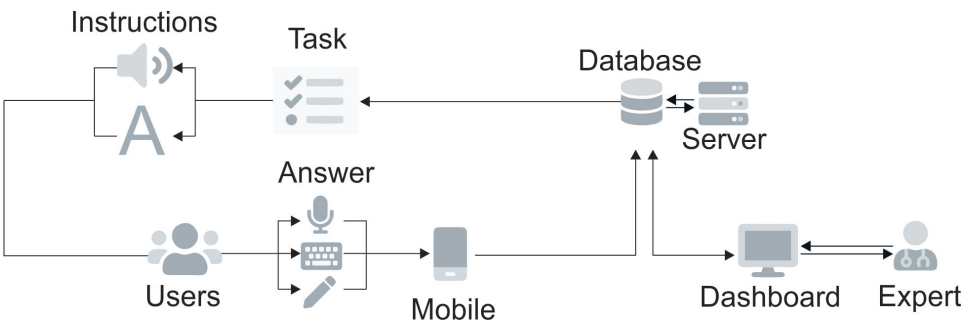


Figure 3.1: Cognimobile Platform Architecture Diagram

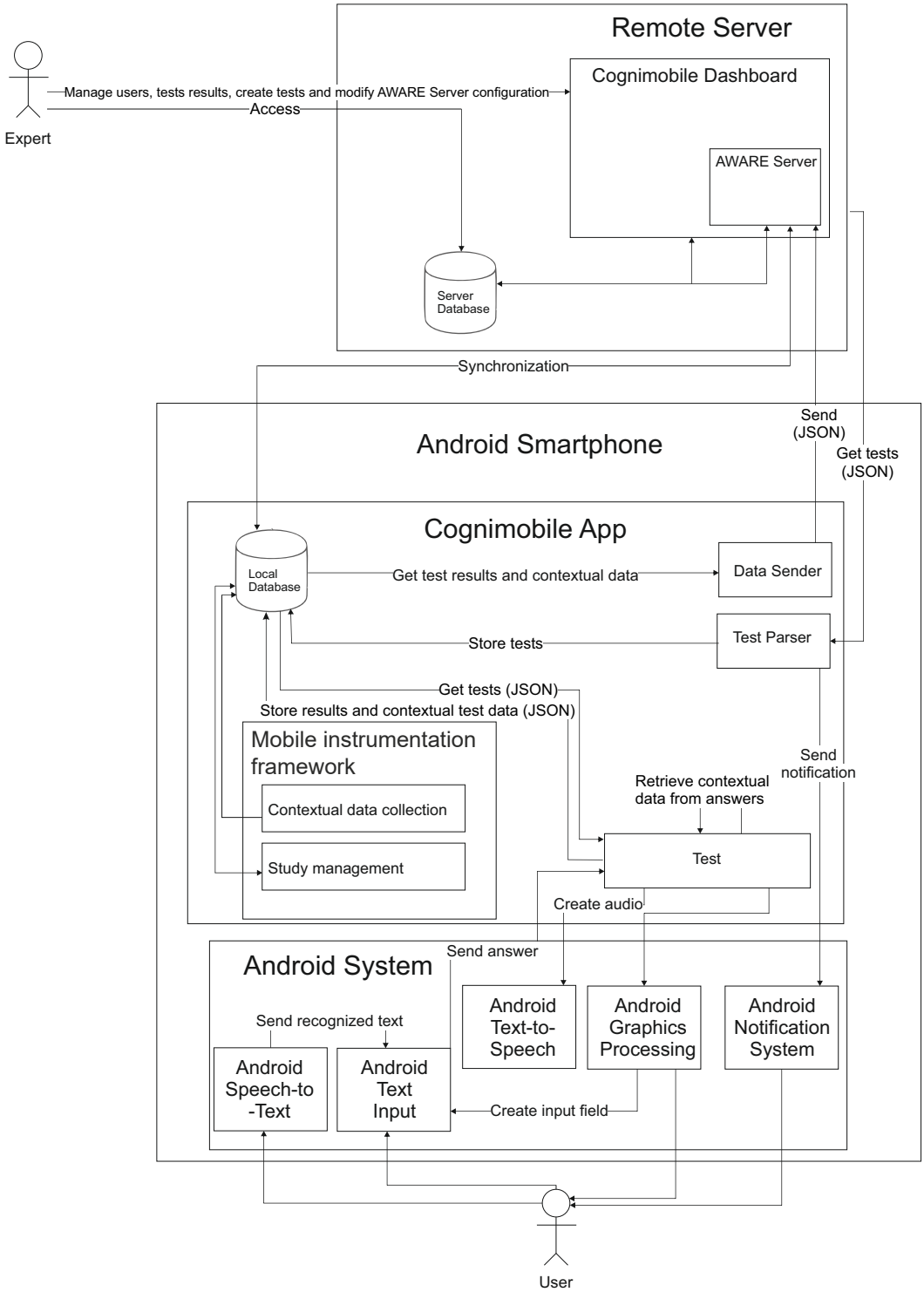


Figure 3.2: Cognimobile Platform Architecture Low-level diagram [21]

The MoCA test consists of fourteen tasks, explained in the Cognitive assessment techniques section:

1. **Conceptual alternation.**
This task asks the patient to alternate numbers with letters to draw a graph; starting with the number "1" a line is drawn up to the "A" letter to be connected to the number "2", in a sequence ending with the "E" letter. According to the MoCA Test Results Administration and Computing Instructions, the score of this task consists of: *"A point is assigned if the patient performs the following sequence: "1 – A – 2 – B – 3 – C – 4 – D – 5 – E". Zero is assigned if the person does not immediately correct an error whatever it is."*

2. **Visuoconstructive capabilities (Cube).**
This task asks the patient to copy a wire cube. According to the MoCA Test Results Administration and Computing Instructions. The score for this task is: *"A point is assigned if the drawing is done successfully.*

   - *The drawing must be three-dimensional*
   - *All lines are present*
   - *No lines added*
   - *Lines are relatively parallel and approximately the same length (rectangular prisms are acceptable)*

   ZERO is assigned if ALL of the above criteria have not been met"

3. **Visuoconstructive capabilities (Clock).**
This task asks the patient to draw a clock with all their numbers and have the hands pointing (or pointed) at a specific time. According to the MoCA Test Results Administration and Computing Instructions the score for this task is:
"*One point is assigned for each of the following three criteria:*

   - *Contour (1 pt.): The outline should be a circle with little deformation.(e.g. a mild deformation when closing the circle).*
   - *Numbers (1 pt.): All numbers must be present, without adding any; the numbers must follow the correct order and be well placed; Roman numerals as well as numbers placed outside the outline will be accepted.*

- *Needles (1 st.): The two hands must indicate the correct time; the hour hand should be clearly smaller than the minute needle. The needle junction point should be near the center of the clock.*

Points are not assigned if the above criteria have not been respected.“

4. **Denomination.**
In this task, the app asks the patient to name a series of drawings of animals, usually these are: a lion, a rhinoceros and a dromedary. According to the MoCA Test Results Administration and Computing Instructions, the score for this task consists of:
“A point is assigned by the correct identification of each of the drawings: (1) lion (2) rhino (3) camel or dromedary.“

5. **Memory.**
This task is linked to another task that will be managed soon after. The patient is asked to memorize a series of words that will later have to be said again by the patient. According to the MoCA test results administration and computing instructions, this task has no score.

6. **Attention (Number Sequence).**
In this task, five numbers are given to the patient at the rate of one number per second. Then the patient has to repeat the same sequence. According to the MoCA Test Results Administration and Computing Instructions, the score for this task is:
“A point is assigned if the sequence is correct.“

7. **Attention (Reverse number sequence).**
In this task, three numbers are given to the patient at the rate of one number per second. The patient then has to repeat the inverted sequence. According to the MoCA Test Results Administration and Computing Instructionsthe score for this task is:
“A point is assigned if the sequence is correct considering it is a reverse sequence.“

8. **Attention (Concentration).**
This task asks to hit the table every time the patient listen to a certain letter. Once given the instructions, letters are read out loud to see the patient’s reaction. According to the MoCA Test Results Administration and Computing Instructions, the score for this task is:

"No point is assigned if more than one mistake is made (e.g., the person taps with the wrong letter or does not tap with the letter 'A')."

9. **Attention (Serial 7's).**
This task asks the patient to subtract from a high number, usually 100, another small number, usually 7. According to the MoCA Test Results Administration and Computing Instructions. The score for this task is:
"This test gets three points in total. No points are assigned if no subtraction is successful. 1 point per 1 correct subtraction. 2 points for 2 or 3 correct subtractions. 3 points for 4 or 5 correct substraces. Each subtraction is evaluated individually. If the patient makes an error in the subtraction and gives an erroneous figure, but correctly subtracts 7 from that erroneous figure, points are assigned, for example, 100 - 7 x 92 - 85 - 78 - 71 - 64. "92" is incorrect, but all of the following numbers are correct. Since these are 4 correct answers, the score is three points."

10. **Repetition of phrases.**
This task asks the patient to repeat the same phrase that has been told. Normally the task consists of two sentences. According to the MoCA Test Results Administration and Computing Instructionsthe score for this task is:
"A point is assigned for each phrase repeated correctly. The repetition must be accurate. The examiner should pay attention to errors in omission, replacement, or addition"

11. **Verbal fluidity.**
In this task the patient has to say eleven or more words starting with a specific letter, this letter changes depending on the language. In Spanish the letter "P" is used. According to the MoCA Test Results Administration and Computing Instructions the score for this task is:
"A point is assigned if the subject says 11 words or more in a minute."

12. **Similarities.**
This task involves giving the patient two words so that the patient mentions any similarities between them. A simple way to check if the patients understood the task is to ask them about the similarities between an apple and an orange. This first question does not count for scoring, as it is just an example. According to the MoCA

Test Results Administration and Computing Instructions, the score for this task is:
"*One point is assigned for each of the last two pairs answered correctly. The following answers are accepted: for train/bicycle - means of transport, means of locomotion, to travel; ruler/clock–measuring instruments, for measuring. Unans acceptable answers: for train/bike – they have wheels, roll; and for ruler/clock: they have numbers.*"

13. **Deferred memory.**
This task is linked to the previous task (memory). The patient is asked about the words memorized. According to the MoCA Test Results Administration and Computing Instructions, the score for this task is:
"*A point is assigned for each of the words remembered spontaneously, without clues.*"

14. **Orientation.**
This last task asks the patient about the current day of the month, month and year, as well as the exact place where they are. According to the MoCA Test Results Administration and Computing Instructions, the score for this task is:
"*One point is assigned for each of the correct answers. The patient must tell the exact date and exact location (hospital, clinic, office, etc.). No point is assigned if the patient is wrong for a day on the day of the month and the week*" [1].

3.5 Budget

A Gantt's diagram was made before implementing the project, where the tasks were specified and timed:

[1] Instructions for administering and computing MoCA test results. Catch-On. Retrieved from `http://catch-on.org/wp-content/uploads/2016/12/MoCA-Instructions-Spanish.pdf`

TASK NAME	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER
Cognimobile							
Implementación ejercicio grafo	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio cubo	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio reloj	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio animales	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio memoria	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio números	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio lista de letras	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio resta	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio frases	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio palabras que empiezan por una letra	17/8/19	17	21/8/19	4	4	0	Guillermo
Implementación ejercicio abstracción, comparativa	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio resta	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio recordatorio	17/8/19	17	20/8/19	3	3	0	Guillermo
Implementación ejercicio preguntas sobre el día	17/8/19	17	20/8/19	3	3	0	Guillermo
Adecuación código AWARE	17/8/19	17	3/9/19	17	17	0	Guillermo
Reorganizar TTS (singleton)	2/10/19	2	8/10/19	6	6	0	Guillermo
Mostrar el ejercicio cuando termine TTS	29/9/19	29	30/9/19	1	1	0	Guillermo
Centrar inputs	29/9/19	29	1/10/19	2	2	0	Guillermo
Implementar STT	29/9/19	29	1/10/19	2	2	0	Guillermo
Boton STT	29/9/19	29	30/9/19	1	1	0	Guillermo
Ejercicio de memoria	21/8/19	21	26/8/19	5	5	0	Guillermo
Secuencia	22/8/19	22	27/8/19	5	5	0	Guillermo
Resta	29/9/19	29	1/10/19	2	2	0	Guillermo
Frases	22/8/19	22	23/8/19	1	1	0	Guillermo
Palabras	21/8/19	21	21/8/19	1	1	1	Guillermo
Implementación ejercicio abstracción, comparativa	21/8/19	21	23/8/19	2	2	0	Guillermo
Implementación ejercicio recordatorio	21/8/19	21	22/8/19	1	1	0	Guillermo
Implementación ejercicio preguntas sobre el día	21/8/19	21	21/8/19	1	1	1	Guillermo
Introducción	18/3/20	18	20/3/20	2	2	0	Guillermo
Quitar el microfono en los animales	21/8/19	21	22/8/19	1	1	0	Guillermo
Quitar el "no lo sé" en algunas tareas	26/8/19	26	28/8/19	2	2	0	Guillermo
Tutorial	18/3/20	18	23/3/20	5	5	0	Guillermo
Propia base de datos para AWARE	27/3/20	27	3/4/20	7	7	0	Guillermo
Prueba de base de datos remota	6/4/20	6	13/4/20	7	7	0	Guillermo
Cambiar icono de ayuda	18/3/20	18	20/3/20	2	2	0	Guillermo
Adecuar todos los botones	18/3/20	18	19/3/20	1	1	0	Guillermo
Configuración backend AWARE	18/3/20	18	26/3/20	8	8	0	Guillermo
Confirmación de salir de la tarea si el input está vacío	18/3/20	18	24/3/20	6	6	0	Guillermo
Usuarios de la interfaz web	27/3/20	27	27/3/20	1	1	1	Guillermo
Transformar datos en informe	27/3/20	27	2/4/20	6	6	0	Guillermo
Gestionar el servidor de Aware	27/3/20	27	31/3/20	4	4	0	Guillermo

