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UNIVERSIDADE Ð
COIMBRA

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ACCESSIBILITY OF AUTHENTICATION TECHNIQUES FOR PEOPLE LIVING WITH NEURODEGENERATIVE DISEASES

Dissertation in the context of the Master's in Design and Multimedia, advised by Professor Paula Alexandra Silva and presented to the Department of Informatics Engineering of the Faculty of Sciences and Technology of the University of Coimbra

Abstract

People diagnosed with Amyotrophic Lateral Sclerosis (ALS) are often unable to authenticate themselves, due to disease progression and ability loss. Technology is used by differently-abled people as a strategy to maintain participation, however, this requires an increased level of complexity and effort to access specialized services. Authentication is an important step to participation and one's individuality, so, if we are to allow people with ALS to remain independent, it is crucial to investigate how to increase accessibility in authentication processes. Following a Research through Design approach, this dissertation contributes to addressing this problem by designing, developing and evaluating two objects: an electromyography prototype and a set of authentication scenarios with two types of credentials. To accomplish that, a review of previous work was performed and a set of interviews with a Human-Computer Interface expert diagnosed with ALS were carried out. Afterwards, the two objects were designed following accessibility guidelines, and later implemented using Bitalino, for the prototype, and Unity, for the authentication scenarios. Finally, an experimental evaluation was conducted with nine healthy participants. Two sets of credentials were evaluated with two different dwell times and two keyboard dispositions. The analysis of the results revealed that (i) rows and columns are imputed faster in QWERTY keyboard dispositions and slower in number keyboard dispositions, (ii) shorter dwell times lead to more input errors in number keyboards, (ii) selection errors of the item preceding the target item only happen with longer dwell times, and (iv) PINs are perceived as easier and less tiring, but passwords are perceived as safer. This dissertation benefits people living with ALS and who are unable to authenticate themselves and further contributes to topics of accessible design and user interfaces design and implementation for authentication.

Keywords

Amyotrophic Lateral Sclerosis, Assistive Technologies, Authentication, Ability-Based Design, Accessibility, Research Through Design

Resumo

Um diagnóstico de Esclerose Lateral Amiotrófica (ELA) apresenta uma rápida progressão e perda de capacidades, o que frequentemente significa que pessoas que vivem com ELA não se conseguem autenticar a si próprias. A tecnologia é utilizada, por pessoas com incapacidades, como estratégia para manter a participação, no entanto isso exige um alto nível de complexidade e esforço para aceder a serviços especializados. A autenticação é um passo importante para a participação e individualidade de cada um, por isso, se quisermos manter a independência das pessoas que vivem com ELA, é importante investigar como aumentar a acessibilidade nos processos de autenticação,. Seguindo uma metodologia de Investigação através do Design, esta dissertação contribui para a resolução deste problema através do, design, desenvolvimento e avaliação de dois objetos: um protótipo eletromiografia e de um conjunto de cenários de autenticação, com dois tipos de credenciais. Nesse sentido, foi realizada uma revisão de trabalhos relacionados e foram efetuadas entrevistas com uma especialista em Interação Humano-Computador diagnosticada com ELA. De seguida, os dois objetos foram concebidos de acordo com diretrizes de acessibilidade, e posteriormente implementados utilizando Bitalino, no protótipo, e Unity, nos testes de autenticação. Por fim, foi efetuada uma avaliação experimental com nove participantes saudáveis. Foram avaliados dois tipos de credenciais com dois tempos de espera diferentes e duas disposições de teclado distintas. A análise dos resultados revelou que (i) linhas e colunas são introduzidas mais rapidamente em teclados com disposição QWERTY e mais lentamente em teclados com disposição de números, (ii) tempos de espera mais curtos levam a mais erros nas tentativas de introdução em teclados de números, (iii) erros de seleção do item anterior ao item alvo acontecem apenas em tempos de espera mais longos e, (iv) PINs são percecionado como sendo mais fáceis e rápidos, enquanto palavras-chave são percecionadas como sendo mais seguras. Esta dissertação beneficia pessoas que vivem com ELA e são incapazes de se autenticar e contribui para temas relacionados com conceção e implementação de interfaces de utilizador acessíveis para cenários de autenticação.

Palavras-chave

Esclerose Lateral Amiotrófica, Tecnologias Assistivas, Autenticação, Design com Base em Capacidade, Acessibilidade, Investigação através do Design

Acknowledgements

First and foremost, I wish to show my deepest gratitude to my supervisor and mentor, Professor Paula Alexandra Silva, for all the time devoted, the endless willingness and the wise advice.

I would also like to praise Dorothy Rachovides, for giving me the opportunity to learn from her and for always having an attitude of positivity and refusal to bend before adversity.

I also express my appreciation to APELA, for opening their doors to me and for caring and fighting consistently for the rights of people that live with ALS.

I would also like to thank the NeuroRehab Lab research group from the University of Madeira, for providing their softwares and help.

My heart goes to my family, especially my parents and brother, for always supporting my choices, giving me this opportunity and being present in the face of adversity.

And last but not least, a whole-heartedly thanks to my friends, those who are present and those who are not, for being the source of my joy and always sticking with me, both in bright and dark times.

My deepest regards to everyone!

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Acronyms

AD - Alzheimer's Disease

ATd - Assistive technology device

ALS - Amyotrophic lateral sclerosis

UMN - Upper motor neurons

LMN - Lower motor neurons

CNS - Central nervous system

RtD - Research through Design

PD - Parkinson's disease

PIN - Personal identification number

PLwALS - Person living with ALS

ACD - Assistive communication device

BLE - Biocybernetic Loop Engine

EEG - Electroencephalography

EMG - Electromyography

CAPTCHA - Completely Automated Public Turing test to tell Computers and Humans Apart

VSD - Visual screen display

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Chapter 1

Introduction

This chapter provides an overview of the theme and the objective of this dissertation, the motivations behind it, the approach that will be taken to achieve its goals and the overall structure of the document. By skimming through it the reader will get an overview of the dissertation.

1.1. Context and Motivation

About one in six people are diagnosed with a neurodegenerative disease worldwide (NIEHS, 2022). This is synonymous with a chronic and progressive loss of abilities over time, either that be motor, cognitive, sensory or a combination of the three. Some of the most known disorders of this group are Alzheimer's disease (AD), Parkinson's disease (PD), amyotrophic lateral sclerosis (ALS), multiple sclerosis, Huntington's disease and multiple system atrophy (Gao & Hong, 2008). Among these, Amyotrophic Lateral Sclerosis (ALS) stands out due to its rapid decline and constant need for adaptation to new and ever changing circumstances, in a short period of time (Hardiman et al., 2017). ALS implies a loss of physical abilities in almost every field of the motor ability spectrum. This encompasses almost all the manifestations of the other diagnosis with a high probability of loss. On account of these overnight changes, many people with ALS prefer to get themselves acquaintanced with what the next stage might imply in terms of technology (Chiò et al., 2004). This constant need for adaptation represents a high cost both financially and in time devoted to getting acquainted with the technology. Given this, the main focus of this dissertation is Amyotrophic Lateral Sclerosis (ALS), a condition which has been receiving growing scientific and clinical interest since the 90's (Kiernan et al., 2011). This also means that, to some degree, the findings and byproducts of this dissertation can be extrapolated to other neurodegenerative diseases besides ALS.

In 2021, the number of internet users worldwide was an estimated 4.9 billion (Statista, 2021), and keeping this data in mind, the matter of security surfaces. We all value our privacy, but what if this had to be managed by someone close to us or even multiple strangers? This is a reality for many people living with ALS. Bank accounts, social media or even something as simple as unlocking your phone, can present itself as a real challenge. This is not only triggered by a lack of abilities on the user's part, but also by a serious lack in technology design.

1.2. Goal and Objective

The goal of this dissertation was to design alternative authentication solutions that could improve the accessibility of authentication techniques for people with neurodegenerative diseases. These solutions were tested with participants, so as to determine the effectiveness of the proposed alternatives and identify potential improvements to be implemented in future assistive technologies.

To achieve this, we studied three different areas of knowledge: neurodegenerative diseases, assistive technologies, and authentication. The review of neurodegenerative diseases identifies different types of neurodegenerative diseases, their different symptoms and how they affect the ability spectrum. This then tapers down to a review on ALS, its symptoms, progression and how it affects the ability of the diagnosed person in its different stages. When reviewing assistive technologies, a definition and a set of examples for different types of assistive technologies is provided. Afterwards, a report of an in depth research of assistive technologies for people with a specific set of abilities is provided. The same strategy was applied when reviewing literature on the subject of authentication, where we provide an overall report on authentication, its steps, processes and practices. These three main topics raised gaps of understanding about the subject of authentication while living with a neurodegenerative disease. When researching and reviewing each of these areas of knowledge, our approach was to always report them in a way where they can be related to each other.

In order to conduct tests with users we need a set of authentication scenarios and a means of interaction. The scenarios for the tests were created from scratch, after defining what device and which authentication techniques are best suited to work for the people we will be working with. To achieve at least one prototype was also the goal of this dissertation, which was our means of interaction. The prototype uses electromyography (EMG) and, with it, the testers were able to interact with the authentication scenarios; this was a proof of concept and not marketable, although they can later be improved and made available as a cheaper open source alternative for people with neurodegenerative conditions.

One of our goals was also to report what we learned for testing in terms of authentication and the prototype. We learnt and reported what are some good and bad practices in terms of user experience and interaction, for the authentication methods we tested with the prototype. We also aimed to understand how the users receive, learn and adapt to a first interaction with an assistive technology, the prototype.

Having concluded this work the following contributions were made:

1. A review synthesis on ALS, authentication techniques, assistive technologies and how these three topics affect each other;
2. A user characterization of a person living with ALS;
3. Design, development, and experimental evaluation of an EMG prototype and set of authentication scenarios with different credentials and keyboard dispositions.

1.3. Overview of Research Approach

This dissertation followed a Research through Design (RtD) approach. RtD implies that an iterative and incremental process is applied for the creation of an object as a way to prompt research in the matter (Olson & Kellogg, 2014). In this dissertation, RtD was applied to design and develop a prototype that will be used to carry out a series of studies of various authentication scenarios. In creating the prototype, cost, practicality and technology longevity were key concerns.

RtD was combined with a Participatory Design process, this provided a better understanding of the user needs (Goodman et al., 2012). A person who is currently diagnosed with ALS was actively involved in the research process. We developed an understanding of the users and their context, by reviewing both lay and scientific sources and primary research through interviews with a person living with ALS. From this research came the argument for the development of two objects, the authentication scenarios and the EMG prototype. The objects were simultaneously developed, given that they need to work together. The experiment was developed, the study received ethical approval and, after implementing the objects, the participants were recruited. After the tests were finalized, the data was analyzed and the results were reported.

1.4. Document Structure

This document is structured in seven chapters that describe all work phases, from problem understanding to evaluating the obtained results. These chapters encompass:

1. **Introduction:** Describes the context and motivation, the objectives, its approach and the contributions of the work.
2. **Background and State of the Art**: Provides a review of the three main topics underlying the research presented in this dissertation: neurodegenerative diseases, assistive technologies, and authentication.
3. **Methodology:** Presents the proposed methodology, the strategies adopted throughout the project and the materials that will be used. A work plan is presented, highlighting the challenges and constraints that changed the initial plan.
4. **User Research and Context Understanding:** Outlines how and where we collected information about our user group. Both the preliminary user research, and the design and analysis of the interviews with people living with ALS are found in this section.
5. **Object Design and Development:** Describes how the two objects, the prototype and the authentication scenarios were designed, planed, implemented and finally tested and iterated upon;
6. **Experiment Design and Evaluation:** Documents the preparations before user testing, from the ethics approval to participants recruitment. This chapter describes how the experiment was conducted, how and what data was recorded, its analysis. It also details what results were obtained.
7. **Results and Discussion: Conclusion and Future Work:** Concludes the work, highlighting the accomplished objectives, as well as the shortcomings of the work and the next steps and future work for the project.

Chapter 2

Background and State of the Art

This chapter reviews the three main topics underlying the work of this dissertation: ALS, authentication methods, and assistive technologies. In doing so, it also provides a mapping of previous work on related topics and research.

2.1. Amyotrophic Lateral Sclerosis

Neurodegenerative diseases are a set of chronic and progressive disorders, characterized by a loss of neurons in the central nervous system (CNS) (Dugger & Dickson, 2017). A diagnosis of such a disease represents a progressive and chronic loss of motor, cognitive or sensory abilities. Examples of neurodegenerative diseases are: Alzheimer's, Parkinson's, Multiple Sclerosis, Amyotrophic Lateral Sclerosis, Huntington's disease and Multiple System Atrophy (Gao & Hong, 2008). Neurodegenerative diseases are usually classified by their clinical features, for instance parkinsonism, dementia, motor neuron degeneration or demyelination ((Dugger & Dickson, 2017).

Some symptoms are shared by more than one of these diseases, in different degrees of damage and permanence. Table 2.1 presents an overview of how each symptom manifests in each diagnosis and to what degree. In this Table, we can cross the spectrum of physical ability in each body part with different neurodegenerative diseases. The physical ability spectrum is divided by a body area which is then divided into smaller parts. For example, we can see how the overall movement of the hands changes with the disease progression, but we can also understand how it changes, for instance, if the person can bend the fingers and grab or grip things. As illustrated in Table 2.1, the attribution of ability is classified by the probability of loss during the course of the disease. This classification is done by checking the previous ability: a) has a high chance of becoming an impairment; b) has some chance of becoming an impairment; c) has a low chance of becoming an impairment or d) won't become an impairment due to the impairment.

The Table's range of physical ability is divided by body group and ability as a way to specify which areas are affected and how. For example, in the arm group, we can analyze different abilities supported by different muscle groups, lifting the shoulders, bending the elbows and moving the wrists. This representation was chosen because different diseases have similar affected groups but different abilities. To further illustrate, both Amyotrophic Lateral Sclerosis and Multiple System Atrophy have the mouth group affected, but unlike Amyotrophic Lateral Sclerosis, which loses all its mouth abilities, Multiple System Atrophy only loses the swallowing ability. For example, Alzeimer's disease mainly affects the overall body with a high probability of developing body stiffness, bradykinesia, tiredness and losing balance and coordination. This disease has a similar progression in almost all people diagnosed with it, where the loss of these abilities is expected. Concerning Multiple Sclerosis, the whole spectrum of physical ability might be randomly affected during the disease course, depending on what neurons are affected by the inflammation. Multiple Sclerosis is often described as a "SnowFlake disease" because every diagnosis progresses in a different manner. ALS affects most body groups except those of the eye movement and sphincter muscles and, as detailed in the next section, can very quickly become a disabling condition.

PHISICAL ABILITY		NEURODEGENERATIVE DIAGNOSIS: Amyotrophic Lateral Sclerosis	Alzheimer's disease	Parkinson's disease	Multiple Sclerosis	Huntington's disease	Multiple System Atrophy
Eye	Gazing movement	◤	◗		◗	●	
	Blinking	◤			◗	●	
Mouth	Swallowing	●	●	◗	◗	●	●
	Sucking	●			◗		
	Blowing	●			◗		
	Biting	●			◗		
	Moving tongue	●			◗		
	Smiling	●			◗		
Voice	Speaking	●		◗	◗	●	◗
Head	Turning head	●			◗		
Arm	Lifting shoulders	●			◗		
	Bending elbows	●			◗		●
	Moving wrists	●			◗		
Hand	Bending fingers	●		◗	◗		
	Grabbing	●		◗	◗		
	Gripping	●		◗	◗		
Leg	Lifting Leg	●			◗		
	Bending knee	●			◗		●
	Turning ankle	●			◗		
Overall Body	Bending toes	●			◗		
	Trembling	●		●	◗	●	
	Twitching	●		●	◗	●	
	Stiffness	●	●	●	◗	●	
	Balance	●	●	●	◗	●	●
	Bradykinesia	●	●	●	◗	●	●
	Coordination	●	●	●	◗	●	◗
	Tiredness		●		●	●	

Label	
●	Will become a disability
◗	Might become a disability
◤	Small chance of becoming a disability
	Won't become a disability

Table 2.1 - Comparison of physical ability degradation throughout different body areas in several neurodegenerative diseases. Adapted from Whittington (2017).

2.1.1. Symptoms manifestation

ALS is a progressive, still incurable neuromuscular disease, a severe form of neurodegenerative disease. It is characterized by the constant deterioration of motor neurons in the spinal cord and brain which ultimately results in paralysis. Research is still seeking to understand the whole scope of ALS, yet the pathogenic mechanism of ALS remains unknown (Hardiman et al., 2017).

According to Hulis (2018), ALS has two primary classifications, **familial** (fALS) and **sporadic** (sALS), where the latter is idiopathic and the former genetic. The familial type affects 5% to 10% of individuals with ALS diagnosis and often occurs due to a genetic dominant trait, has a 1:1 ratio female to male rate and normally appears in a person's teens and early adulthood. The sporadic kind affects 90% of individuals with ALS diagnosis, is considered idiopathic and has no known cause, and has a 67% rate for men and tends to appear in the mid-to-late fifties.

Figure 2.1 illustrates the motor system, which is composed of the **corticospinal (upper) motor neurons** (UMN) and **bulbar and spinal (lower) motor neurons** (LMN) (Brown & Al-Chalabi, 2017). While the UMNs are located in the motor cortex and their disruption results in brisk reflexes and slowed coordination of the limbs with spasticity and stiffness of the muscles, failure of the LMNs (which innervate skeletal muscle) is first exhibited by spontaneous muscle twitching or fasciculations, and then progressive atrophies, which tend to begin in the limbs and eventually progresses to the eye and sphincter muscle neurons, in its last stages (Hulisz, 2018). Once the muscle weakness spreads to the diaphragm, people lose the ability to breathe on their own, and typically death due to respiratory paralysis occurs in three to five years (Brown & Al-Chalabi, 2017).

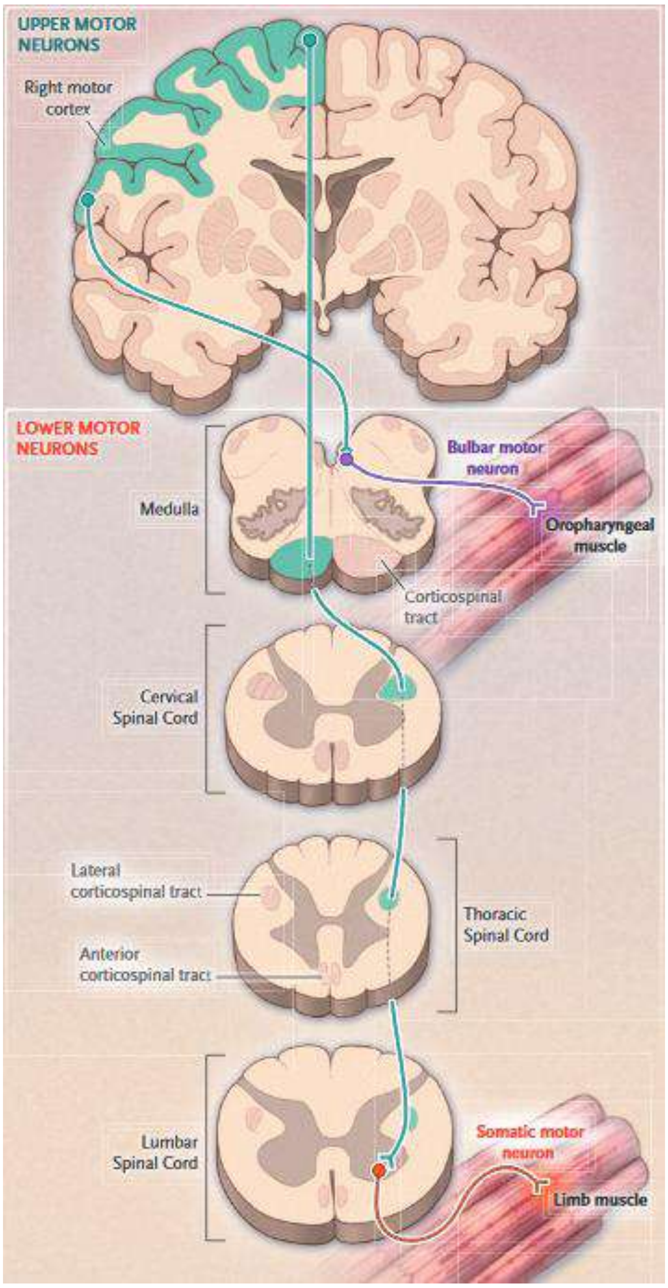

Figure 2.1 - The Motor System. In Brown & Al-Chalabi (2017).

According to Brown & Al-Chalabi (2017), ALS can also be classified as **spinal-onset ALS** and **bulbar-onset ALS**. Spinal-onset ALS initially derives from a combination of UMN and LMN involvement, while bulbar-onset ALS presents swallowing and speech difficulties initially and limb features later in the disease course. Besides their disparate manifestation, spinal- and bulbar-onset ALS also have different survival rates. Figure 2.2 shows the survival curves for these two types of ALS and two other types of motor neuron disease, Primary Lateral Sclerosis and Progressive Muscular Atrophy. Primary Lateral Sclerosis has a pure UMN involvement while Progressive Muscular Atrophy has pure LMN involvement. The Figure shows that a person with spinal-onset ALS may on average live 100 months more than a person with bulbar-onset ALS.

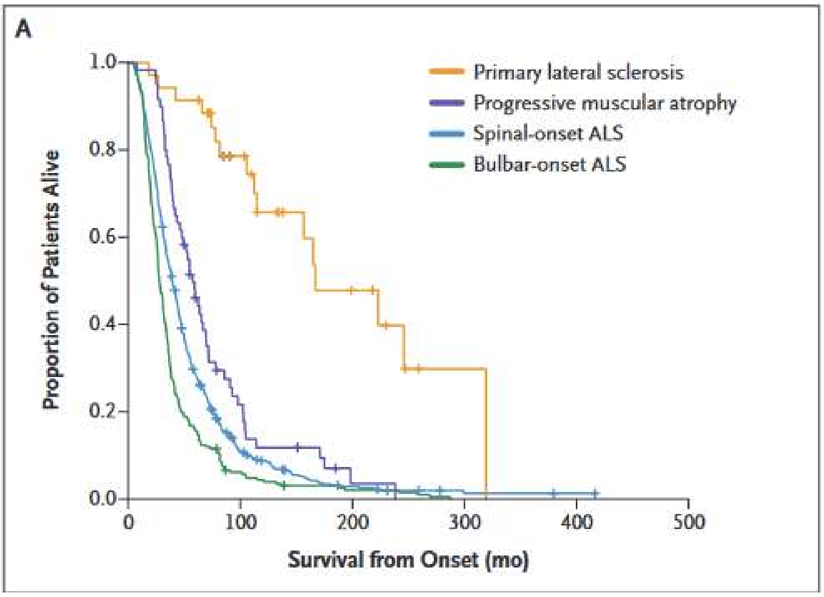

Figure 2.2 - Phenotype and Survival in ALS compared to two other motor neuron diseases, primary lateral sclerosis and progressive muscular atrophy. In Brown & Al-Chalabi (2017).

Although ALS's progression is more or less unpredictable, Kiernaman et al. (2011) state that "motor neurons without a monosynaptic connection with corticomotoneurons, such as the oculomotor, abducens, and Onuf's nuclei, are typically spared in ALS, a finding which was also mentioned when explaining the LMNs degradation and is represented in Figure 2.3. This means that at the very last stage of the disease, PLwALS are likely to maintain the ability to move and focus their eyes, contract the upper eyelid and are able to control their sphincter and orgasm. Once all physical abilities are lost, it is considered that the PLwALS is in a locked-in state and unable to communicate by themselves in any way (Borgheai et al., 2020).