Figure 3.3: List of tasks of the Gantt's Diagram

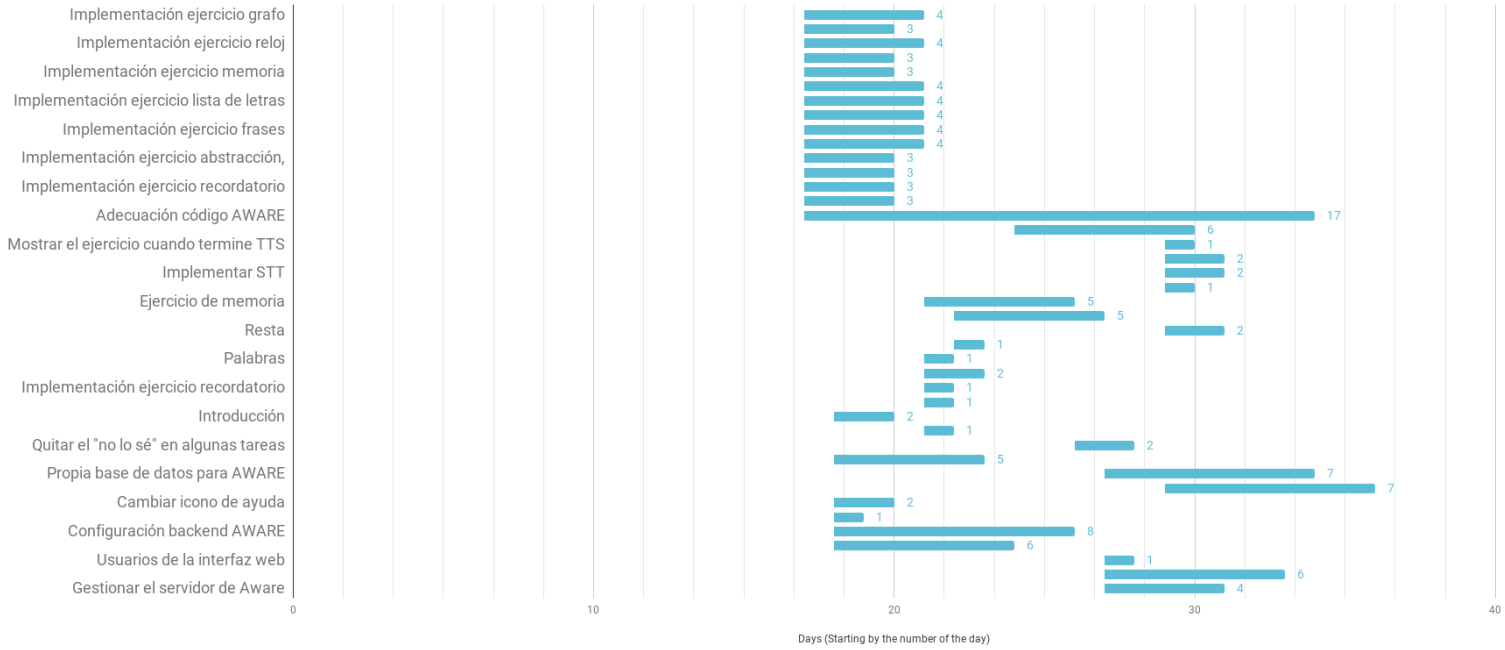


Figure 3.4: Gantt's Diagram

With this diagram and taking into account the market price [22] [23], the project estimated price is 25.701,82 euros.
Below is shown the budget breakdown for the "*Cognimobile Platform*":

Description	**Hours**	**Price per hour**	**Total**
App			
Making an app	704 hours	€25.56	€17.994,24
Dashboard			
Making web dashboard	352 hours	€4.96	€1.745,92
Materials			
Materials without cost			€0
Overrun			
Extra hours	160 hours	€9,375	€1.500
Taxes			
21% VAT			€4.460,43
Total			**€25.700,59**

3.6 Summary

Developing a similar application that is as reliable as the original paper format based test requires careful considerations to be taken, starting with the analyses of how the test operates so that similar methods could be applied in digital format. The MoCA test [4] has been chosen for its higher performance against MMSE test [6].

Chapter 4

Implementation

4.1 Tools used

The following development tools have been used to implement this project:

- Android Studio , to develop the mobile app [24].
- AWARE a framework to capture data from the patient's mobile sensors for research purposes [25].
- Laravel©, a framework to quickly develop web projects [26].
- CoreUI , an open source UI template to make the web project more attractive [27].
- A small version of "SCRUM" for agile software development [28].

Android Studio is one of the most widespread tools for developing apps on the Android environment. This tool was chosen over others as it allows for a quick development of an application, and due to the previous experience gained with it. Although Java is no longer the only option to develop in Android, it was chosen for its extensive use and for the experience already gained. The MoCA test has been digitized thanks to the AWARE framework, as AWARE makes it easy to access the sensors and capture the required information. In addition, it has a repository to deploy its own server in minutes, called "Aware-micro".

4.2 Framework AWARE

AWARE is a framework for developers, researchers and users that uses phone sensors for context data collection. Both hardware, software and user information is captured from the phone and analysed by AWARE

extensions to translate it into understandable information. It is an open source project, free access and free for non-commercial use under the Apache version 2.0 license. AWARE uses a client-server architecture, where users register by linking to a research study using a URL or QR code, after which the information needed to initialize the information collection can be downloaded. AWARE then creates a local database, with a UUID (Universal Unique Identifier) identifying each device that has joined the study, after which a JSON (JavaScript Object Notation) is obtained with the information of which sensors to activate and how often it has to measure certain parameters from the server (among other settings). This project benefits from these features as it uses AWARE not only to capture information, but also to send personalized data such as the results of cognitive tests through the RESTful API **bibid** itself, where operations are performed to a database via HTTP queries.

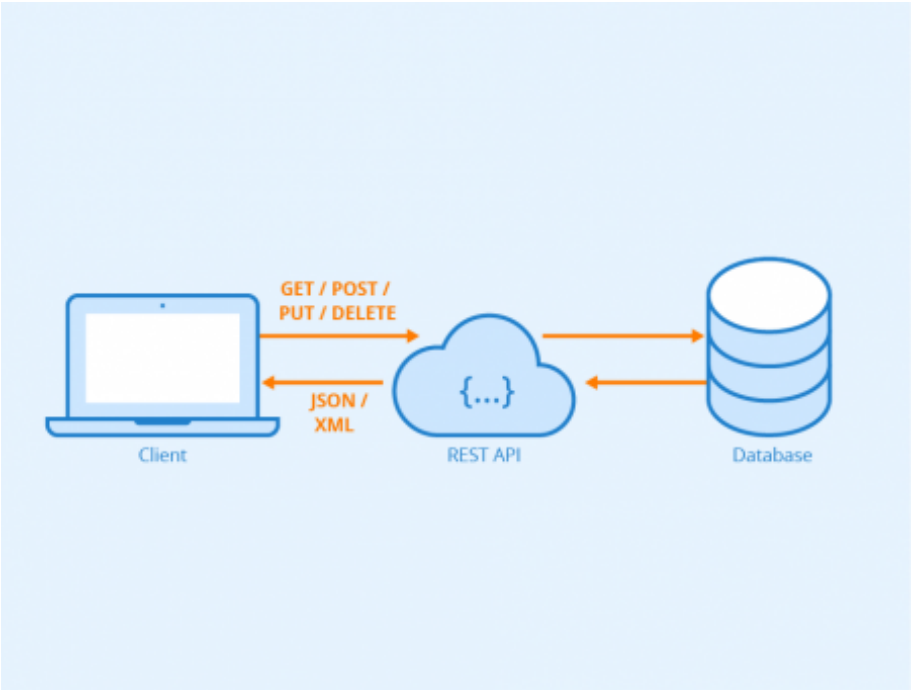


Figure 4.1: Picture about how a RESTful API works **bibid**

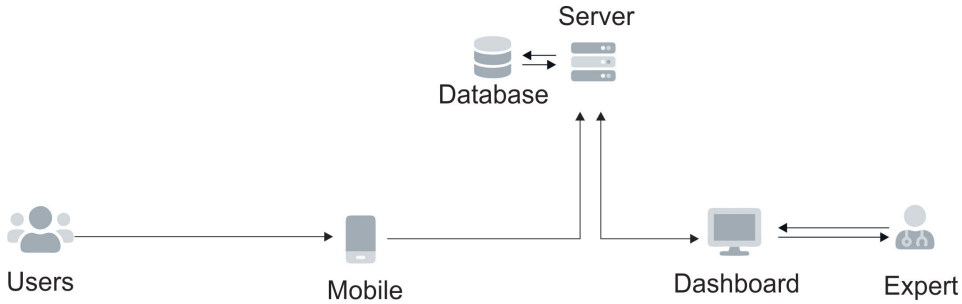


Figure 4.2: AWARE Platform Architecture Diagram

The implementation of AWARE in an Android project can be done in two ways: the project can be an extension of the AWARE application itself, where the project would become an AWARE “plugin“, or integrating AWARE as an internal library of the platform, where the project would become a “standalone“ or own application. The second option was chosen as it offered for several advantages it offered: to being an application implemented with AWARE, it could only be used with this single project; having it as an AWARE extension would force you to install the project in addition to the AWARE application.

4.3 Implementing the Cognimobile app

To begin the implementation of the project a variant of the agile SCRUM methodology was used. It consists of performing a certain load of tasks stipulated by the team, in a previously specified timeframe. Tasks are discussed by the team, estimated in time and prioritized. In this case, since the team was one person, decisions were easy to reach. The duration of the Sprints was stipulated, time was allocated for every task and for a complete review after two weeks.To develop an application with the Model View Controller pattern, it is essential to define a class diagram that allows the correct implementation.