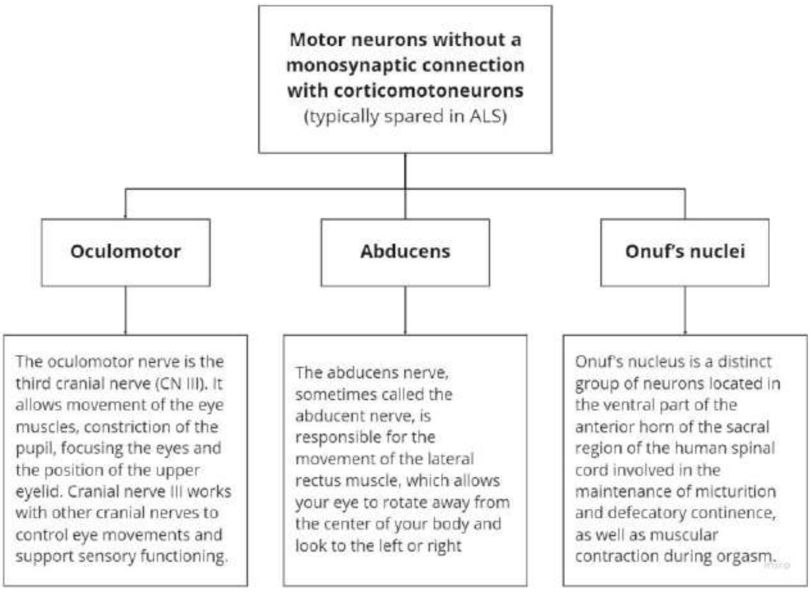

Figure 2.3 - What is typically spared in ALS and the meaning of specific motor neurons.

2.1.2. Disability and impairment

To have an **impairment** is different from experiencing a **disability**. Impairment refers to the property belonging to the person, such as being blind or paralyzed, whereas disability is the problem that arises in certain situations, like not being able to read something or lift things (Oestreicher, 2019). Furthermore, the definition of disability is changing rapidly and no longer represents only people who have a permanent disability.

As defined by Microsoft (2022), "Disability is a mismatch in interaction between features of a person's body and the features of the environment in which they live", and can be classified by its location in the body and duration, as seen in Figure 2.4 (Wobbrock et al., 2018). As see Figure 2.5 illustrate, disabilities can be classified as **situational**, **temporary** and **permanent** (Microsoft, 2022). Before, only different-abled people would be considered to have a disability, like someone with an amputated arm, a permanent disability. But considering that disability is the inability to perform in a given scenario, location and duration, a mother holding her child is also unable to perform certain actions, the same applies to someone that has a cast to heal a broken arm, which are situational and temporary disabilities, correspondingly.

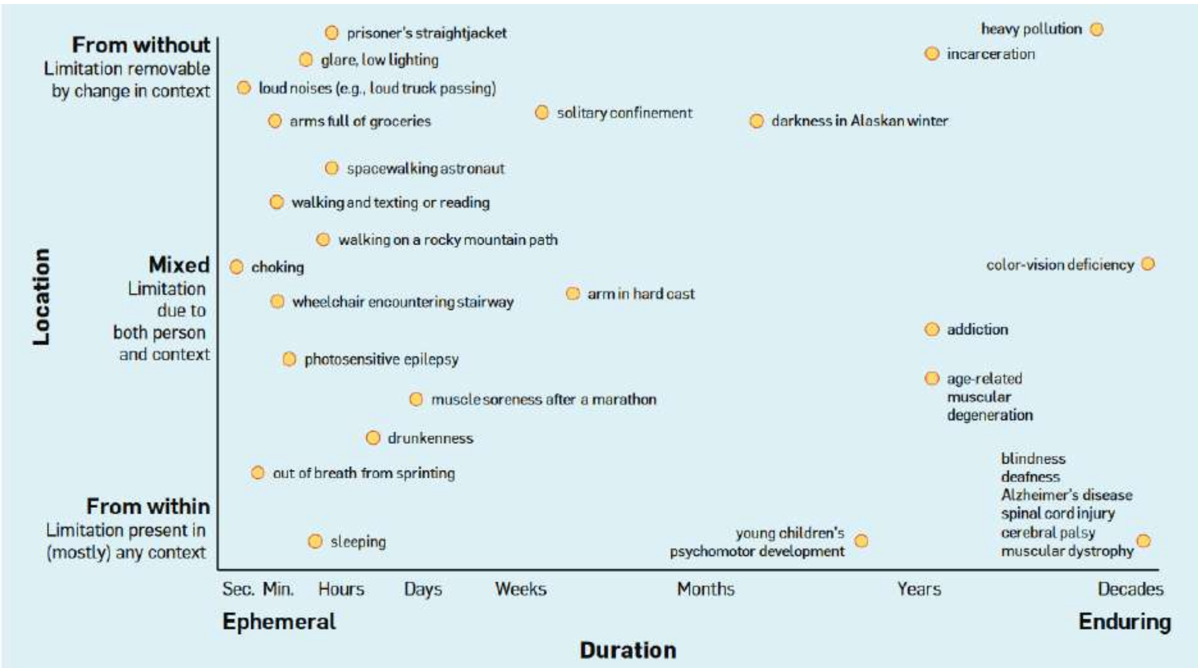

Figure 2.4 - Contexts that impair one's ability to use technology are defined by context and duration. In Wobbrock et al. (2018).

Encarnação (2015) states that disabilities can be of the **motor**, **cognitive** or **sensory** type. Motor disabilities are defined by the inability to use a function of a body part, for instance being able to use an arm or having poor stamina. Cognitive disabilities relate to limitations in mental function, some examples are being able to communicate or keep focus. Sensory disabilities encompass the ability of the human brain to process sensory information (sight, hearing, taste, touch, and smell), for instance not being able to see or hear something.

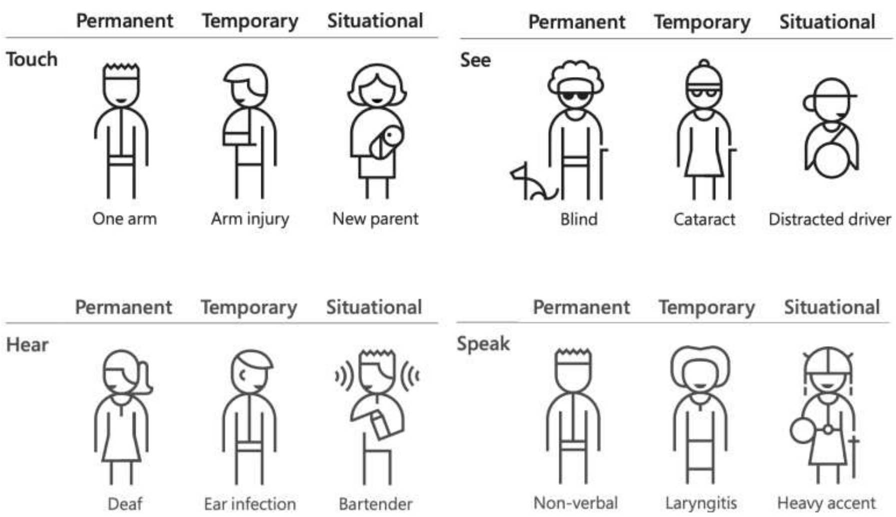

Figure 2.5 - Mismatches and motivations across a spectrum of permanent, temporary, and situational scenarios. In Microsoft (2022).

The earliest evidence of disability accommodation, in human evolution, dates back to around 500.000 years ago (Hublin, 2009). This historical context is important to help us understand that, in our core as a species, we always have been empathizing beings that value societal participation. Meanwhile, while you are reading this, someone with ALS is unable to communicate due to a lack of access to assistive technology, denying them that same basic right to participation.

2.1.3. Adaptive strategies

As the disease progresses, PLwALS need to find and use **adaptive strategies** to compensate for the loss of abilities. Adaptive strategies require learning new skills or modifying old ones, in order to adapt to an increasing level of disability (Chiò et al., 2004). This can be achieved by a number of techniques, whether that be through therapy, routine changes, nontechnical assistive devices or assistive technologies.

Figure 2.6 shows body sites and signals commonly used as input for device control and can be used to counteract the disappearance of previous abilities. The body sites encompassed in this group are, by ascending order of longevity, movement in muscle groups such as the neck, hand/finger, foot/toe, facial and tongue, then eye movements, and finally, cerebral activity (Gamboa, 2016). Knowing the longevity of these abilities provides insight into the focal areas to consider when developing better-suited adaptive strategies.

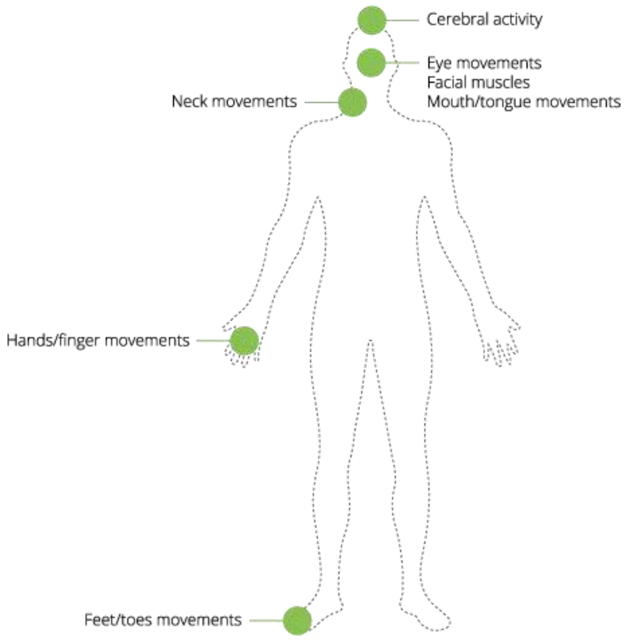

Figure 2.6 - Body sites and signals commonly used to control input devices by ALS patients. Adapted from Gamboa (2016).

Table 2.2 provides an overview of adaptive strategies, together with the symptoms of the disease and care strategies, where we can find from a common wheelchair to ventilatory support.

Symptoms	Care
Weakness and disability	Orthotics (eg, ankle foot orthosis, neck collars) Physiotherapy Adaptive aids (eg, walking frame, wheelchair)
Dysphagia	Assessment by speech therapist and dietitian Insertion of gastrostomy tube
Dyspnoea and poor cough	Ventilatory support Chest physiotherap Suction machine Manually assisted coughing techniques
Pain	Physiotherapy, NSAIDs Re-positioning and pressure area care Pressure-relieving cushions and mattress
Dysarthria	Assessment by speech pathologist Communication aids Educate family and caregivers
Cognitive changes	Explain symptomatology to caregivers and family
Sialorrhoea	Radiation of salivary glands Mouth-care products Suction
Thickened saliva	Ensure adequate hydration Suctioning of the mouth Mouth care
Emotional lability	Educate patients with ALS and caregivers
Depression and anxiety	Counselling
Sleep disturbance	Treat underlying problem Respiratory review, non-invasive ventilation
Constipation	Dietary changes (eg, increase fluid and fibre intake) Use formulations high in bran, bulk, or fibre

Table 2.2 - Symptomatic care for people living with ALS.

The sparing of the motor neurons, as shown in Figure 2.3, allows for the use of eye-tracking technology, one of the most used adaptive strategies for communication longevity for PLwALS (Caligari et al., 2013). Before eyetracking, once voice and mobility were lost, the only communication method available to PLwALS was through nontechnical communication systems, such as the visual screen display (VSD) shown in Figure 2.7, photographed during a visit to the Portuguese Association of Amyotrophic Lateral Sclerosis (APELA). However, the use of such a system requires the involvement of both the person living with ALS and their care provider, where the latter would point to an image or phrase, and the former would blink or make a sound when the correct phrase is chosen. This means that the PLwALS's communication depends on numerous factors such as: circumstance, location, and the availability of a care provider. Considering that a PLwALS was in a bathroom equipped with nontechnical VSD, and had a care provider present, if the PLwALS dropped something behind a sink and wanted to ask for help to pick it up, the care provider would need a VSD with an image of a keyboard, for the PLwALS to communicate, in "writing", the need/request that needed to be attended. Please note that no picture is available of a sink that could allow for the communication that needs to be initiated. This represents one example of how an adaptation can help overcome some limitations that PLwALS experience throughout the disease progression.

Figure 2.7 - Bathroom communication system between PLwALS and their care providers. Captured in APELA's bathroom.

The next section provides an overview of how technology, in particular assistive technologies, are used as adaptive strategies that are key in the daily routine of PLwALS.