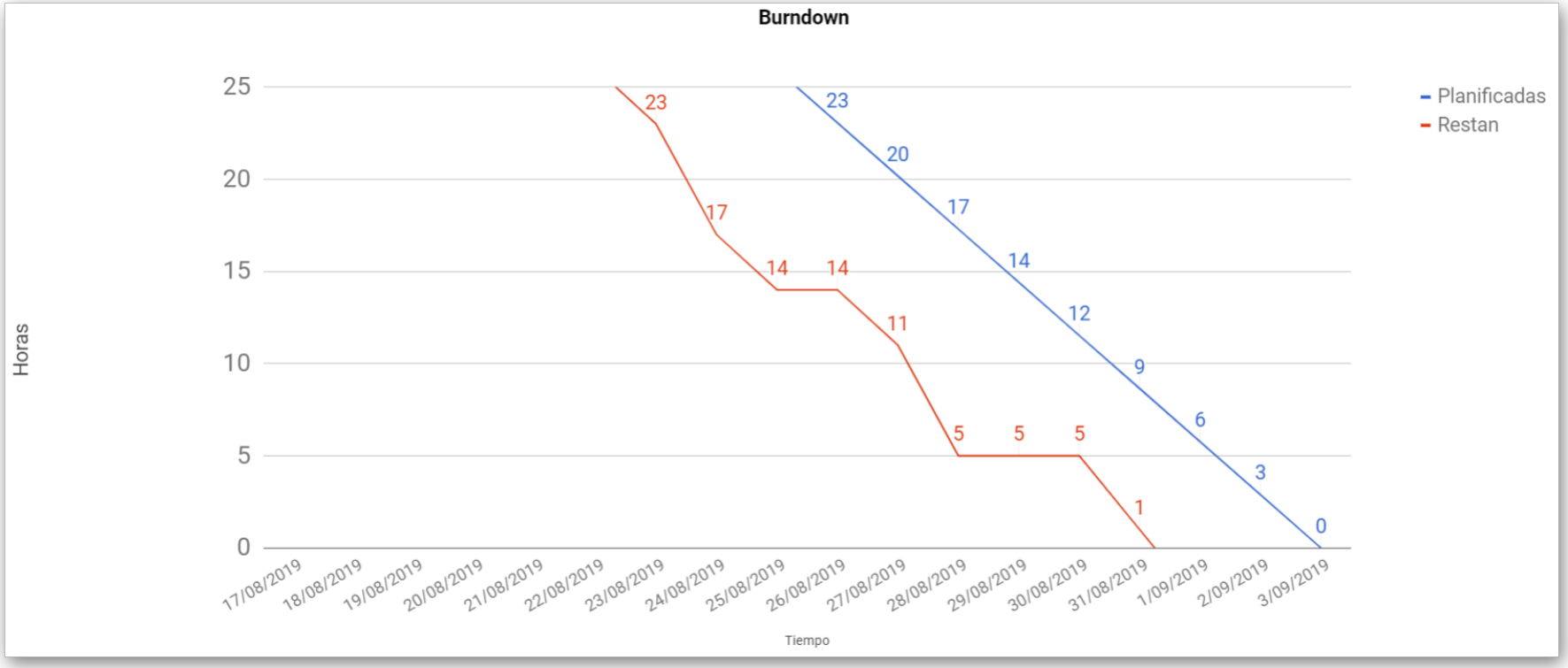


Figure 4.3: Burndown Chart of the task to be performed in August 2019

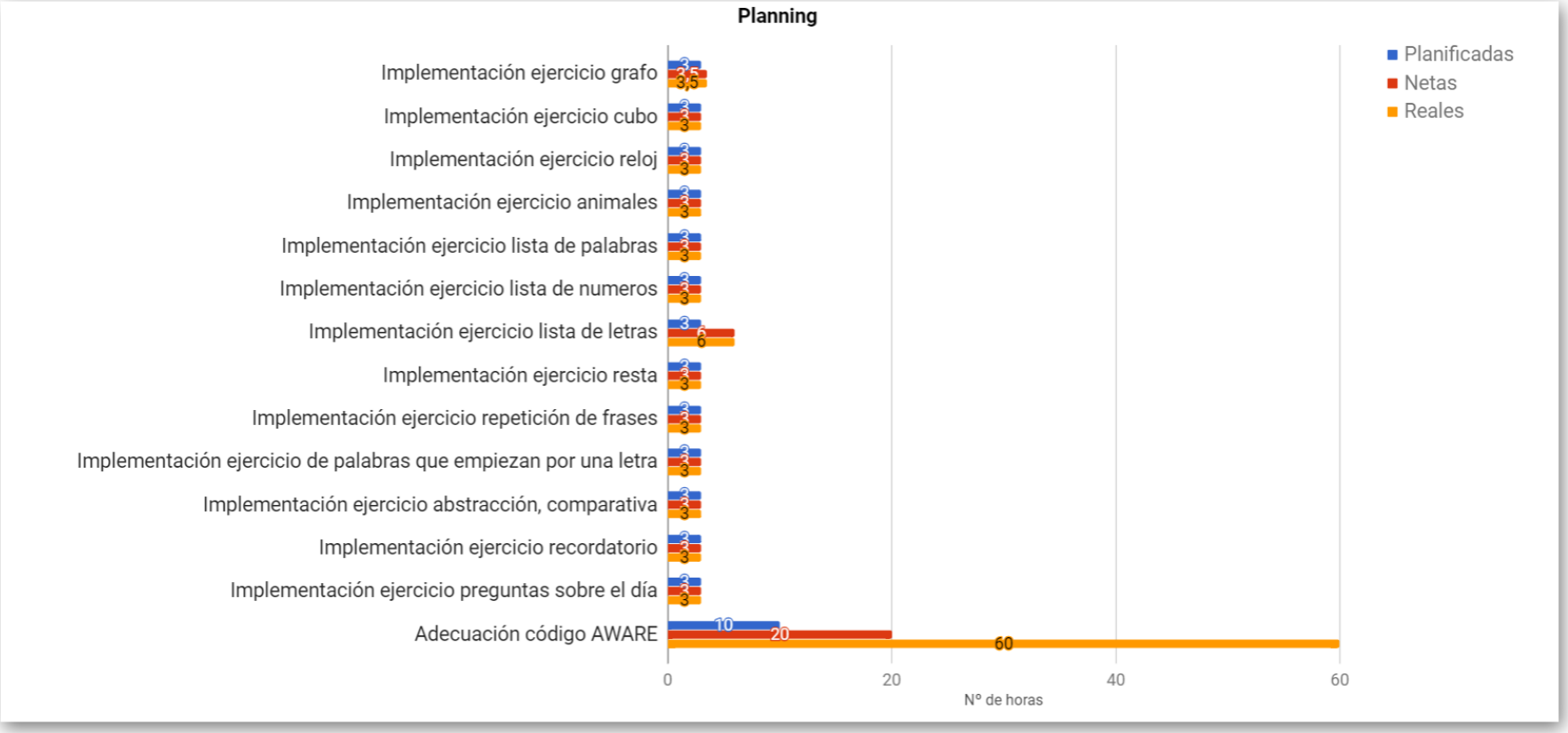


Figure 4.4: Chart Planning of the tasks to be performed in August 2019

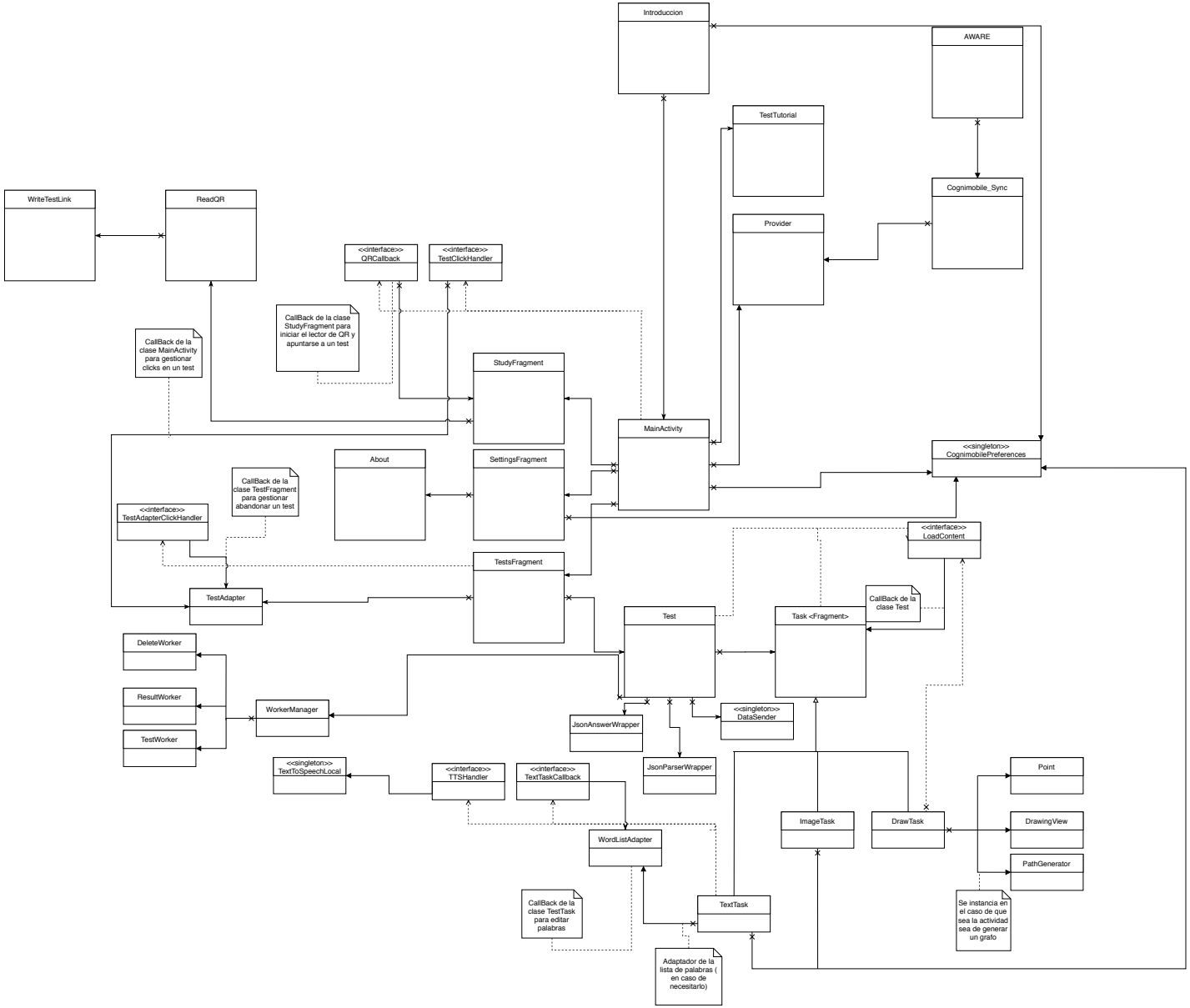


Figure 4.5: Class diagram [29]

Finally, a state diagram was defined describing the different scenarios of the app.

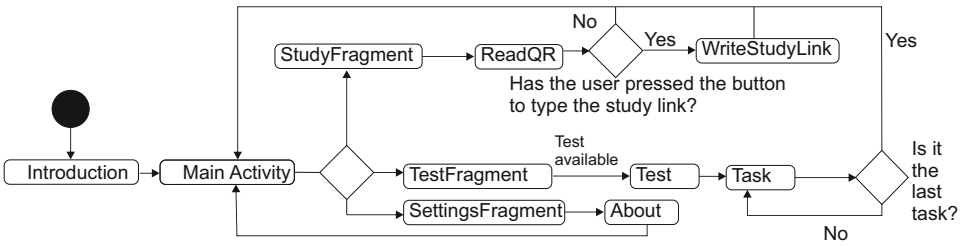


Figure 4.6: State diagram

Android is characterized for using activities, which represent a single module with some logic and a user interface. In the case of Cognimobile there are 6 activities:

- "Introduction", which is about introducing the program to the user, with various animations of what the application is about.

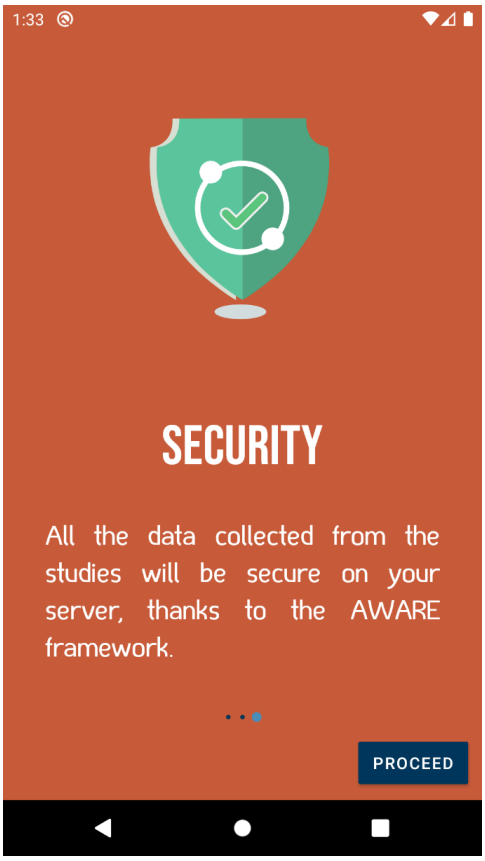
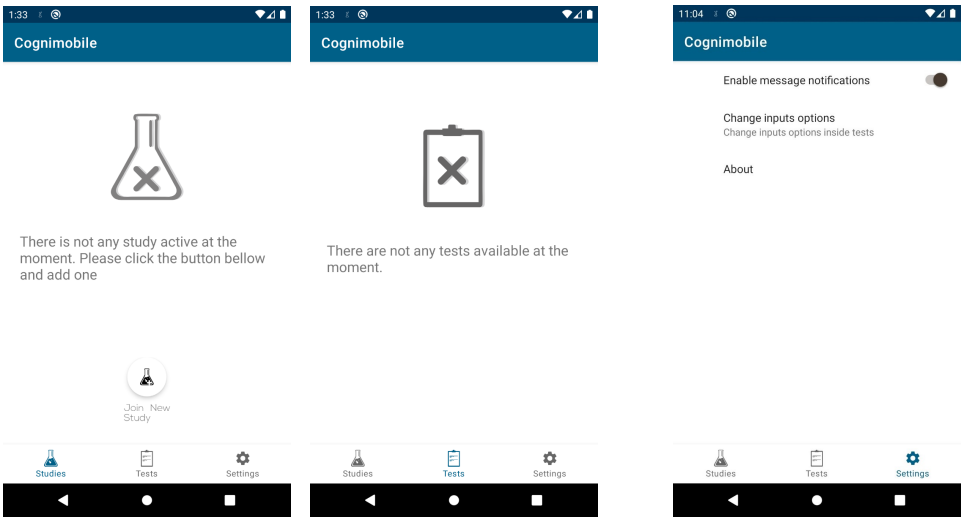


Figure 4.7: Sample of activity "Introduction"

- “MainActivity“ encompassing three different sections: the enlisted study screen, the screen of available cognitive tests and application settings.



(a) Study section **(b)** Tests section **(c)** Settings section

Figure 4.8: Sample of the different sections in “MainActivity“

- “ReadQR“: allows to read a QR code to enrol in a study, it is contained in the enlisted study section. This option is only available if you are not in a enlisted study.
- “WriteStudyLink“: allows to manually enter the study link, this is contained by the previous section.
- “Test“: Displays the test that the user has chosen in the section of the cognitive tests available for the user to complete.
- “About“: a screen that shows the “about“ app.

When starting for the first time, the user is given the option to be trained with an interactive tutorial on how the tests will be performed.

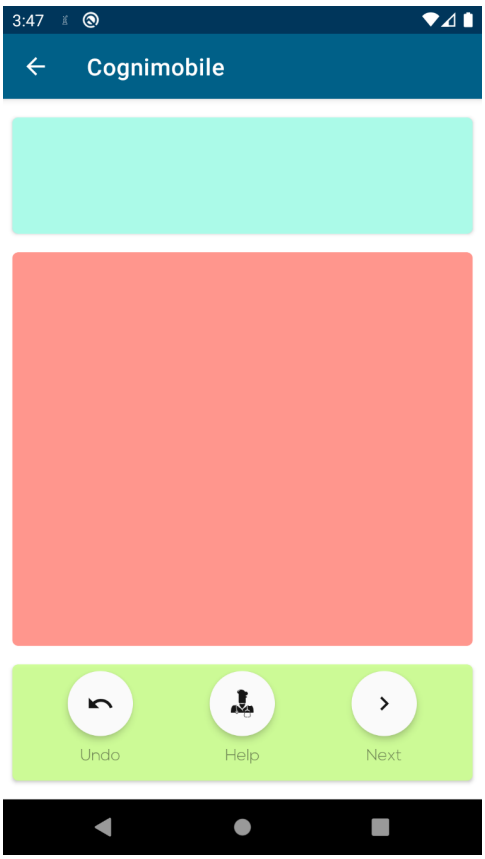
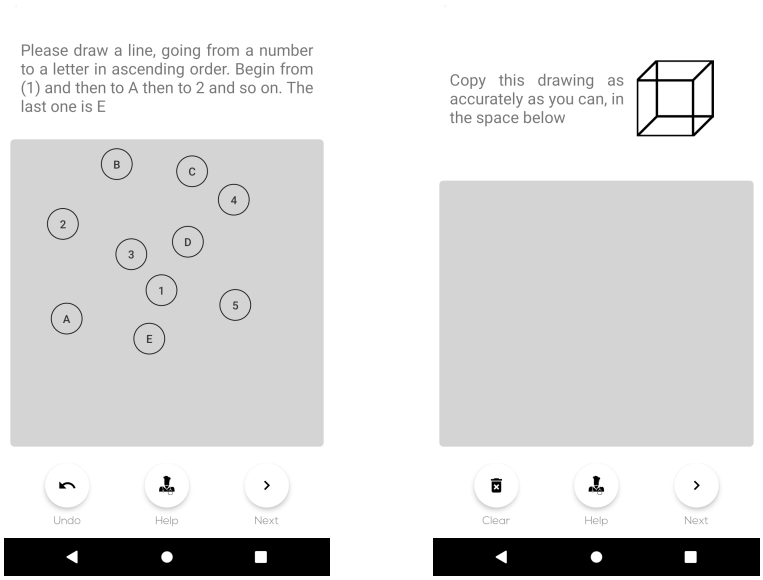


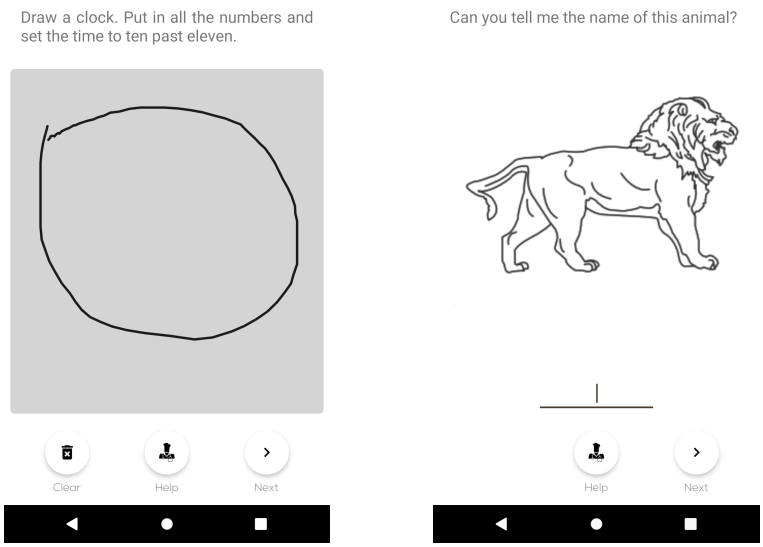
Figure 4.9: Sample of the tutorial

Test tasks are divided into three parts; in the top blue a fixed instruction is indicated on what to do in the exercise. The red middle is used to perform the task and finally the bottom contains the control buttons: the left is the undo button that is only available in certain exercises, the middle button is the help button that activates a more explicit animation of how to do the exercise and the right button is the button to continue to the next task. As stated above, the layout has been designed resembling the paper version:



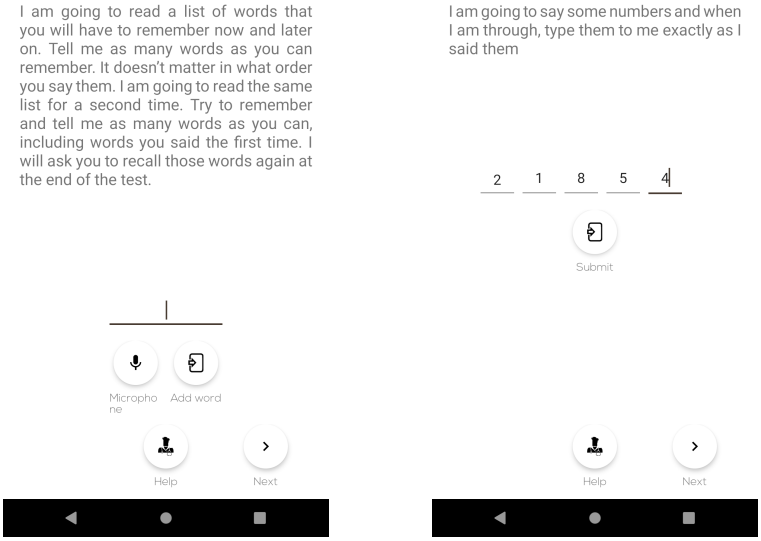
(a) Alternating Trail Making **(b)** Visuoconstructional Skills (Cube)

Figure 4.10: Sample of tasks: Alternating Trail Making y Visuoconstructional Skills (Cube).



(a) Visuoconstructional Skills (Clock) **(b)** Naming

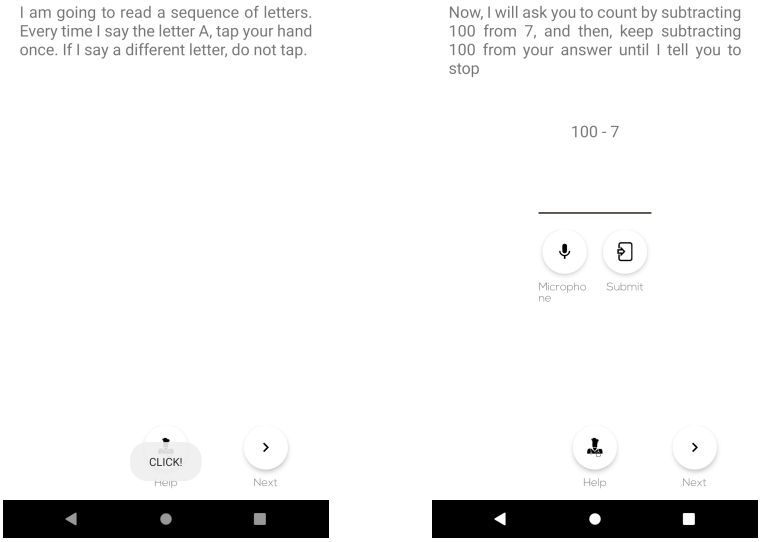
Figure 4.11: Sample of tasks: Visuoconstructional Skills (Clock) y Naming.



(a) Memory

(b) Attention (Forward digit span and backward digit span)

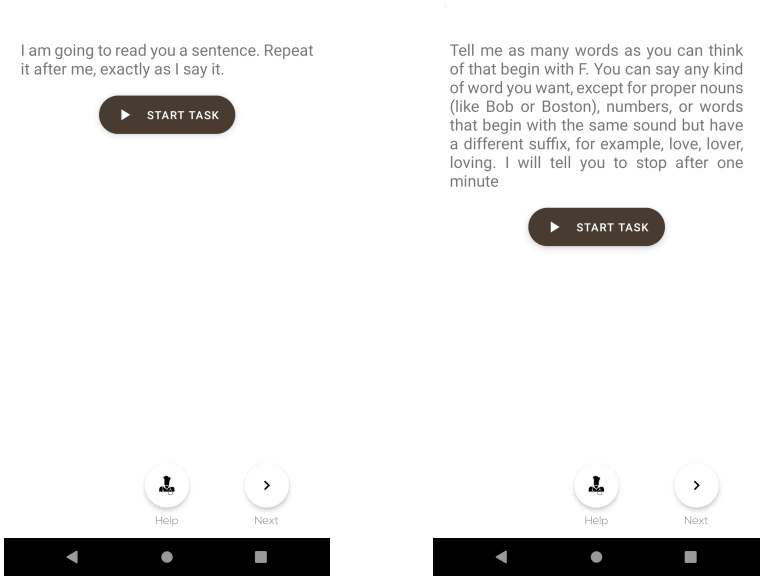
Figure 4.12: Sample of tasks: Memory y Attention (Forward digit span and backward digit span).



(a) Attention (Vigilance)

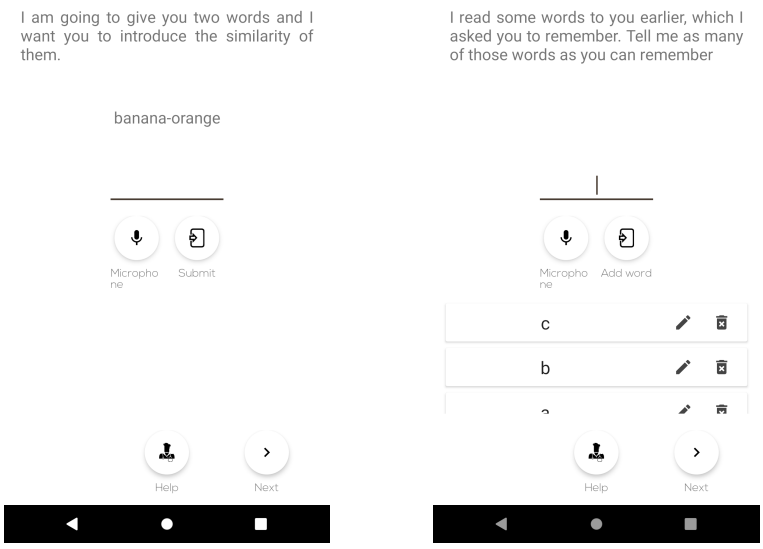
(b) Attention (Serial 7's)

Figure 4.13: Sample of tasks: Attention (Vigilance) y Attention (Serial 7's).



(a) Sentence repetition **(b)** Verbal fluency)

Figure 4.14: Sample of tasks: Sentence repetition y Verbal fluency.



(a) Abstraction **(b)** Delayed recall

Figure 4.15: Sample of tasks: Abstraction y Delayed recall.

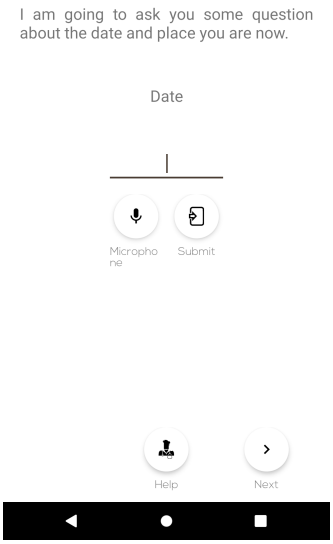


Figure 4.16: Sample of task: Orientation

As shown in the different screenshots, the original black and white printed version has been transformed into attractive display which can make it more appealing for the user when doing the tasks, but not with disruptive colours that can change the patient's mood [30]. After each test is performed, the resulting data and user interactions are sent in JSON format. They are stored using the following structure, where "data" is in JSON format.

	Field	Type	Null	Key	Default	Extra
1	_id	int(11)	NO	PRI	NULL	auto_increment
2	timestamp	double	YES	MUL	0	
3	device_id	varchar(150)	YES			
4	data	json	YES		[]	

Table 4.1: SQL table structure in "Aware-micro"'

Along with the cognitive test results, user's contextual data are collected and sent. The names of the events in the Java programming language have been referenced for notation. They are classified into two categories, "Generic" that are captured in all tasks and "Specific" that is only captured in certain tasks as flows:

Event	Description
GenericTimeHelp	Captures the push time of the help button
GenericTimeBeforeTask	Captures the time before the task begins (in case the user has to hit “start task“)
GenericTimeStartTask	Captures the start time of the task
GenericTimeEndTask	Captures task completion time
GenericTimeNextTask	Captures the click time of the next button
GenericSkippedTask	Captures if the user has decided not to do the task
SpecificATMTimeBetweenClicks	Captures the time between keystrokes of the graph buttons
SpecificATMAlreadyClickedButton	Captures the keystrokes of the buttons already pressed on the graph
SpecificATMPoints	Captures the coordinates of the points in the drawing
SpecificATMDistanceBetweenCircles	Captures the distance between the buttons that the user presses
SpecificVSCubeStartDraw	Captures the coordinates of the user’s stroke start in the drawing
SpecificVSCubeEndDraw	Captures the coordinates of the end of the user’s stroke in the drawing
SpecificVSCubePoints	Captures the coordinates of the points in the drawing
SpecificVSClockStartDraw	Captures the coordinates of the user’s stroke start in the drawing
SpecificVSClockEndDraw	Captures the coordinates of the end of the user’s stroke in the drawing
SpecificVSClockPoints	Captures the coordinates of the points in the drawing

Event	Description
SpecificNamingCharacterChange	Captures the characters entered by the user
SpecificNamingStartWriting	Captures the time the user starts typing
SpecificNamingSubmitAnswer	Captures the time the user finishes typing
SpecificMemoryCharacterChange	Captures the characters entered by the user
SpecificMemoryScrollingList	Captures the initial time the user scrolls through the list
SpecificMemorySettlingList	Captures the end time when the user has scrolled through the list
SpecificMemoryStartWriting	Captures the time the user starts typing
SpecificMemorySubmitAnswer	Captures the time the user finishes typing
SpecificAttentionNumbersItemPosition	Captures the position of the number that the user has filled in
SpecificAttentionNumbersStartWriting	Captures the time the user starts typing
SpecificAttentionNumbersItemPositionBackwards	Captures the position of the number that the user has filled in
SpecificAttentionNumbersSubmitAnswer	Captures the time the user finishes typing
SpecificAttentionLettersTimeToAnswer	Captures when the user has tapped the screen
SpecificAttentionLettersSoundTimes	Captures when the letter has been played
SpecificSubtractionCharacterChange	Captures the characters entered by the user
SpecificSubtractionStartWriting	Captures the time the user starts typing
SpecificSubtractionSubmitAnswer	Captures the time the user finishes typing
SpecificSRCharacterChange	Captures the characters entered by the user
SpecificSRStartWriting	Captures the time the user starts typing
SpecificSRSubmitAnswer	Captures the time the user finishes typing

Event	Description
SpecificFluencyCharacterChange	Captures the characters entered by the user
SpecificFluencyScrollingList	Captures the initial time the user scrolls through the list
SpecificFluencySettlingList	Captures the end time when the user has scrolled through the list
SpecificFluencyStartWriting	Captures the time the user starts typing
SpecificFluencySubmitAnswer	Captures the time the user finishes typing
SpecificAbstractionCharacterChange	Captures the characters entered by the user
SpecificAbstractionStartWriting	Captures the time the user starts typing
SpecificAbstractionSubmitAnswer	Captures the time the user finishes typing
SpecificRecallCharacterChange	Captures the characters entered by the user
SpecificRecallScrollingList	Captures the initial time the user scrolls through the list
SpecificRecallSettlingList	Captures the end time when the user has scrolled through the list
SpecificRecallStartWriting	Captures the time the user starts typing
SpecificRecallNumbersOfWords	Captures the number of words the user has typed
SpecificRecallNumbersOfCorrectWords	Captures the number of words the user has entered correctly
SpecificRecallSubmitAnswer	Captures the time the user finishes typing
SpecificOrientationCharacterChange	Captures the characters entered by the user
SpecificOrientationStartWriting	Captures the time the user starts typing
SpecificOrientationSubmitAnswer	Captures the time the user finishes typing

Table 4.2: List of events and data captured by Cognimobile App

In the unlikely event that the user has not been able to send the data because was disconnected from the network, the application has a mechanism to send them as soon as it has an unmetered network, with no data limit. This is made possible by the “PeriodicWorkRequest“ [31] class, which allows to develop periodic tasks on Android with relative ease.