2.2. Assistive Technologies

2.2.1. What is an ATd?

Assistive technologies (AT's) are "any item, piece of equipment or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of people with disabilities" (Jeffords, 1998). This definition originated from a period where adaptations had to be made to mainstream technology to accommodate different-abled people (Cook & Hussey, 1995). However Cook & Polgar (2015) argue that the bidirectional exchange between **information and communication technologies** (ICT's) and AT's boost both the social participation of people living with permanent disabilities and the usability of technology for people living without a permanent disability. A list providing insight of mainstream ICT's and their derivative AT can be found in Table 2.3, as synthesized by the authors.

Technology Name	Assistive Use	Mainstream Use
Closed captioning	Textual translation of voice and sounds on TV for people who are deaf or hard of hearing	Television screens in lounges and gyms (more used here than by people who are deaf)
Voice recognition	Text entry for those who are unable to use their hands to type on a keyboard	Anyone wanting to enter text faster than they can type; widely used by lawyers; telephone prompt systems
On-screen keyboards	Text entry for those who are unable to use their hands to type on a keyboard	Tablets and personal digital assistants (PDAs); many emerging computing platforms do not have a keyboard attached and require the use of an onscreen keyboard for text entry
Speech synthesis	Computer-generated speech used to communicate for those unable to speak using their own voices	Voice prompt telephone systems; many software applications where verbal feedback is provided
Digitized speech	Computer-generated speech used to communicate for those unable to speak using their own voices	Voice prompt telephone systems; many software applications in which verbal feedback is provided
Computer keyboard equivalents	Keyboard access and control of menu items for people who are unable to use a mouse or see the screen	Shortcuts to save time by anyone (e.g., Control-S to save)
Mouse keys	Control of the cursor via the numeric keypad for people who are unable to use the mouse	Graphic designers who wish to move the cursor a single pixel at a time and have difficulty doing so with a mouse
Sticky keys	Assist one-handed typists in accomplishing key combinations, such as Shift-A	Anyone who is a two-finger typist can use this feature (and there are many)
T9 disambiguation	A quick way to enter text using scanning by someone who is unable to use a keyboard (fewer keys means less time scanning)	The majority of cell phone companies in the world have now licensed this technology to speed text entry using the numbers on the telephone keypad.
Word prediction	Speed text entry for people who are unable to use their hands to type on a keyboard	Used everywhere from spreadsheets to language learning software. Word completion and word prediction help speed text entry for everyone.
Abbreviation expansion	Speed text entry for people who are unable to use their hands to type on a keyboard	Now a standard feature in most mainstream word processing applications; type common terms, such as your name and address, with a single abbreviation
Single latches on laptops	Allow people with only one arm to open the lid on a laptop	Ever had one arm full of papers and tried to open your laptop lid? You will immediately appreciate this feature when you do.
On/off push button toggle switches	Ability for people with limited motor control to turn on/off computers (instead of the traditional rocker switches in the rear)	Now almost every computer made uses this type of switch because it is simply easier for everyone
Call-out control descriptions	Allow people who are blind to have the description of a control icon read to them via speech synthesis	Anyone wondering what a certain toolbar icon is supposed to mean can now dwell over it and get the text description
Screen enlargement	Allows people with low vision problems to more easily see the screen of the computer	Often used during presentations or in kiosks to make certain parts of the computer screen more viewable by the public
System color schemes	Allow people who are color blind or have low vision to see the computer screen easier	Who do you know who has not played with the system colors and customized them to their own tastes? High-contrast modes are often used in presentations to large audiences when the screen must be seen from large distances.
Wearable computers	Allow someone with a disability who is using a computer for communication to have it with them at all times (e.g., glasses-mounted displays)	This is just emerging. There are specialized uses for it now, such as the military, but it will become more common for everyone in the future.
Head tracking devices	Allow someone without the use of their hands to control the cursor	Gamers who are using their hands for other things such as firing buttons can still control the cursor. Also used by database entry clerks and other computer operators who must have their hands on the keyboard at all times. Used in hazardous environments where the computer is behind a window yet can still be controlled.

Table 2.3 - List of mainstream derivatives from assistive technologies. In Cook & Polgar (2015).

There are two main types of assistive technologies, **hard technologies** and **soft technologies** (Odor, 1984). Hard technologies are systems that are readily available and can be purchased in order to be assembled into assistive technologies (Cook & Polgar, 2015). Soft assistive technologies are those which require a person's decision to take part in activities, such as training and the development of strategies and special skills (Cook & Polgar, 2015).

Assistive technology tools and appliances require training of both the care providers and users of the technology, for example when a person with limited mobility acquires a new seating system (hard technology), training needs to happen on how to position the person and how to maintain a proper position for the person (soft technology). That being said, the conjugation of hard and soft technologies is a must for the successful use of assistive technologies (Vanderheiden, 1987).

The Human Activity Assistive Technology Model proposes a framework for understanding assistive technologies within the 'place' of those living with disability (Cook & Polgar, 2015). According to this model, hard assistive technologies' basic structure can be divided into four different components: someone (**human)**, doing something (**activity**), with an enabler (**technology**), in a given place (**context**) (Cook & Polgar, 2015). The HAAT model (see Figure 2.7) is an adaptation of the Human Performance Model (Bailey, 1996), which only accounted for the human, activity and context.

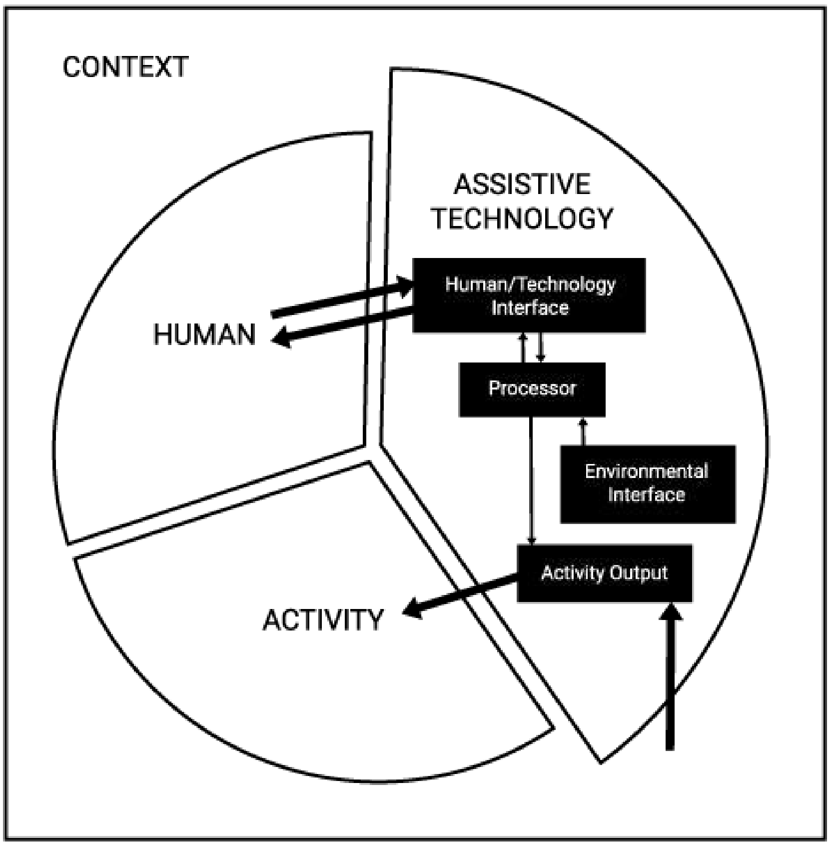

Figure 2.7 - HAAT model with assistive technology components identified. Adapted from (Cook & Polgar, 2015).

As seen in Figure 2.7, the relation between the human and the AT is called **human/technology interface** (HTI), which can play various roles in the AT system:

I. The means through which the user can control the AT, a **control interface** (e.g. joystick or a keyboard) and/or a **user display** (e.g. the screen on a smartphone);

II. The support provided to the user by the system (e.g. support in typing and reading provided by a braille keyboard to a blind user);

III. Mounting of components for easy access by the user (e.g tablet stand for a electrical wheelchair);

IV. Feedback about the environment, provided to the user by the system (e.g. speech output of a digitized book to a user who is blind);

V. Feedback about the device, provided to the user by the system (e.g. visual displays or auditory feedback of low battery on a electric wheelchair);

Unlike hard technologies, soft technologies are intangible and consist of the human areas of decision making, strategies, system and/or device selection, fitting and setup of the system/device (Cook & Polgar, 2015). Without soft technology, the full potential of hard technologies cannot be achieved and people without proper training in their AT rarely benefit from its full potential. Soft technologies are provided in three different ways:

VI. Directly through people (e.g. professional care providers, family, AT technicians);

VII. Written manuals or other types of documents (e.g. manual of a braille keyboard);

VIII. Electronic artifacts (e.g. websites, built-in helper screens, tutorials);

Figure 2.9 shows real-life examples of these concepts. While looking at the braille keyboard (A) we have: (I) the keys in the keyboard as control interface; (II) support in typing and reading; (IV) ability to read via braille output; (VII) the device's manual; (VIII) online resources on the functionalities of the keyboard. The same exercise can be applied to the combination of assistive technologies that make up the learning system, the laptop with portable Tobii eye gaze system and Communicator 5 software (B): (I) laptop screen as user display; (II) table supported by arm connected to electric wheelchair; (III) computer usage aid; (IV) visual feedback by the software; (V) feedback about laptop status by the laptop's screen; (VI) aid given by caregiver/teacher; (VII) physical manual of the laptop and Tobii eye gaze system; (VIII) built-in and online tutorials about the three systems.

Figure 2.9 - Examples of hard technologies of assistive technologies. (A) keyboard with key input for typing and braille output for reading, (B) conjugation of two assistive technologies: electric wheelchair; laptop with portable Tobii eye gaze system and Communicator 5 software.

There are several types of assistance provided by ATs to the user: mobility, manipulation, communication, orientation, and cognition (Cook & Polgar, 2015). **Mobility ATs** are systems that assist in movement in several types of physical contexts (e.g. electrical wheelchairs, vertical platform lifts). These systems aid in several contexts, for example, electrical wheelchairs and vertical platform lifts can help people who need assistance in walking, and going up stairs. Electrical canes can help people with low vision navigate (Figure 2.10).

Manipulation ATs provide individuals with tools which help control a physical environment in order to complete a task (Encarnação, 2017). IoT devices are a prime example of this, where a person with mobility issues can turn on the lights in a room using their phone, without needing to use the physical light switch. Electrical prosthetics, such as a robotic arm for an individual who is amputated, are also an example of a manipulation AT.

According to the *American Speech-Language-Hearing Association (ASHA*, n.d.), **communication ATs** compensate for participation restrictions for people who have limitations in comprehending or processing language, which encompass both written and spoken communication. In person communication can be described as multimodal, since it comprises not only language, but also tone, body expression and context (Encarnação, 2015). There are several types of communication ATs (Abascal, 2008). Hearing aids provide support for people who are hard of hearing and helps them understand speech and sounds . Braille keyboards are an example of a system that helps people with vision problems reading and writing. Visual screen displays (VSD) aid in communication, for example they provide a good learning environment for children with cognitive disabilities; and people with tetraplegia are able to communicate if we pair VSDs with, for example, eye tracking technology.

Orientation ATs help people navigate both in time and space. Specialized smartwatches that tell time out loud are helpful for people with low vision or cognitive deficits. Much like GPS systems help people navigate through a city, a smartphone application that helps with navigating the inside of buildings could improve the life of people with Alzeimers.

Cognitive support ATs provide assistance with organizing and utilizing knowledge, which include memory, problem solving, attention and decision making and others (Cook & Polgar, 2015). Intelligent environments are collections of AT systems that provide help, for instance, to people living with dementia, by creating a safe livable environment for these people, and that can wake them up, open the window shutters, remind them to take their meds and do their basic hygiene needs, warn them to eat their meals throughout the day, and much more (Encarnação, 2015). Decision making trees can also be helpful in providing this support, for instance, a child with cerebral palsy who wants to participate in didactic activities but has to use a electric wheelchair, can beneficiate from a decision making software that chooses the best path to follow without overloading the child, leaving most of its attention to exploring an environment.