The class accepts a number of constraints to trigger this action, such as running as soon as it connects to an unmetered network. For different components the “singleton“ pattern has been used to try to avoid different instances of a single component. This is the case of “DataSender“ and “TextToSpeechLocal“.

When viewing the data, the expert advisor will use the Cognimobile dashboard. This board has been developed with the help of the Laravel framework, allowing rapid development and deployment. This framework bases the architecture of projects on the Model-View-Controller architecture style, allowing an organization of its components for proper project maintenance. This board is based on the “LaravelDaily“ [32] version, where it houses a template to develop web projects by combining Laravel with “CoreUI“, as discussed earlier in the section.

Laravel©allows to create components easily with a command manager called “artisan“. It allows the deployment of the project with the following command:

```
Php artisan serve
```

This command deploys the project to the ip entered in the “.env“ configuration file. It divides its components into various categories. The Cognimobile Dashboard elements are divided into:

- Model: Laravel has several ways to work with the database, directly querying or using migrations. Migrations is a type of versioning, but on-the-back. This allows different components of a team to work without being aware of the database itself, but from its migrations. These migrations work in turn with models. These models are classes that abstract data from a certain table, assigning them CRUD methods.
- Views: Laravel uses the default “Blade“ template engine, making it easier for the developer not to enter code in the view.

- Drivers: The logic that are executed by the user to interact with the views or when introducing certain links.
- Routers: Rules that allow to use drivers or other components when the user accesses a network address. For example, as soon as the user logs in the “Cognimobile Dashboard“ it is redirected to “admin/index“ which in turn uses the controller “ResultController“ to display the results sent by users when using the mobile app and complete cognitive tests.

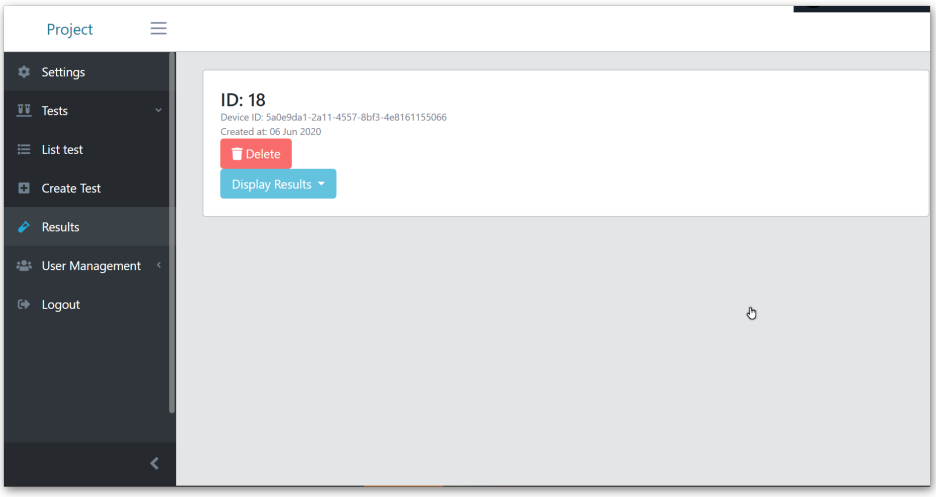


Figure 4.17: Sample of the dashboard, on the home page

Javascript was used to unravel test results. Showing the following.

[0]For additional information, see:`https://laravel.com/docs/7.x/blade`

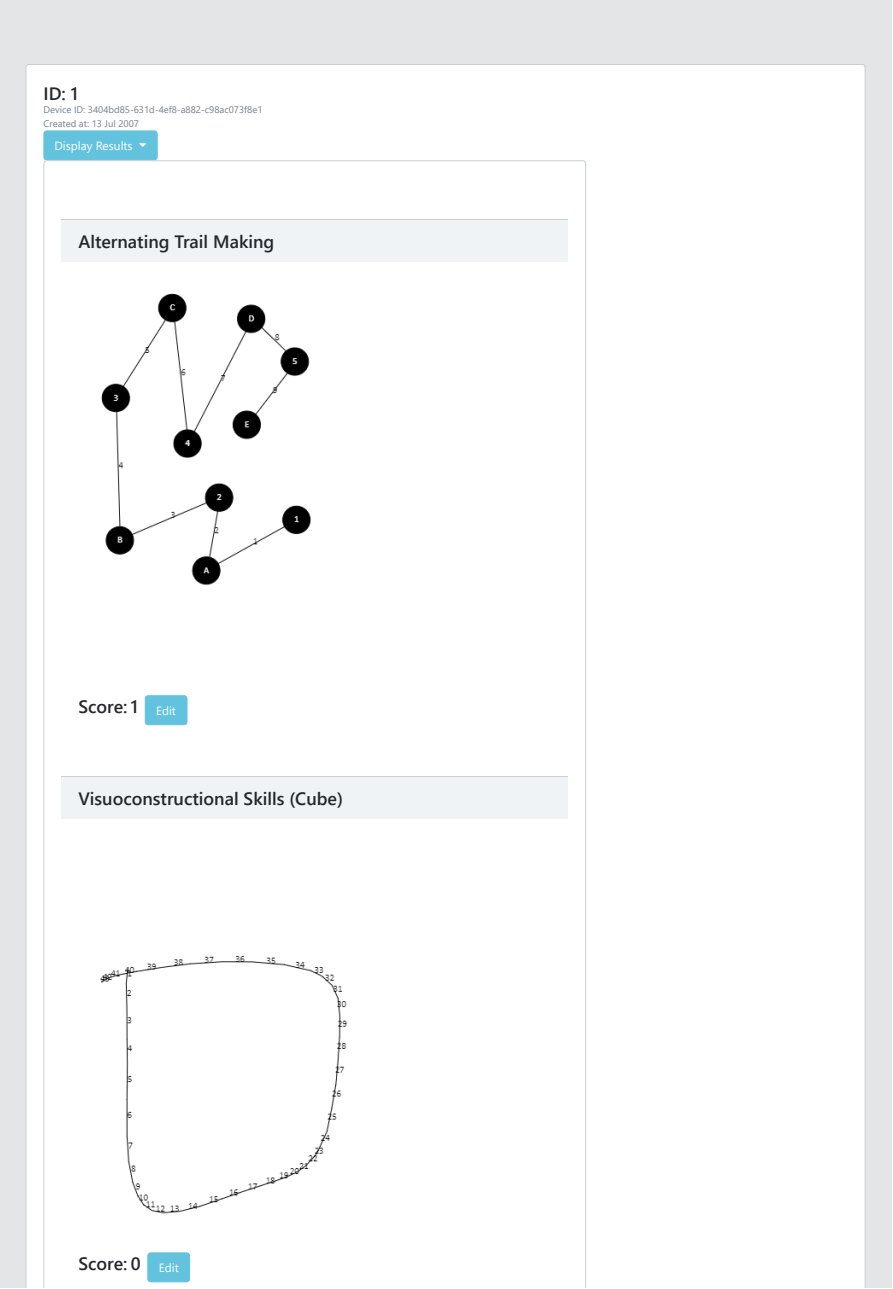


Figure 4.18: Sample of the dashboard, on the sample page of the results

Another section of the board is the creation of tests, introduced as another objective to complete in this project. This web interface makes easy for the expert the creation of a cognitive test, facilitating the cor-

rect JSON formatting, avoiding possible errors when the mobile has to read it.

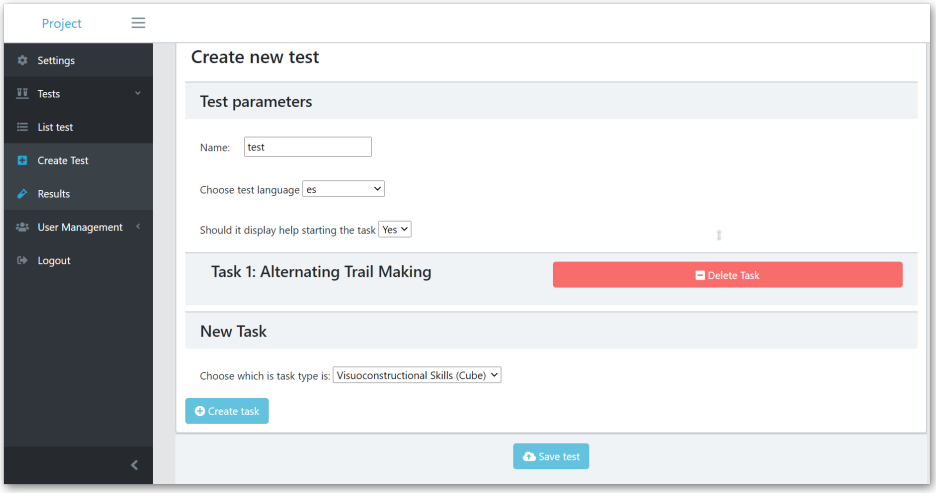


Figure 4.19: Sample of the dashboard, on the test creation page

The last purpose of the dashboard is the dynamic configuration of the AWARE server by changing the study name and its parameters. This makes the study configuration easier, allowing the expert organization to configure which name and description use when the user joins into the study, which “plugins“ and sensors to enable and further configuration such as the frecuency of the accelerometer, how often checks the network, etc.

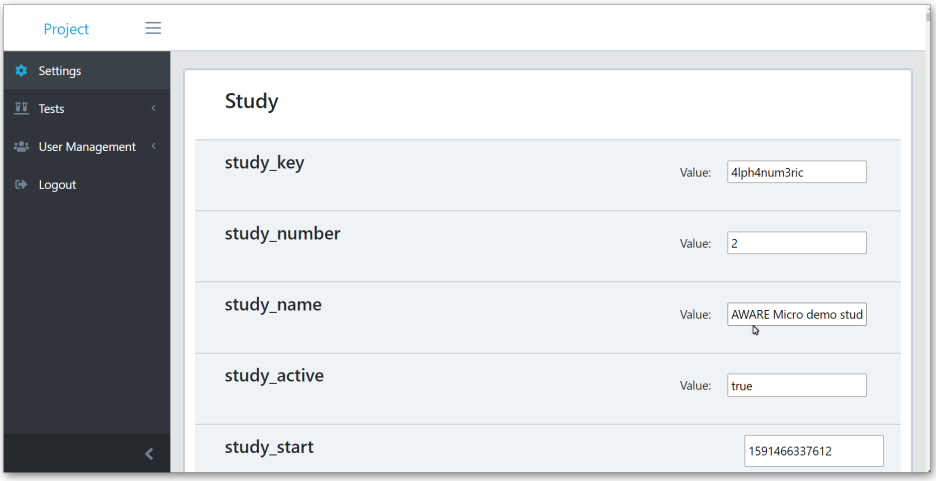


Figure 4.20: Sample of the dashboard, on the configuration AWARE-based server page

Chapter 5

Results and discussion

This chapter details the usability of the project which implementation has been described in the Implementation chapter. Below is discussed the tools used to measure usability, the results of the project and the conclusions drawn from this data.

5.1 Study description

The System Usability Scale has been used to define the usability of the project. The System Usability Scale is a questionnaire that allows for the usability evaluation of the system by answering a list of ten questions:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

The effectiveness of this test has been tested on many occasions, being a clear reference when checking the usability of a product [33] [34].

The following formula is used to evaluate the obtained data:

- The sum of the values:

  Five minus the value of the even questions.

  The value of odd questions minus one.

- Multiplied by 2,5.

This is summarized in this formula:

$$SUSScore = 2.5 \times \sum_{n=1}^{10} \left(\left(\frac{2n}{n} \in \mathbb{Z} \right) \rightarrow (5 - S_n) \right) \wedge \left(\left(\frac{2n+1}{n} \in \mathbb{Z} \right) \rightarrow (S_n - 1) \right)$$

Figure 5.1: The System Usability Scale formula

To complete with more data, some additional questions have been added to the test, with their possible answers:

- Gender question:

  Female or Male.

- Age range question:

  18-30, 30-45, 45-60, >=60.

- Internet experience:

  Low, Medium, Advanced.

- Technology experience: PC (Windows), PC (MAC/Linux), Mobile (Android), Mobile (IOS/Nokia/Windows), Tablet.

  Low/none, Sometimes, Usually, Daily.

The purpose of the study is to check if the application is usable for people who do not yet have any cognitive impairment, but who in the future may have it and for potential family members who could help guiding in the use of the application, in case the study subject needs help.

The test has been performed on 24 people. Most people were 45 years

of age or younger, 66.6% (16), of whom 33% (8) were in the range of "18-30" years. In the age range "45-60" has been the 20.8% (5) and ">60" 12.5% (3). All the demographic information about the participants are in Demographic data.