Figure 2.10 - Electric wheelchair wheelchair with a chin and hand manipulation control. Captured in a visit to APELA.

Table 2.4 lists ATd's that PLwALS can use as the disease progresses and analyzes the ability that is required to operate the ATd by body part. For example, to operate a switch, the PLwALS can use their arm, chin, finger, foot, hand or head to operate the switch with low agility; can use her/his tongue or sucking/blow to operate the switch, which requires a high level of agility; to see they are doing, they need to use their eyes, with low acuity.

REQUIRED ABILITY	TECHNOLOGIES: Smartphone	Tablet	Head mounted display	Eye tracker	Head tracker	Electroencephalogram	Switches
Arm	■	□	■				□
Brain						■	
Chin							□
Eye	▲	▲	▲	▲	▲	△	△
Finger	■	□	■				□
Foot							□
Hand	■	□	■				□
Head					■		□
Suck/Blow	■	■					■
Tongue							■
Voice	●	●	●				

LABEL	
■	High agility
□	Low agility
▲	High acuity
△	Low acuity
●	High clarity

Table 2.4 - Cross reference of available assistive technologies with what level of ability is required to operate them by body part. Adapted from Whittington (2017).

With regard to the definition of disability provided above, assistive technologies are also changing its status of a mere adaptation to improve the functional capabilities of different-abled people. User's cognitive and physical abilities vary considerably over short periods of time, due to fatigue, motivation, interest and attention, and by consequence interaction changes with it (Abascal, 2008).

Following an **Ability-based Design** approach, the focus of the designer is on what people can do, rather than what they cannot do, and on systems and environments adapting to the users rather than the other way around (Wobbrock et al., 2018). With that being said, much like differences in height or weight are not referred to as dis-hight or dis-weight, abilities should be considered as a spectrum rather than being referred to as disabilities (Wobbrock et al., 2011). Figure 2.11 illustrates how designing products with adaptability built-in can help lessen the burden of the user, by allocating the demand of adaptation to the system. Table 2.5 synthesizes seven principles designers need to keep in mind when developing new assistive products. These guidelines should be observed throughout the design process, from ideation to development, in order to optimize accessibility.

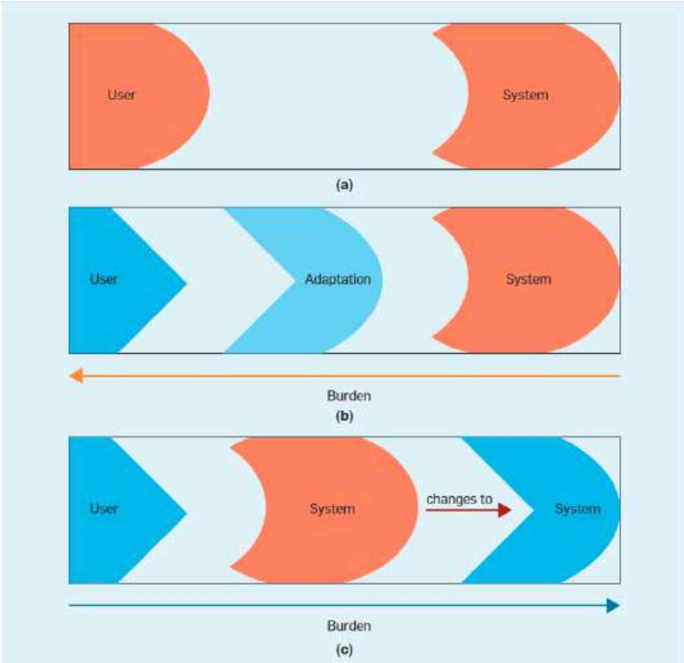

Figure 2.11 - User abilities and a system's ability assumptions: (a) user abilities match a system's ability assumptions; (b) in assistive technology, the user acquires an adaptation to remedy a mismatch; and (c) in ability-based design, user abilities drive changes in the system. In Wobbrock et al. (2018).

	Principle	*Description*
Designer Stance (required)	Ability	Designers focus on users' abilities, not disabilities, striving to leverage all that users can do in a given situation, context, or environment.
	Accountability	Designers respond to poor usability by changing systems, not users, leaving users as they are.
	Availability	Designers use affordable and available software, hardware, or other components acquirable through accessible means.
Adaptive or Adaptable Interface (optional)	Adaptability	Interfaces might be adaptive or adaptable to provide the best possible match to users' abilities.
	Transparency	Interfaces might give users awareness of adaptive behaviors and what governs them and the means to inspect, override, discard, revert, store, retrieve, preview, alter, or test those behaviors.
Sensing and Modeling (optional)	Performance	Systems might sense, monitor, measure, model, display, predict, or otherwise utilize users' performance to provide the best possible match between systems and users' abilities.
	Context	Systems might sense, monitor, measure, model, display, predict, or otherwise utilize users' situation, context, or environment to anticipate and accommodate effects on users' abilities.

Table 2.5 - Seven principles of ability-based design. In Wobbrock et al. (2018).

2.2.2. Specific AT's for ALS

Even though technology should always be as adaptable as possible, it is impossible to design systems that embrace the whole ability spectrum. The development of an AT depends on which disability needs assistance. As outlined above, there are several types of assistance areas in ATs, communication, mobility, cognition, manipulation, vision, audition and tact (Gamboa, 2016).

Much like there are specific ATs for people who have reduced abilities in the vision spectrum, such as braille keyboards or text-to-speech systems, there is a set of ATs that counteract the impairments caused due to ALS. In order to augment communication abilities of PLwALS, there are assistive communication devices (ACD). These technologies are controlled by the PLwALS's body functions through an input device to access the ACD, as seen in Figure 2.2. The body functions that are used as input depend on the abilities that are maintained by the PLwALS (Figure 2.4 in the Amyotrophic Lateral Sclerosis section).

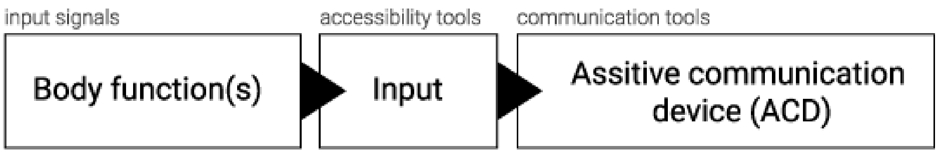

Figure 2.12 - Input devices (accessibility tools) are controlled by body functions and translated into commands for controlling communication tools of the AT device. Adapted from Gamboa (2016).

Table 2.6 summarizes three aspects to consider while choosing an ADC for the PLwALS, which are often applicable to other progressive neurodegenerative diseases. These aspects are: ALS affects speech, ADCs compensate the loss of the ability to speak but need an input device which is often operated with upper body limb functions that are also affected by disease progression (Fager et al., 2012), both need to be assessed; depending of symptoms and progression different PLwALS beneficiate from different ADCs; ACD choice depends on individual need and context (Shane et al., 2012).

ASPECT TO CONSIDER	REASONING
Communication support must include assessment of input devices and ACD (access and communication tools)	In ALS, both speech and upper limb functions are severely affected. As so, patients will need communication tools (for example, a speech synthesizer) and specific access tools to compensate functional impairment in upper limbs (for example, an input device to access a keyboard using eye movements) (Fager et al., 2012).
Time and characteristics of symptoms and progression deeply influence communication and access needs.	Some characteristics that are specific of ALS are determinant for the specification of ACD that should best match to patients' communication and control needs. It is then especially important to estimate the rate of progression and know the stages of the disease, to plan ACD according to expected advance of the symptoms.
Communication needs depend on each patient's individual needs and context and may not be restricted to replacing speech dysfunction.	Communication needs of the patients may go beyond dysfunction of speech. Solving communication problems in today's digital world requires consideration of multiple functions, depending on the age, circumstances, interests, and preferences of each person. Interpersonal communication, information, online services, entertainment, education, health and safety, are different functions of present communication tools, services and facilities (Shane et al., 2012).

Table 2.6 - Input devices (accessibility tools) are controlled by body functions and translated into commands for controlling communication tools of the AT device. Adapted from Gamboa (2016).

Some of these technologies are eye tracking devices, electromyogram (EMG) input devices, encephalogram (EEG) input devices and button input devices. Table 2.11 provides a list of some of these devices, their manufacturer, their development stage and a brief description of these technologies (Millar, 2022). But even though these technologies are all very different from one another, they all fall into one of two types of access methods, **direct selection** or a **scanning method** (Gamboa, 2016). Direct selection allows the user to choose directly any function of the ACD, a few examples are touch, laser pointers, head tracking and eye gaze. For instance, when using an eye gaze as an input signal, the user can select any letter on the keyboard or function of the ACD directly by looking at a specific screen point, as one would with a touchscreen device or a mouse. On the other hand, the scanning method takes more time and effort in order to select a single command, some examples are switches, EMG, EEG . Since the user relies on a single switch (simple 0/I signal), all options are highlighted in a sequential order and frequency (e.g. one option/second), this can be done by scanning the options one by one or by using a row/column method, choosing a whole row first and then selecting its column lastly, Figure 2.13 provides an example of this method. For instance, when using EMG as an input method, once the correct option is highlighted, the user can move the muscle group that is being recorded to select it. Both methods can be made quicker by using support acceleration techniques, for instance, word prediction or different scanning sequences; velocity is one of the factors that contributes to AT acceptance (Abascal, 2008).

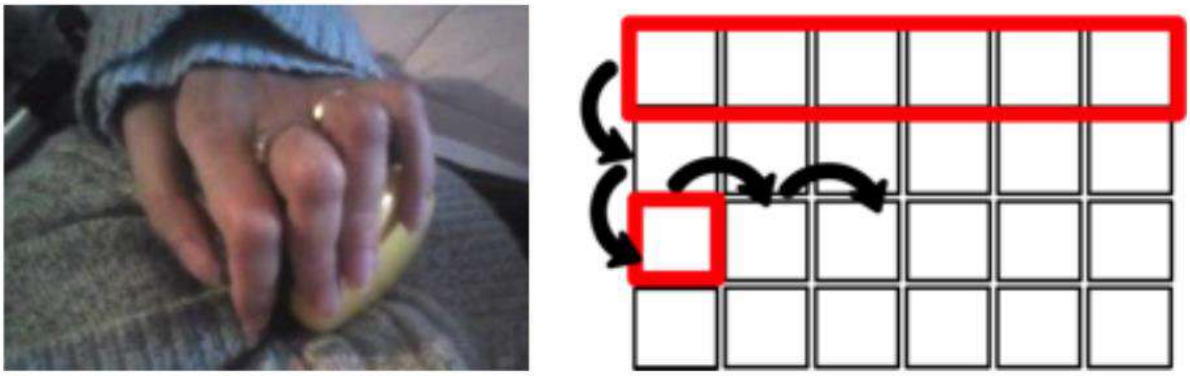

Figure 2.13 - (left) Switch being used by a patient with ALS for accessing communication tools in an ACD using a scanning method. (right) Scheme illustrating scanning method. In Encarnação (2015).

Eye tracking has always been a prevalent method of communication for PLwALS, even before eye tracking technology, by using nontechnical VSDs (Calvo et al., 2008). Communication through nontechnical VSDs, are operated by having thePLwALS looking at an image or phrase and a third person identifying what the PLwALS is looking at and trying to say (Figure 2.5). This was later transmuted to an AT where the user interacts with a digital VSD, the software is usually installed in a personal computer or tablet, due to the screen size.

Eye tracking can be screen based or resort to the use of glasses (Figure 2.14 shows the differences between each method). Screen based eye tracking is highly dependent on face discovery, which can be accomplished by two different techniques, **highlight based** and **picture based**. With a highlight based strategy, the facial properties (e.g. eyes and nose) are distinguished and evaluated by comparing the position of the different facial properties. This strategy is known for its speed and pixel exactness and relies on four projections for eye recognition: Edge-Projection, Luminance Projection, Chrominance Projection and Final Projection.