5.2 Results

5.2.1 Usability Test

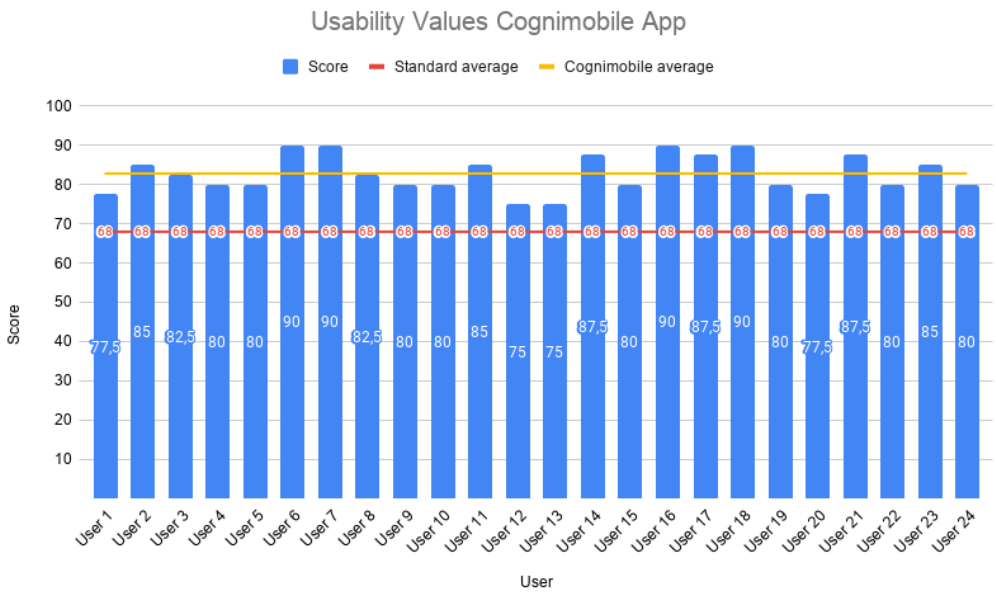


Figure 5.2: The System Usability Scale results

As it can be observed in Figure 5.2, the blue bars are the scores obtained by the users, the yellow line is the average mean of scores of the users and the red line is the limit of that every good application should have.

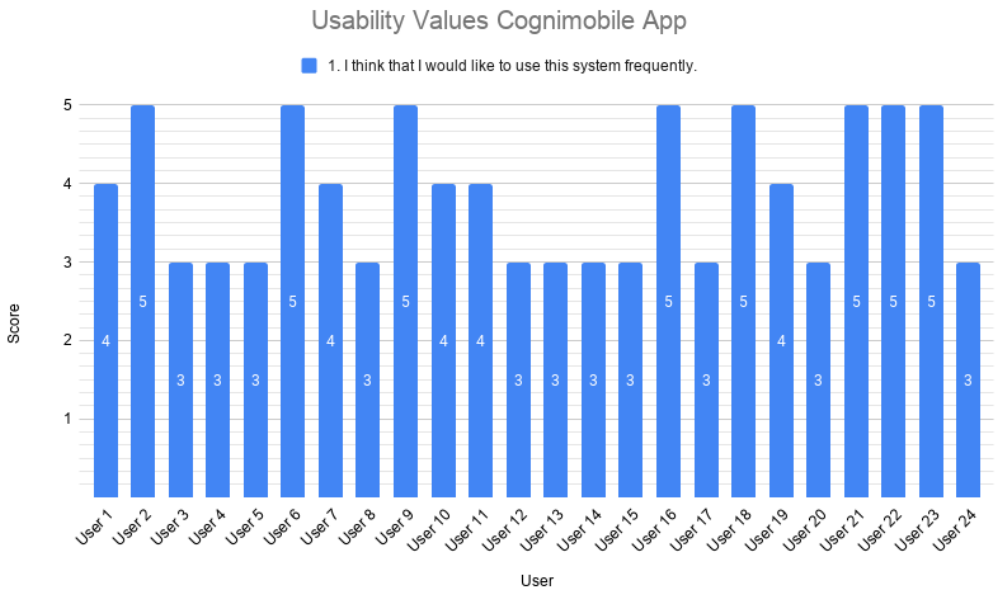


Figure 5.3: Sample of the question number 1

As it can be observed in Figure 5.3, the blue bars are the scores obtained by the users in the first question. The number of the question is odd, so the higher the score, the better. 62% percent of the total users think that they would use the mobile app frequently.

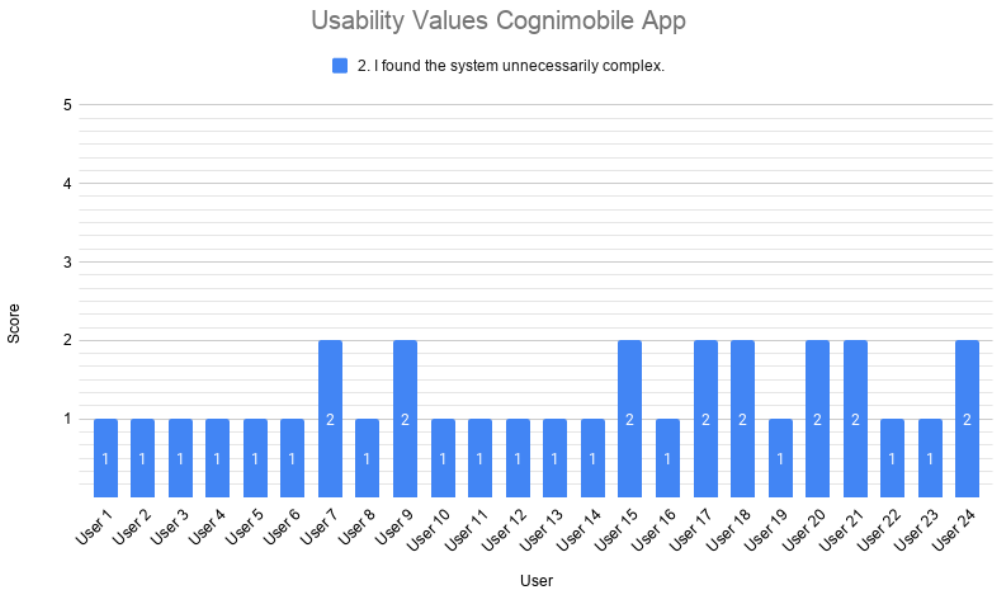


Figure 5.4: Sample of the question number 2

As it can be observed in Figure 5.4, the blue bars are the scores obtained by the users in the second question. The number of the question is even, so the lower the score, the better. 67% percent of the total users think that the system was not unnecessary complex.

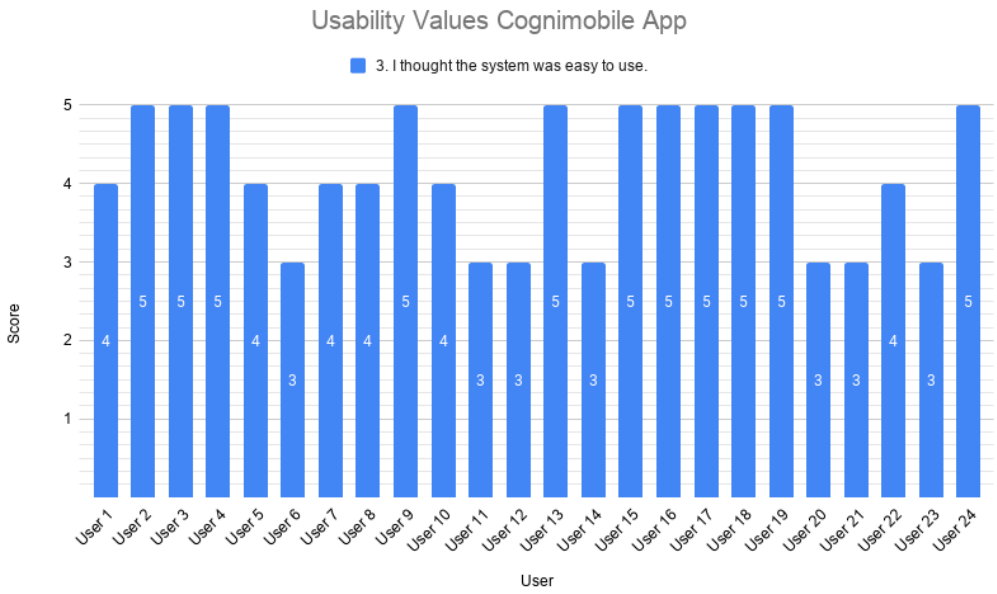


Figure 5.5: Sample of the question number 3

As it can be observed in Figure 5.5, the blue bars are the scores obtained by the users in the third question. The number of the question is odd, so the higher the score, the better. 70,8% percent of the total users think that the system was easy to use.

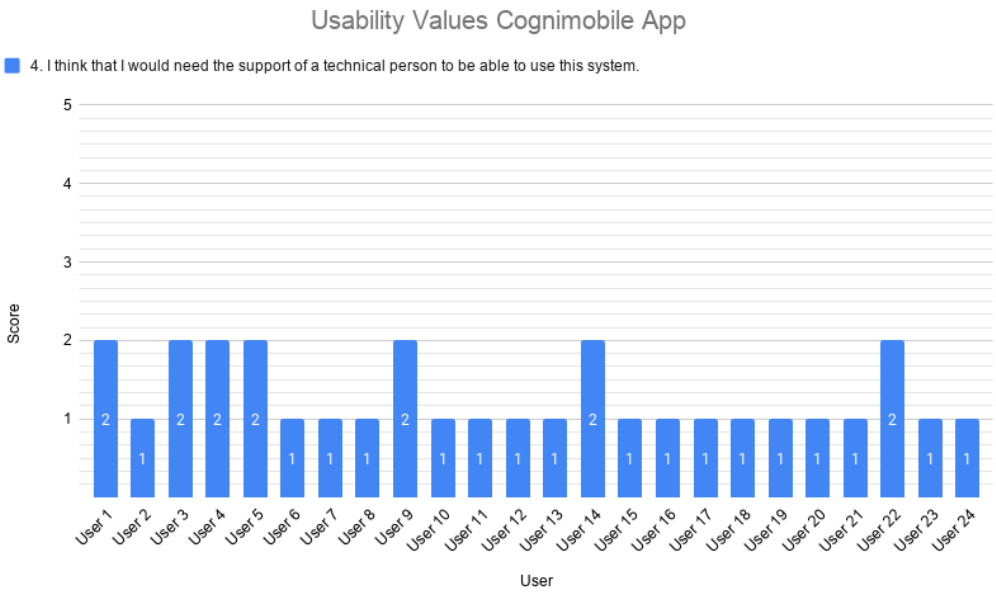


Figure 5.6: Sample of the question number 4

As it can be observed in Figure 5.6, the blue bars are the scores obtained by the users in the fourth question. The number of the question is even, so the lower the score, the better. 70,8% percent of the total users think that they would not require support to use the mobile app.

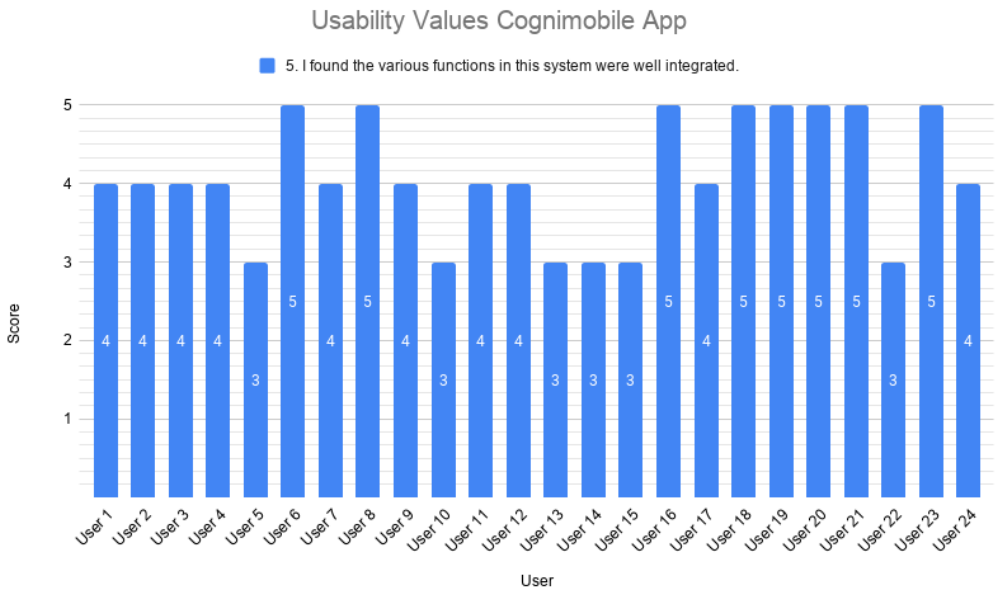


Figure 5.7: Sample of the question number 5

As it can be observed in Figure 5.7, the blue bars are the scores obtained by the users in the fifth question. The number of the question is odd, so the higher the score, the better. 75% percent of the total users think that the system functions are well integrated.