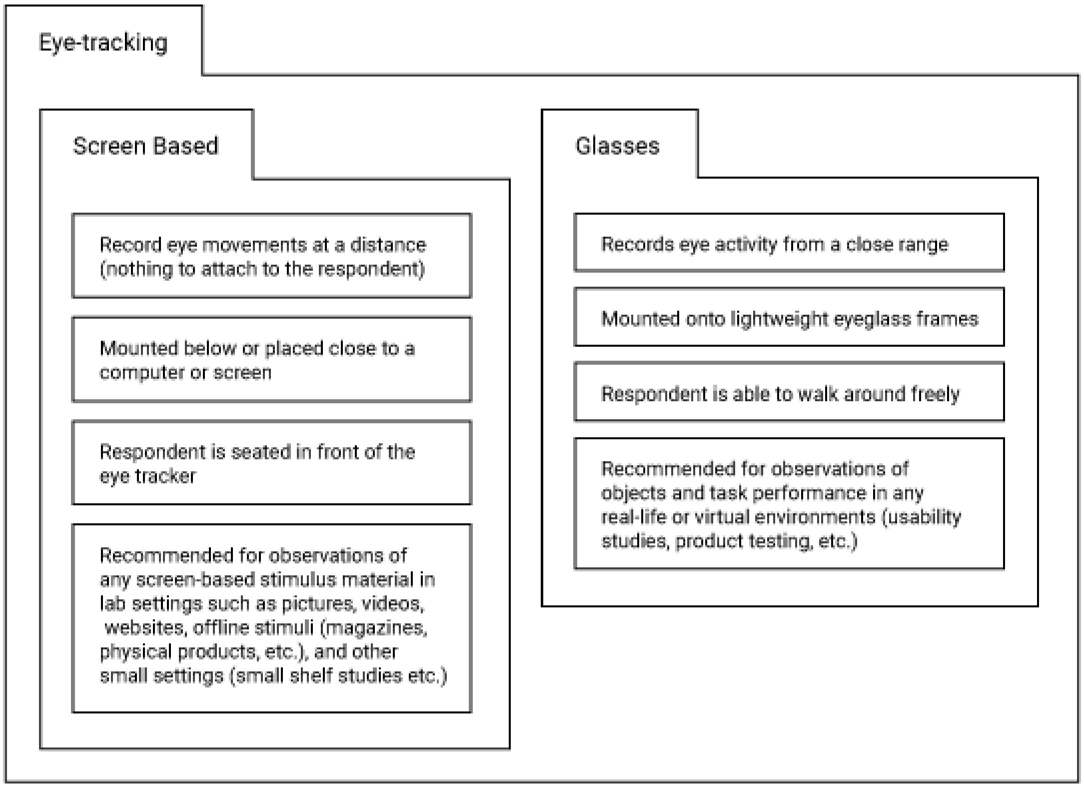

Figure 2.14 - Differences between screen based and
glassed eye trackers. Adapted from Farnsworth (2022).

Eye tracking has several metrics to describe its several interaction acting parts (Farnsworth, 2022). **Gaze points** are a basic unit of measure, one gaze point equals one raw sample captured by the eye tracker, if the eye tracker measures 60 times each second, then each gaze point represents a sixtieth of a second. **Fixation** denotes a period in which our eyes are locked towards a specific object, its duration is usually 100 to 300 milliseconds. Eyes don't move smoothly across a line when reading, instead they jump and pause generating a large number of sequences, those sequences between each fixation are known as **saccades**. Both saccades and fixations are involved in reading, and each saccade involves perceptual spans where. On the other hand, moving objects don't generate saccades, but instead the eyes move on a **smooth pursuit** trajectory.

Committing an interaction while using eye tracking can be accomplished by several methods, such as using a different input method, namely voice control and hand input; if these methods are unavailable, the user must fall back into a **dwell method**. The dwell method, as depicted in Figure 2.15 consists of two sequential steps: a) look at a target that needs to be selected; b) to confirm your intention to select the target, use a secondary explicit input, simply fixate the target that needs to be selected (Sostel, 2023). This presents a challenge as it can take a long time to interact, however, this can be helpful to novice users and the dwell time can be adjusted to better suit the needs of expert users.

Figure 2.15 - Dwell states during interaction. In Sostel (2023).

2.3. Authentication Methods

2.3.1. The basics of authentication

Keates (2018) defines authentication as the process of proving your identity to an electronic device . This presents itself as an important step while securing systems and shielding private files and data (Andrew et al., 2020a). This being said, authentication is an aspect of our lives that most users encounter several times a day as a means to access a wide range of both devices and services. This constant need to prove one's identity requires the user to ponder whether the effort of having it in the first place justifies its usage. The users consider what they are trying to protect with authentication and decide if it is worth protecting. Often, if users have a negative experience with authentication, they might reconsider not using authentication even if they should, or even not using a technology or service that requires authentication (Keates, 2018).

It is then important to understand what authentication is, why it is needed, and how it can be done. Keates (2018) states that when deciding how to secure a technology or service, the a few key aspects need to be defined:

- *security:* what level of security is needed;
- *users:* who is using it and what effort are they expected to put into authenticating themselves;
- *device:* what is supported by the technology;
- *context:* in what situation will the user need to put this into action.

Having defined the above terms, it is now important to understand what type of authentication credentials can be used and to define their key aspects, because the user's willingness to use the technology or service might depend on how they authenticate themselves. Authentication credentials fall into three user centered categories (Keates, 2018):

- the user needs to *know:* a secret, like a password, personal identification or PIN;
- the user needs to *have:* a physical token, like a card or an IoT device;
- the user *is* something: behavior or biometric characteristic, like facial features or fingerprint.

These three categories can be used as stand-alone techniques, yet, when used simultaneously, they are referred to as multifactor authentication (Keates, 2018). One example is when a phone can be unlocked both by entering a PIN or by using a fingerprint scanner. However, when we have two factors of authentication, and both fall into the *is* category, we call it multimodal, for example, when a phone can be unlocked both by using facial recognition or by using a fingerprint scanner. Table 2.7 shows existing authentication methods and how they fit in these categories (Guan et al., 2021).

Requirement	Type of authentication	Authentication method	How it works
knows something	Password-based	Password	String of letters, numbers, or special characters
		PIN	Sequence of numbers
		Pattern	Sequence of movements that form a pattern
	Generative	Code	Code generated from the user's device
has something	Phisical object	Token	Encrypted object that can unlock something
		IoT device	Smart object that unlocks automatically with proximity
	Document	Certificate	Electronic document based on the idea of a driver's license or a passport
is something	Behaviour	Captcha test	Completely automated public turing test to tell computers and humans apart
	Biometrics	Fingerprint scanner	Match the unique patterns on an individual's fingerprints
		Facial recognition	Matches the different face characteristics of an individual trying to gain access to an approved face stored in a database
		Voice biometrics	Examines a speaker's speech patterns for the formation of specific shapes and sound qualities
		Eye Scanners	Iris recognition and retina scanners

Table 2.7 - List of current authentication methods and their necessary input for credential verification, structured by its requirement and type.

Even though there are multiple techniques for authentication, the user always has to follow the same steps in their devices. Understanding the steps underlining the whole authentication process is needed and, according to Lewis & Venkatasubramanian (2021) (see Figure 2.17), there are three stages:

Setup: this stage involves an initial preparation of the device so that it accepts the credential. Firstly, there should be a registration of a credential and any subsequent tasks needed for the system to accept them (e.g. placing a specific finger on a specific place when trying to set up a fingerprint scanner, and having to rotate it several times before reaching the verification screen), or setting up any assistive technology (AT) required to reach the credential verification screen. Once this stage is completed, the device is ready to authenticate the user that went through the setup stage.

Credential verification: at this stage the device is ready to identify the user and concede access to the device. The user inputs a fresh set of credentials as asked by the device, which will in turn compare it to the credentials recorder in the setup stage. At the conclusion of this stage, if the user is successful, the user will have access to the device, on the other hand, if the user is unsuccessful, the next stage, failure resolution, will be necessary.

Failure resolution: if the credential verification fails, the user might not have provided a good fresh set of credentials, the user made an error or the user is not the same user that made the setup in the first place. The device will resort to one of two types of resolution: (1) *retry*, the user made a mistake and the device is allowing more authentication attempts with the same type of credentials, (2) *backup*, the user needs to input another distinct type of credentials. In modern technology, retries are often available, granted it does not exceed a set number of attempts, when this number is surpassed, the system resorts to the backup, if available. The backup can either be with another kind of credential, previously set by the user (e.g. resorting to a PIN when failing to authenticate a biometric credential) or a credential set by a given entity (e.g. resorting to a PUC set by a mobile service company when failing three times to insert the PIN). If the device does not provide a backup or the backup authentication also fails, the user will experience a *lockout.* This happens when more attempts by the user's part are barred, which can only be unlocked after waiting for a set period of time or after going through a number of administrative steps in order to regain access.

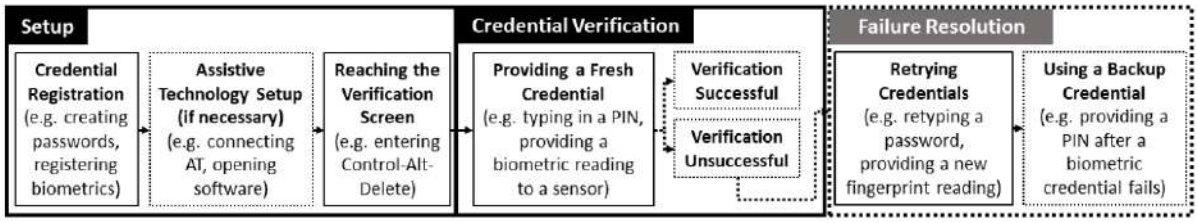

Figure 2.17 - List of current authentication methods. In Lewis & Venkatasubramanian (2021).

2.3.2. Accessibility of authentication methods

Having understood the basic aspects of authentication and what it implies, it is important to understand how it translates to authenticating when a person lives with a disability. Technology has a big role in the lives of people who live with disability (Baumgartner et al., 2021), and as we increasingly rely on devices, authentication's importance increases. It is important that accessibility is considered in authentication so that nobody is left vulnerable to privacy and security attacks (Andrew et al., 2020).

Lewis & Venkatasubramanian (2021) conducted a number of interviews on the topic of accessibility and authentication with people with upper extremity impairment and found accessibility barriers in every authentication process stage. In the setup stage people that live with disabilities find the process difficult and intimidating, ATs slow down the process or make it unreliable and several sequences to reach the verification screen are difficult. In the credential verification stage they found that password-based credentials were difficult to enter and remember but biometrics are not often suited for upper extremity impairment. Finally, the failure resolution stages do not provide sufficient retries and limited options for backup credential create lockouts.

Chapter 3

Methodology

This chapter encompasses all the methodology that was followed throughout the experimenting phase and the materials that are used in tune with the said methods. It provides context as to why certain steps were taken and why taking them can add more value to the dissertation and by consequence, to the research field.

3.1. Research through Design (RtD)

In aiming to address the goal of exploring accessible and adaptable multimodal authentication techniques for people with progressive neurodegenerative diseases, this dissertation will follow a Research through Design (RtD) approach. Olson & Kellogg (2014) state that RtD encourages researchers to investigate the speculative future, probing on what the world could and should be; this approach has to be documented in such a way that it allows other researchers to reproduce or iterate the final artifacts. The valuable knowledge produced by the design actions can take on multiple forms, but this dissertation will focus on the specific technique of creating novel perspectives that advance understanding of a problematic situation (Olson & Kellogg, 2014). This HCI practice, RtD, summons researchers to improve the world by creating new things that disrupt, complicate or transform its current state, always using empathetic understanding of the stakeholders, a synthesis of behavior theory and the usage of current technology; this later serves as a proposal, not a prediction (Zimmerman et al., 2010).

Figure 3.1 shows a modified version of Herriott's (2019) simplified RtD process, which was iterated as a way to best summarize the real year-long process. A breakdown of the research through the design process (see Figure 3.1) in combination with the Gantt chart produced (see Table 3.1. and Table 3.2.) will be made further along, to better understand what each phase encompasses.