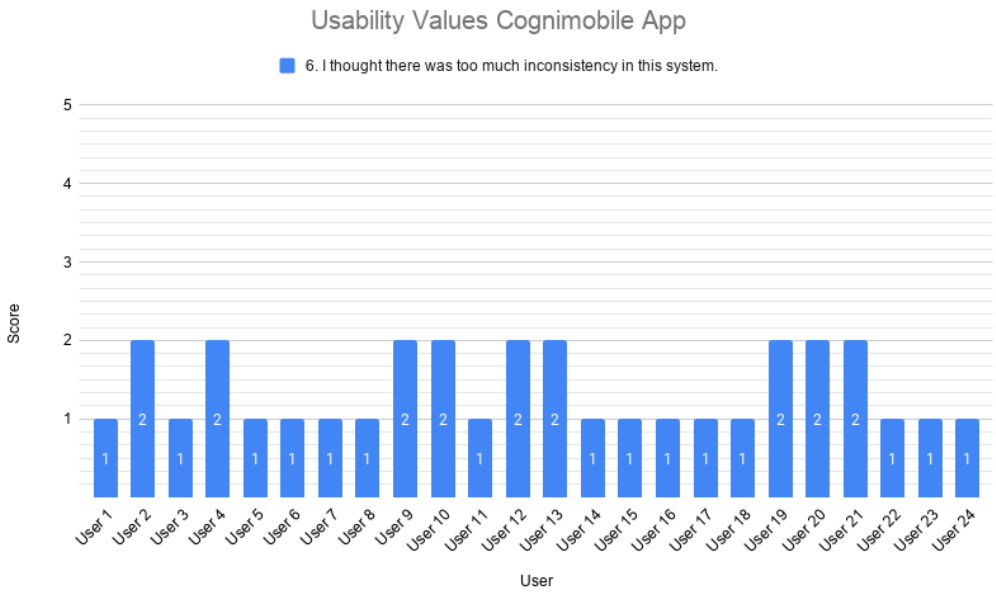


Figure 5.8: Sample of the question number 6

As it can be observed in Figure 5.8, the blue bars are the scores obtained by the users in the sixth question. The number of the question is even, so the lower the score, the better. 62,5% percent of the total users think that the system does not have inconsistency.

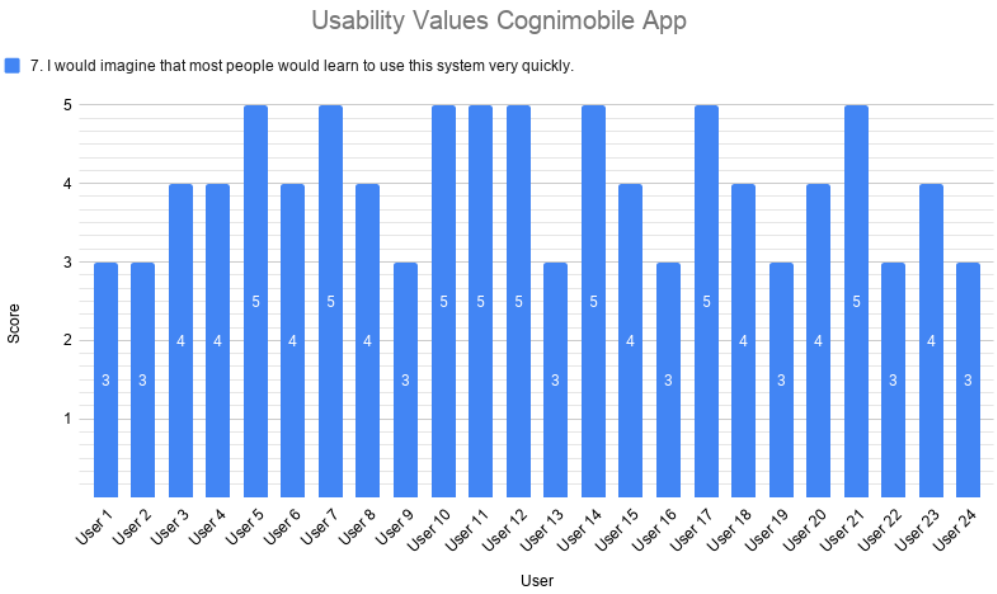


Figure 5.9: Sample of the question number 7

As it can be observed in Figure 5.9, the blue bars are the scores obtained by the users in the seventh question. The number of the question is odd, so the higher the score, the better. 67% percent of the total users think that the system is very intuitive.

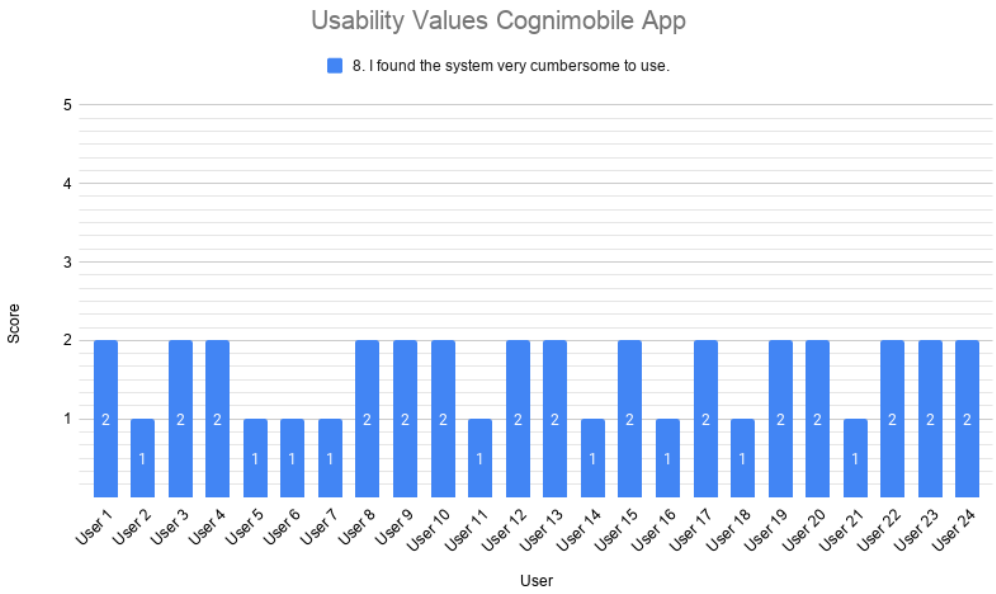


Figure 5.10: Sample of the question number 8

As it can be observed in Figure 5.10, the blue bars are the scores obtained by the users in the eighth question. The number of the question is even, so the lower the score, the better. 37,5% percent of the total users think that the system was not cumbersome at all.

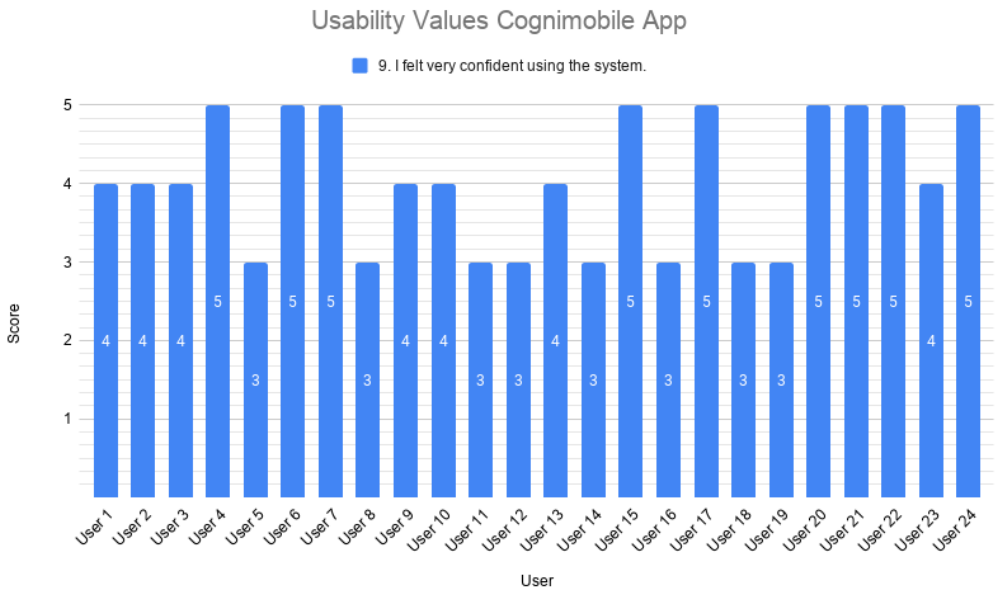


Figure 5.11: Sample of the question number 9

As it can be observed in Figure 5.11, the blue bars are the scores obtained by the users in the nineth question. The number of the question is odd, so the higher the score, the better. 67% percent of the total users think that they are confident using the system.

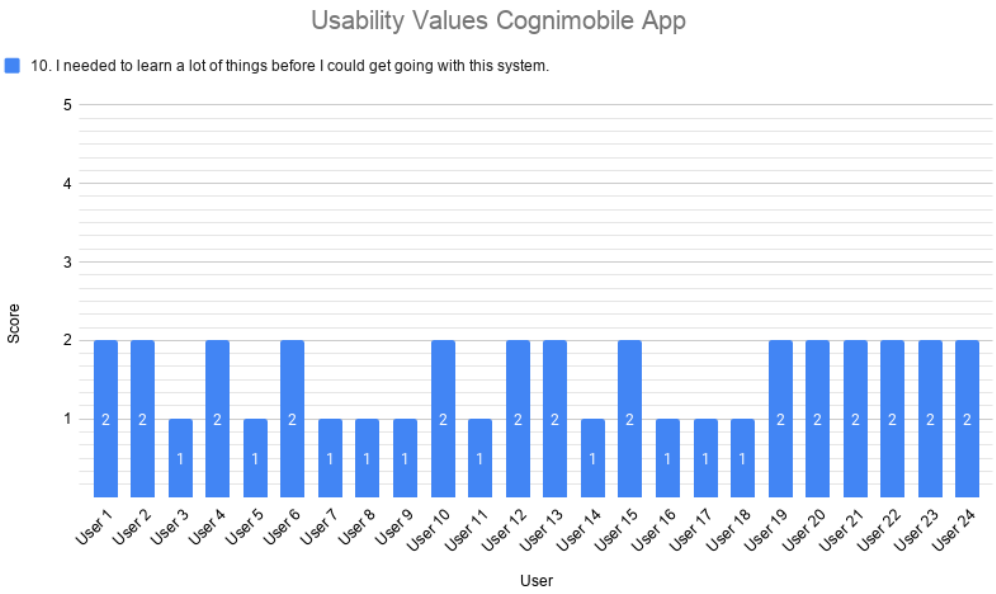


Figure 5.12: Sample of the question number 10

As it can be observed in Figure 5.12, the blue bars are the scores obtained by the users in the tenth question. The number of the question is even, so the lower the score, the better. 41,7% percent of the total users think that they do not need to learn at all to use the system.

5.2.2 Demographic data

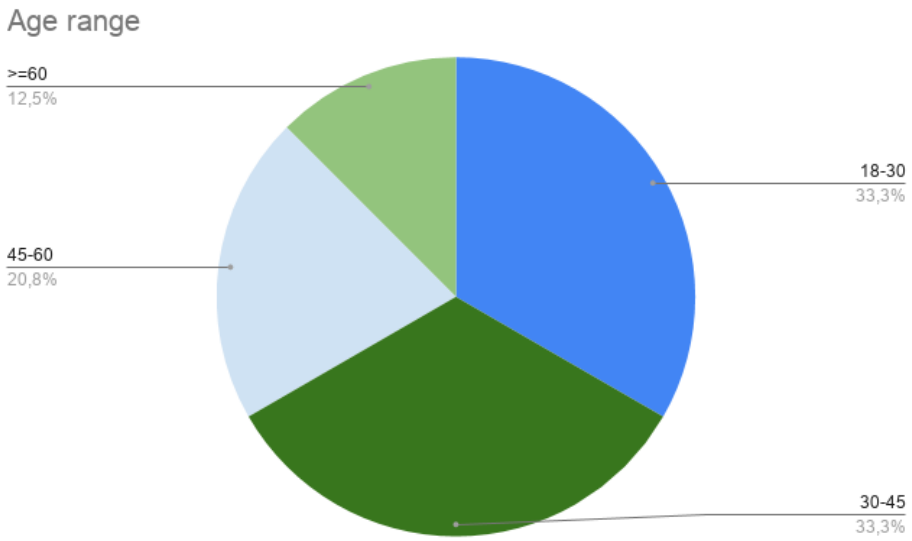


Figure 5.13: Participants' age range

As it can be observed in Figure 5.13, 66,6% percent of the total users age is in a range of 18-45 years old.

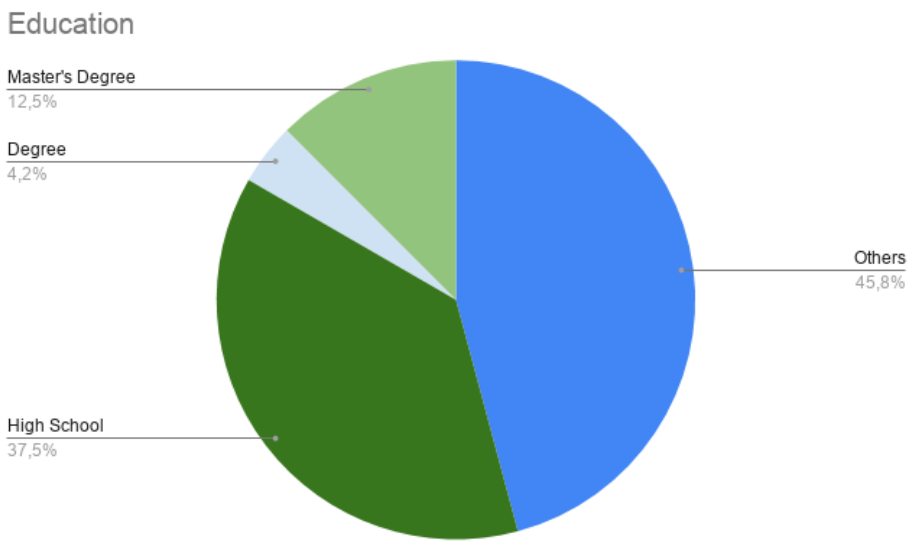


Figure 5.14: Participants' education

As it can be observed in Figure 5.14, 16,7% percent of the total users

education have completed a degree.