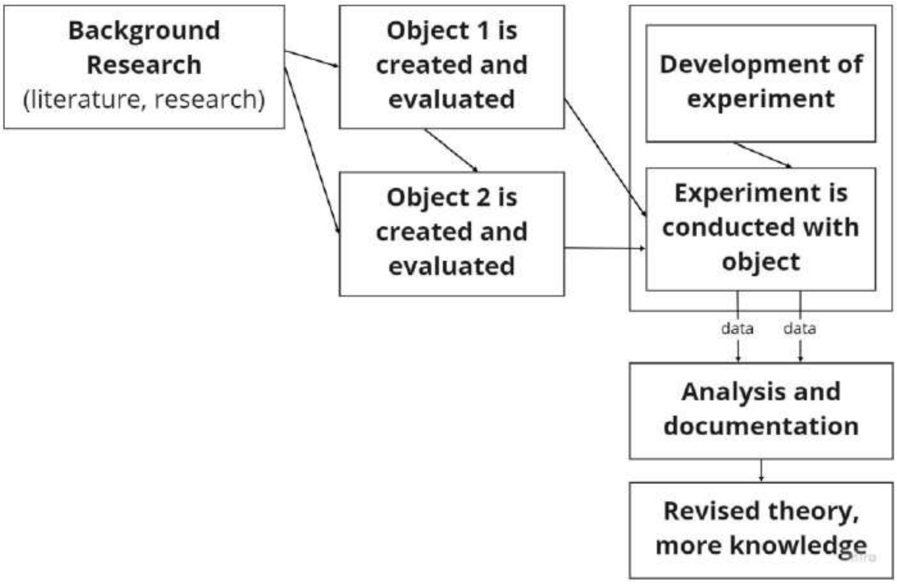

Figure 3.1 - Research through design process for this dissertation. Based on Herriott's (2019).

3.2. RtD application phases in this dissertation

3.2.1. Background Research

The first phase of this research is the Background Research, which will include the *problem analysis* (1)*, literature review & state of the art* (2) and *user research* (3) points in the Gantt chart. This research phase allowed us to develop an understanding of the scope of the problem, what focus points should be taken on, what gaps of knowledge there were and collecting previous knowledge developed by peers on the subject matters. To better understand what processes went into each phase:

Problem analysis: this phase started when the dissertation was proposed, there was a motivation to work on the subject but the theme was too broad and there was a need to define what focus area would be taken on. This phase was developed more or less in tune with the *literature review & state of the art.* The research started with attending a workshop on Diversity, Accessibility and Inclusivity in Cyber Security as part of the 34th British Human Computer Interaction Conference (*British HCI Conference*, 2021). The attendance of the workshop served as a way to gather knowledge in the field and identify papers and recent research on the problem matter. This opened three main concepts for review, *ALS*, *authentication methods* and *assistive technologies*, and after a thorough research on the topics, the focus area of the dissertation was defined and an approach started being developed; only after that did the task planning begun (Table 3.1.).

Literature review & state of the art: in this phase a library of papers and works was created. It started with the development of an understanding about the *neurodegenerative diseases scope* and what problems that might raise in terms of accessibility, both in overall technology and *authentication methods* and what *assistive technologies* are used to compensate for those problems. After defining that ALS would be the main focus, the research also trickled down that specific path, this is where the *user research* also started to take shape, which helped in identifying what assistive technologies there were and what they tried to accommodate for in the lives of people with ALS.

User research: the last activity of the last background research phase, the users were the main focus. Firstly we started the *developing empathy* phase, we had to get familiar with users before interviewing them. The collected information was divided into themes and specific topics of the daily life of people living with ALS, we started the *preliminary user characterization* (Figure 3.2). At this point, the script of the *interviews with participants with ALS* were drafted (see Appendix A). The interviews were done following a semi-structured interview approach (Lazar, 2017). With the gathered information, *personas were created and validated* to synthesize the findings and later think about the use cases for the prototypes.

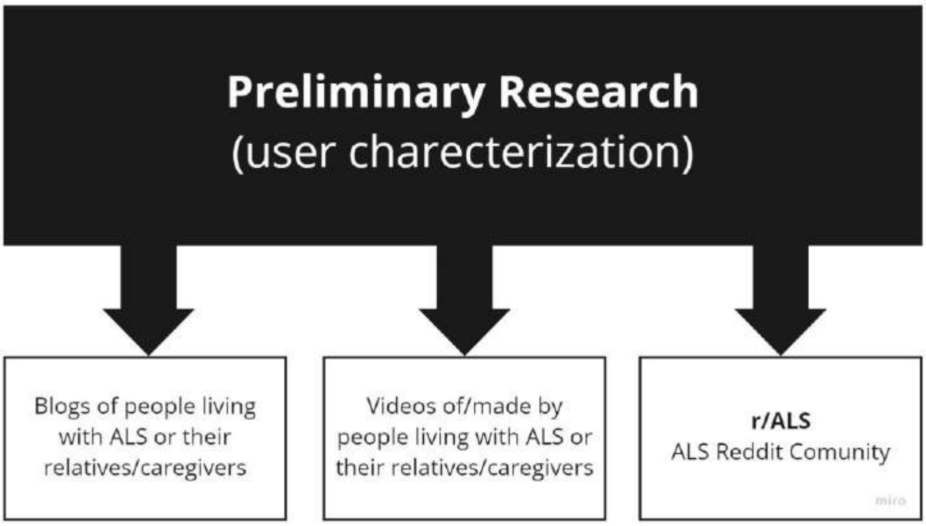

Figure 3.2 - Preliminary research for user characterization, a representation of the developing empathy and preliminary user characterization phases of the User Research.

3.2.2. Object creation and evaluation

The second phase of the process (see Figure 3.1) includes the *Conceptualization of the prototypes*, step four and *Authentication scenario development,* step five in the Gantt chart (see Table 3.3, Table 3.4, Table 3.5). To better understand what processes went into each phase:

Conceptualization of the object: The research started by attending a workshop on electroencephalography (EEG) devices as part of the BCI & Neurotechnology Spring School 2022 (*IEEE Brain*, 2022). The attendance of the workshop served as a way to gather knowledge in the field and identify papers and recent research on the problem matter and to decide to use EMG technology instead of EEG. The *design of the prototype* was done while implementing it, as the process suffered several iterations. A research on interface and authentication accessibility was conducted during the *critical analysis of strategies for the scenarios* phase. The *design of the authentication scenarios* generated high fidelity prototypes of the authentication tests which were implemented in the next step.

Development of the object: the last phase started with the *development of the EMG prototype*, using a tinkering approach (Hendriks-Jansen, 1996), where the prototype was created by modifying existing hardware and software components of developer kits and open source software (Sharp et al., 2019). After understanding how the prototype would work, the *development of the authentication scenarios* took place and both objects were created simultaneously.

Object evaluation: The evaluation of the objects was done by conducting a pilot test with both objects, this allowed for iteration before the experiment with participants began. Appendix D can be consulted for a detailed report on the pilot test.

3.2.3. Development and experimental evaluation

This phase comes after development of prototype and authentication scenarios, It represents the *Experiment design and evaluation* step six in the Gantt chart (see Table 3.2.1 and Table 3.2.2). To better understand what activities will go into each phase:

Recruitment: This phase was *recruiting participants for evaluation* (6.3). There are two strategies in place to recruit participants: (i) submit a detailed plan with a request to involve subjects to the ethics commission of the Faculty of Psychology and Education Science of the University of Coimbra (FPCEUC), *the ethical approval* (6.1); (B) contact non profit organizations dedicated to spreading awareness and helping people diagnosed with ALS, specifically APELA, the *contact with APELA* step (6.2). The participants that evaluated the objects were recruited from the researcher's personal network.

Experiment: The *experiment design* (6.4) was started when seeking for ethical approval and finished before the tests began. After recruiting the participants, the *evaluation with participants* (6.5) began followed by the *result analysis* (6.6).

3.2.4. Analysis of the documentation

This part will be included in the *Dissertation* (8) point in the Gantt chart (see Table 3.1, Table 3.2 and Table 3.3), and in the *Result Analysis* (7.3) activity which was previously explained. To better understand what went into this phase:

Dissertation: this portion was worked on throughout almost the whole process, firstly the *dissertation writing* (7.1) started after gathering knowledge and, right after the submission of the paper, the *dissertation presentation* (7.2) began. These steps were both for the intermediate document and the final dissertation delivery.

3.3. Work plan

Before the intermediate submission, a Gantt chart was created, detailing the expected task management and work timeline, represented in Table 3.1, Table 3.2 and Table 3.3. These tasks have an approximate starting and ending time and are divided into subtasks. Unfortunately, that plan could not be followed due to an overestimate of the amount of work that could be achieved in the timeframe and two restrictions: (i) health issues, highlighted in green (ii) family assistance, highlighted in blue. Although some work was still completed during the health issues period, its pace was extremely slow. The real task management highlights the task plan, in red, compared to the real task duration, in purple (Table 3.1, Table 3.2, Table 3.3).

		Academic year 2021/2022																		
Task	Task name	Jul	Sep		October				November				December				January			
		#3	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
1	**Problem analysis**																			
1.1	Key concepts exploration																			
1.3	Definition of dissertation focus area																			
1.4	Task planning																			
2	**Literature review & state of the art**																			
2.2	ALS																			
2.3	Authentication Methods																			
2.4	Assistive technologies																			
3	**User Research**																			
3.1	Developing empathy																			
3.2	Interviews with participants with ALS																			
4	**Prototyping and evaluation**																			
4.1	Critical analysis of strategies for prototypes																			
4.3	Design of the prototype																			
4.4	Development of the EMG prototype																			
5	**Authentication scenario development**																			
5.1	Critical analysis of strategies for the scenarios																			
5.3	Design of the authentication scenarios																			
5.4	Development of the authentication scenarios																			
6	**Experiment design and Evaluation**																			
6.1	Ethical approval																			
3.3	Contact with APELA																			
6.2	Recruiting participants for evaluation																			
6.3	Experiment design																			
6.4	User testing and evaluation																			
6.5	Result analysis																			
7	**Dissertation**																			
7.1	Dissertation writting																			
7.2	Dissertation presentation																			

Table 3.1 - Real task management for the first semester of the academic year of 2021/2022.

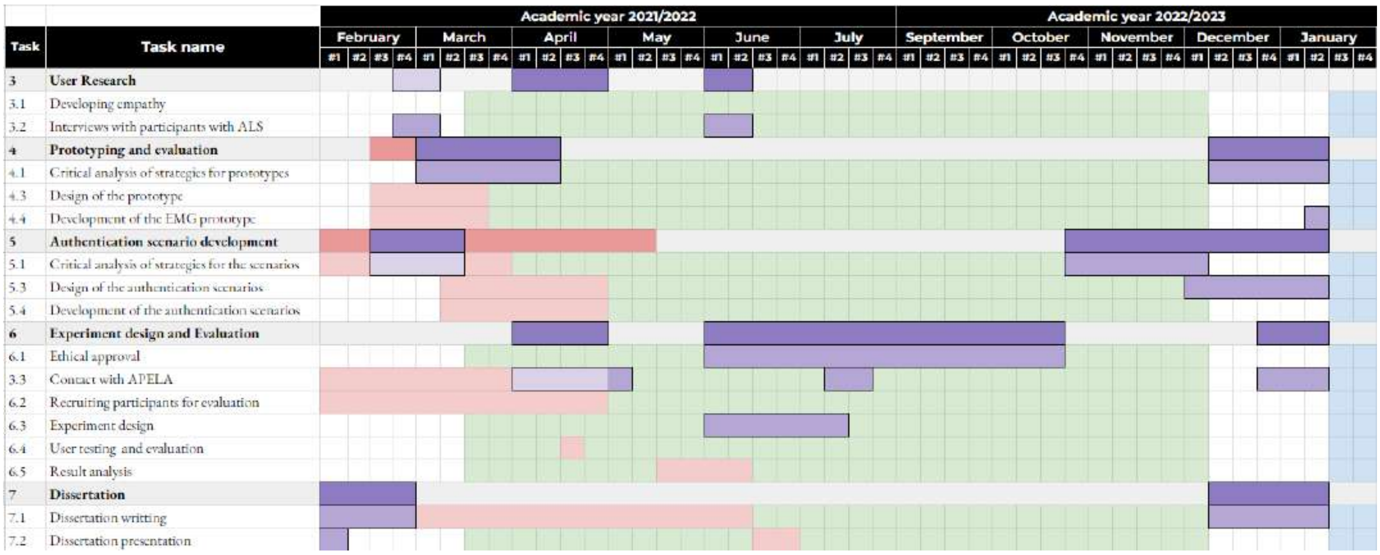

Table 3.2 - Real task management for the second semester of the academic year of 2021/2022 and for the first semester of the academic year of 2022/2023.