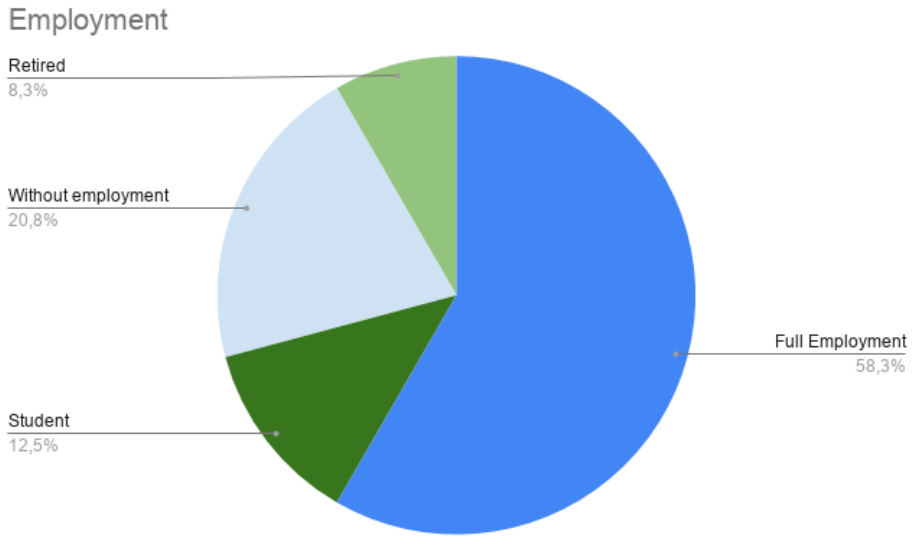


Figure 5.15: Participants' employment

As it can be observed in Figure 5.15, 58,3% percent of the total users have a full employment.

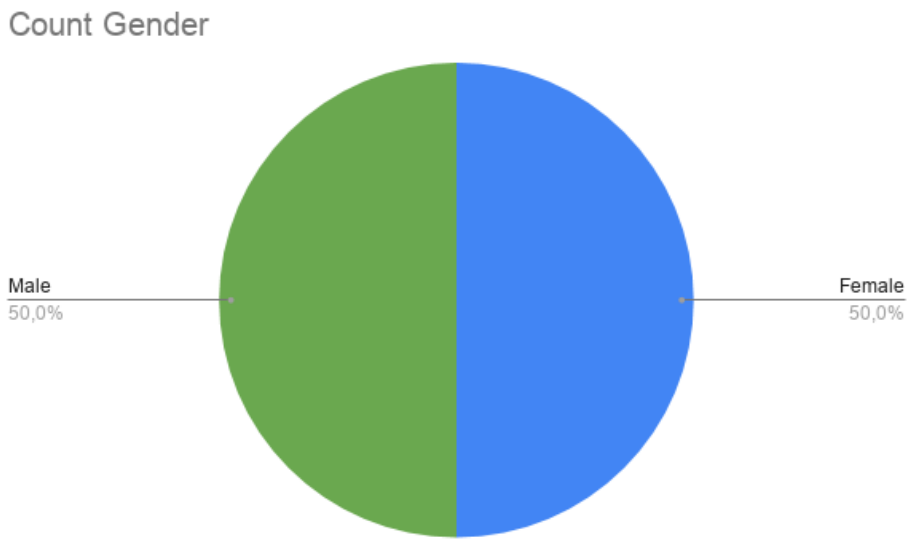


Figure 5.16: Participants' gender

As it can be observed in Figure 5.16, half of the total users are male

and the other half are males.

5.2.3 Technology usage data

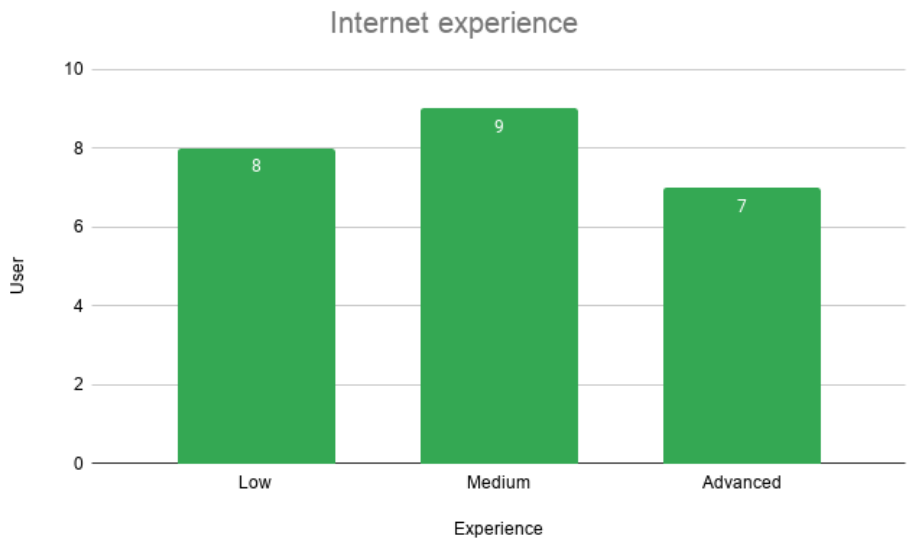


Figure 5.17: Count of participants' Internet usage

As it can be observed in Figure 5.17, 66,7% percent of the total users has a medium or above internet experience.

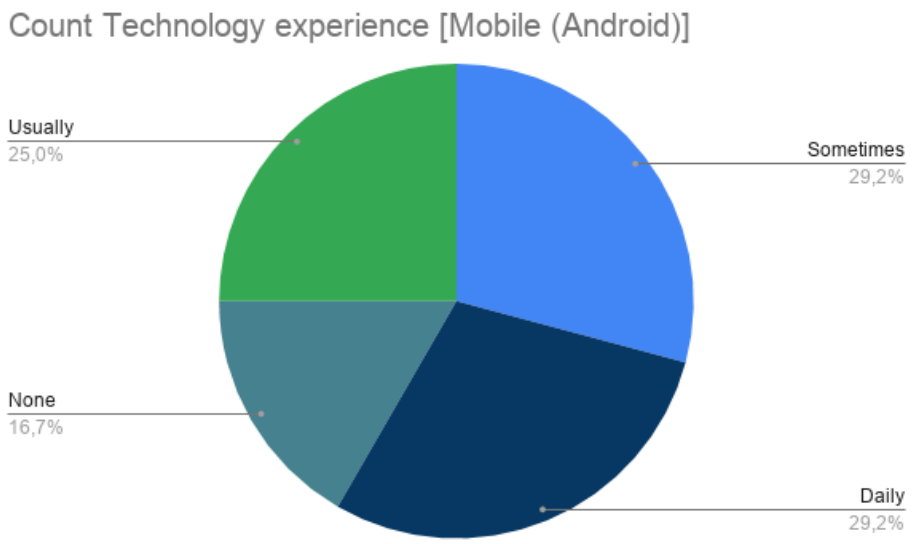


Figure 5.18: Count of participants' Android mobile usage

As it can be observed in Figure 5.18, 54,2% percent of the total users uses the mobile phone (android) usually or daily.

5.3 Statistical analysis

A statistical study has been conducted using Pearson's Chi Square formula, to analyse the possible correlation of SUS test scores with the technological use of the Internet and smartphones with the Android operating system.

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Internet * Score	24	100,0%	0	,0%	24	100,0%

Internet * Score Crosstabulations

			Score			Total
			POOR	GOOD	EXCELLENT	
Internet	Low	Count	0	4	3	7
		% within Score	,0%	44,4%	21,4%	29,2%
	Medium	Count	0	3	6	9
		% within Score	,0%	33,3%	42,9%	37,5%
	Advanced	Count	1	2	5	8
		% within Score	100,0%	22,2%	35,7%	33,3%
Total		Count	1	9	14	24
		% within Score	100,0%	100,0%	100,0%	100,0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3,514[a]	4	,476
Likelihood Ratio	3,681	4	,451
Linear-by-Linear Association	,032	1	,858
N of Valid Cases	24		

a. 8 cells (88,9%) have expected count less than 5. The minimum expected count is ,29.

Figure 5.19: Studying score with Internet use

As it can be observed in Figure 5.20, the p-value is not significant and therefore it cannot be assured that there is a direct correlation of internet experience and the usability score.

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Android * Score	24	100,0%	0	,0%	24	100,0%

Android * Score Crosstabulations

			Score			Total
			POOR	GOOD	EXCELLENT	
Android	Low/none	Count	1	2	2	5
		% within Score	100,0%	22,2%	14,3%	20,8%
	Sometimes	Count	0	0	5	5
		% within Score	,0%	,0%	35,7%	20,8%
	Usually	Count	0	5	4	9
		% within Score	,0%	55,6%	28,6%	37,5%
	Daily	Count	0	2	3	5
		% within Score	,0%	22,2%	21,4%	20,8%
Total		Count	1	9	14	24
		% within Score	100,0%	100,0%	100,0%	100,0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8,550[a]	6	,200
Likelihood Ratio	9,458	6	,149
Linear-by-Linear Association	,668	1	,414
N of Valid Cases	24		

a. 11 cells (91,7%) have expected count less than 5. The minimum expected count is ,21.

Figure 5.20: Studying the score with the use of smartphones with the Android operating system

As it can be observed in Figure 5.21, the p-value is not significant and therefore it cannot be assured that there is a direct correlation of mobile phone experience (android) and the usability score.

5.4 Discussion

The values obtained with the formula show that the average mean (yellow line) is higher (82,8125), than the mean (red line) of what is considered a product with acceptable usability (68) [35].
This project has been reviewed by some international experThe System Usability Scalets and they also were invited to participate in the usabil-

ity test. The average score obtained is 87,5. This last result supports the good value of usability of the project. The following table shows the usability quality of a product, measured with values from :

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 5.21: Quality of an application according to its values in the SUS test [35]

Therefore the usability of the product would be better than expected on average, despite the majority of users (37.5%) had average Internet experience or (33.3%) lower, as indicated by Count of participants' Internet usage. The same goes for the Android smartphone experience, as less than half (41.7%) uses a little this technology, as indicated by Count of participants' Android mobile usage.

The Statistical analysis shows that the values obtained in The System Usability Scale do not have a relationship with the user's knowledge.

The study shows that the mobile app is usable by users that are not familiar with smartphones and its potential to do the remote following of patients. However, it is unclear the capacity of the mobile app to indicate the performance of the users cognitively impaired and those that are not.

Chapter 6

Conclusions and future work

6.1 Conclusions

The objective of this project is to provide a platform to support psychiatric work specialised in cognitive impairment. Cognitive decline is a problem that increasingly affects more people, due to different factors such as illness or the attrition of age itself.
Progress is being made with certain applications and platforms to generate more data and investigate the topic. Still, there is not a global platform that allows researchers to conduct their studies in a standardised way. For this reason, *Cognimobile* has been developed to provide an easy to deploy tool built on free software for further software additions or improvements from other developers.
The assessment and guidance of international experts from the Netherlands in this project, has been an invaluable contribution that has allowed for the project to be enriched with their experience, and has given me a perspective that I would not have been able to gather on my own. It has been a co-design process, where experts from *GGNet* a mental care organization in the Netherlands, were external consultants. Also, they have participated in the elicitation of the requirements allowing to design a system architecture for the mobile app, and after the implementation the testing of the tool. With the design finished, it was possible to implement the whole project: mobile app, front-end and back-end. Once the implementation was finished, both external consultants and users were able to start testing. The results have shown that the tool has a level of usability that will allow to be widely used without too much difficulty by almost any user. Although it has not been possible to prove that

previous knowledge and experience in the use of technologies gives the user an advantage to use the application. Therefore, the main goal has been completed because of the completion of the specific objectives.
Finally, I want to acknowledge the availability of open source free software tools, as they have directly influenced this project, saving me a lot of work. Quoting Richard Stallman, founder of free software,"*A citizen's duty is not to believe in any prophecy of the future, but to act to realize the best possible future.*" Thanks to this kind of mentality we all enrich and evolve, making the world a better place.

6.2 Future work

This project could be improved in the future, working on:

- An Artificial Intelligence that allows the total automation of cognitive evaluation on a test. Examples of this would be to be able to know if a drawing is done correctly or an answer to an open question is correct.
- Performing more inclusive animations, with people of different ethnicities and types.
- Adding new cognitive exercise to the set of implemented tasks.
- Developing theme customization for the platform, both the dashboard and the app.
- Comparing this application with the paper version to confirm its usefulness.

Glossary

Android Studio: Tool created by Google to develop Android projects.
RESTful API: A set of procedures that uses HTTP protocols to send and receive data.
AWARE: Open source tool created by Denzil Ferreira that allows you to use your phone as a context data generator to conduct scientific studies.
Blade: Tool that allows you to create web interfaces, respecting the Model-View-Controller pattern.
QR Code: It is the evolution of the barcode, which allows you to store information in an array.
CognimobileTracker: AWARE extension created by Jahn Wohlfahrt-Laymann that allows to administer cognitive tests based on the Mini Mental State Examination.
CoreUI: An open source tool that allows you to easily and quickly deploy a web page with an administrator interface.
CRUD: An acronym for the basic functions of a Create, Read, Update, and Delete database.
Class diagram: Abstraction of programmed components in computer software.
State diagram: Abstraction of situations that can occur in computer software.
HTTP: Information transfer protocol used on the Internet.
Javascript: Programming language widely used on web pages and servers.
JSON: Simple format for exchanging data in plain text.
Laravel: Framework for developing web applications and services in the PHP programming language.
mindLAMP: Application created by John Torous and his assistants that allows to manage cognitive tasks and questionnaires to patients.
MoCA: Cognitive test created by Z. Nasreddine, which allows to evaluate a person’s cognitive abilities.
MMSE: Cognitive test created by Folstein, which allows to evaluate a person’s cognitive abilities.

MoSCoW: It is a management technique used for project management, among others.
Plugin: Extension of computer software.
SCRUM: Framework for agile software development.
Singleton: Design pattern used in programming to limit the number of objects in a class.
Sprint: The time unit of the SCRUM framework where the tasks are carried out.
Standalone: Application that does not depend on other software to be executed, unlike a plugin.
The System Usability Scale: This is a scale used to measure the usability of a project.
UUID: This is a number that allows you to universally identify a device, for example.

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