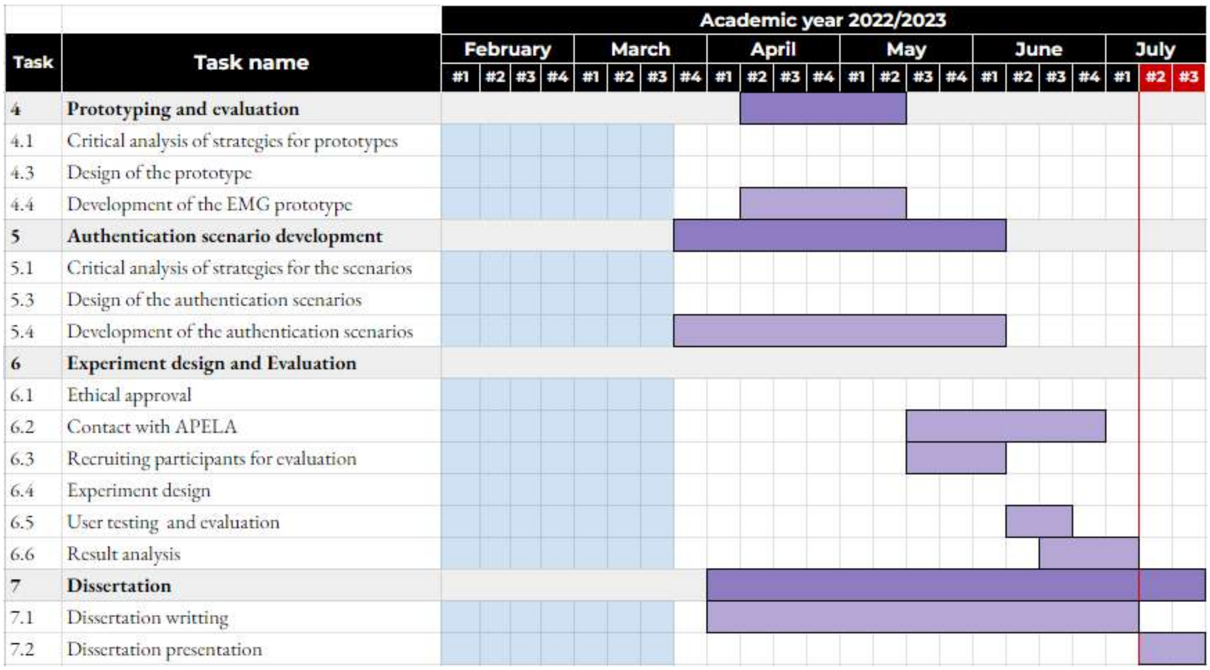

Table 3.3 - Real task management for the second semester of the academic year of 2022/2023.

Chapter 4

User research and context understanding

4.1. Studying the context

A research on the context surrounding PLwALS was conducted by analyzing information available at a variety of sources. Specifically, we reviewed: (a) nonprofit organizations dedicated to spread awareness and help people living with ALS; (b) blogs written either by people living with ALS or their relatives/caregivers; (c) videos and blogs, created by people living with ALS or relatives/caregivers of people living with ALS. These sources are specified in Appendix A (Section I).

After understanding the context, the empathizing phase began and two interviews were scripted and carried out, the first concerning the challenges of living with ALS and the second concerning the use of technology and authentication while living with ALS. The interviews followed a semi-structured interview approach. This type of approach strives to reveal critical comments, design requirements and other insights (Lazar, 2017). According to Lazar (2017), when there is unfamiliarity with the problem domain, it is best to giving the interviewees a chance to educate us. This proved to be of great value as the participant could further elaborate on topics we had not thought of yet and any gaps in understanding that might surface during the interview could be asked in real time.

The first interview's script was drafted (Appendix A, Section II) and it concerned: (a) personal attitudes and experience; (b) personal goals; (c) daily routines; (d) technology use; (e) personal relationships; (f) disease progression. The collected data, from the preliminary research and first interview, was analyzed by themes. The data organization was completed by drafting an affinity diagram, where the unstructured information from each source was grouped by topics (Appendix A, Section I). The topics were: (i) what makes them happy; (ii) what makes them sad; (iii) adaptive strategies; (iv) ALS symptoms and progression. After understanding the main characteristics of PLwALS and their life context, a persona card was created to clarify and represent the attributes of our study group (Figure 4.1). The validation of the persona card was done with the interviewee, a PLwALS, and two HCI experts. The artifact was shown to them and a set of questions were asked concerning its value, which resulted in feedback concerning its suitability:

- Description of the personas include the main characteristics about their abilities or lack thereof (mentioning speech or motor impairments) as well as progression of ALS
- Describes the context, including information about the job, family relationships, hobbies and environments familiar to the user
- Describes the user's interaction with technologies, highlighting challenges as well as solutions identified to overcome eventual obstacles.
- It is possible to identify the intentions and the goal of the persona.

- The tone of the narrative is appropriate. While realistic, it highlights the limitations of the environment, it clearly describes the abilities of the persona and how she interacts with the world.

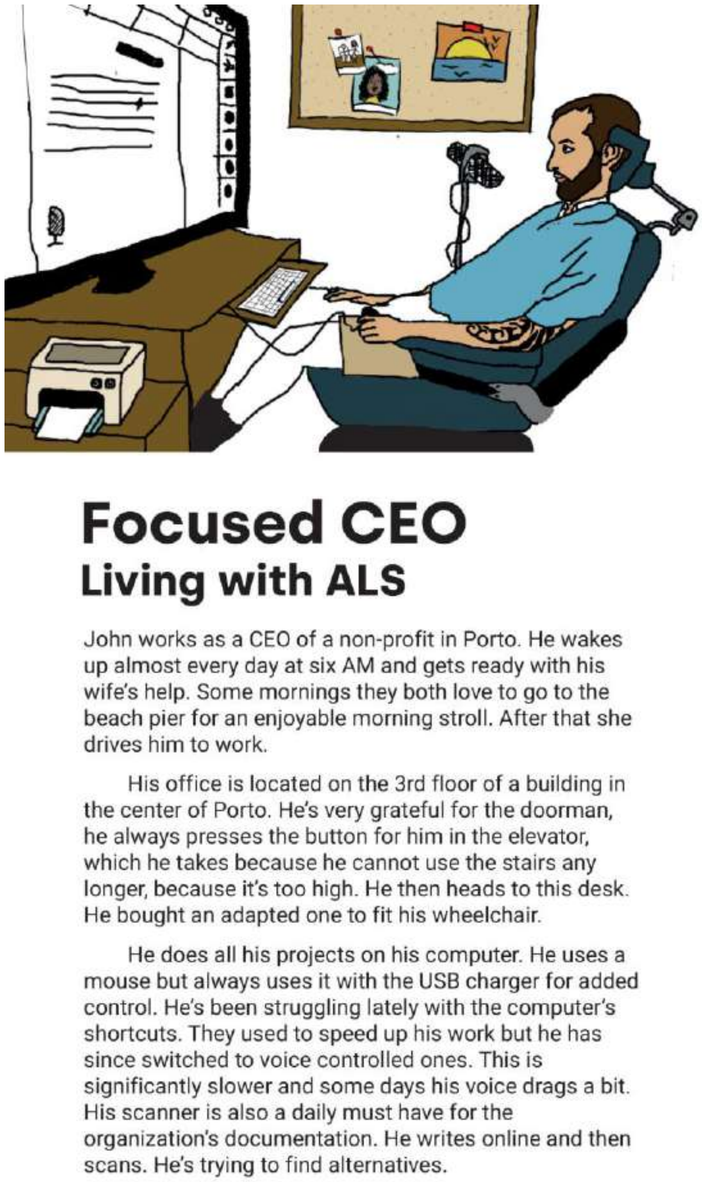

Figure 4.1 - Persona card developed with the collected data.

4.2. Interviews

This section reports on the interview plans, procedures, analysis and findings.

4.2.1. Interview Planning

In order to get the most out of the interview, a plan was created keeping in mind the participant's background. Both interviews were conducted by the researcher, but the supervisor was also present as an observer.

The interviews followed a semi-structured approach had a set of questions to be asked in a specific order, but the interviewee was free to talk about similar topics and into as much detail as they wanted; if gaps of knowledge surfaced during the interview, the interviewer would ask new questions in order fill those new gaps. A supporting script (see Interview 1 and Interview 2 in Appendix A) was written for both interviews, this way, all marks would be hidden and no specific question would be forgotten. Each interview lasted about 50 minutes and a verbal consent was asked of the participant before starting the interview, to record and use the data for academic, publication or presentation purposes.

The first interview served to develop an in-depth understanding of our main stakeholder, people who have a ALS diagnosis. After the preliminary research about the subject, there were still a few gaps of understanding left to disclose, with this interview we were able to go through topics such as the personal attitudes, experiences and goals they might have, what daily routines they have, what technology they use, what are personal relationships like and how does the disease progresses over time.

The second interview was fundamental for understanding what impact does technology have in their lives and their relationship with authentication. Three main subjects arised from the preliminary research, accessibility, technology and accessibility, these were used while creating the script and various notions of the three were presented to the interviewee for a better analysis of her personal experience. From those three main subjects, some topics needed to be analysed, such as what electronic devices are used, what softwares and applications are used and how, what types of authentication methods do they use/used/used to use, how do they adapt to the disease progression and how do they feel about authentication standards as of now.

4.2.2. Participant

The interview was conducted with a 54 year old woman who has been diagnosed with ALS five years ago. At the time of the interview, the interviewee experiences low mobility in both her upper and lower limbs and uses a wheelchair to minimize fall risk. She has difficulty supporting neck weight, has low hand agility, preserves all cognitive capacities, maintains regular eye movement and wears glasses. The interviewee is still able to speak, although slowly, and regardless of it being tiresome, or even impossible some days. Currently the interviewee is the CEO of a non profit organization, before she was diagnosed, she used to be a HCI lecturer and researcher.

4.2.3. Procedures

Two interviews were conducted with the participant, both by the advising professor and the student, respectively. Verbal consent was given by the participant consenting to record and use the data in academic publications or presentations. The interviews were conducted via Zoom and recorded for later analysis. The recordings were fully transcribed and later analysed by the student, a codification of all findings was done.

4.2.4. Interview analysis and results

In order to identify the main themes that surfaced during the interview, an axial coding process was used while using a mixed coding approach: using both *emergent* and *a priori* coding. Lazar (2017) states that a mix of emergent and a priori coding can be useful in situations where certain topics are previously settled while also searching for new topics. Three main themes came from background research: **technology**, **accessibility** and **authentication**. Level 1 and Level 2 topics (Figure 4.2) are considered *a priori codes*, whereas the subsequent Levels of depthness are considered *emergent* codes, given that they spawned from the interview. First the transcript was read and analysed and all the important pieces of text were highlighted; these were then recorded on a spreadsheet. A **code** was attributed to those same pieces of text and each code was clustered into a **sub-category** which in turn would be placed into a **category**. All categories should fit into the three main themes, which are called **patterns** (Lazar, 2017). Once coded, a count was made of each pattern to determine the number of times the interviewee mentioned specific codes during the interview. The participant referred to technology eight times, to accessibility 19 times and to authentication 17 times. The analysis revealed 6 levels of depthness which can be traced back to the 3 categories. The analysis of the second interview, which had as a main focus the accessibility of authentications used by the participant, is synthesized in Figure 4.2. The findings were structured with a tree approach, where the three main topics (technology, accessibility and authentication) were listed as Level 1 depthness topics. As the Levels go up (right to left), more than one child-node can spawn from the parent-node, representing how specific the finding is in relation to lower Level topics and how, from three initial topics, a deeper understanding was created from the interview.

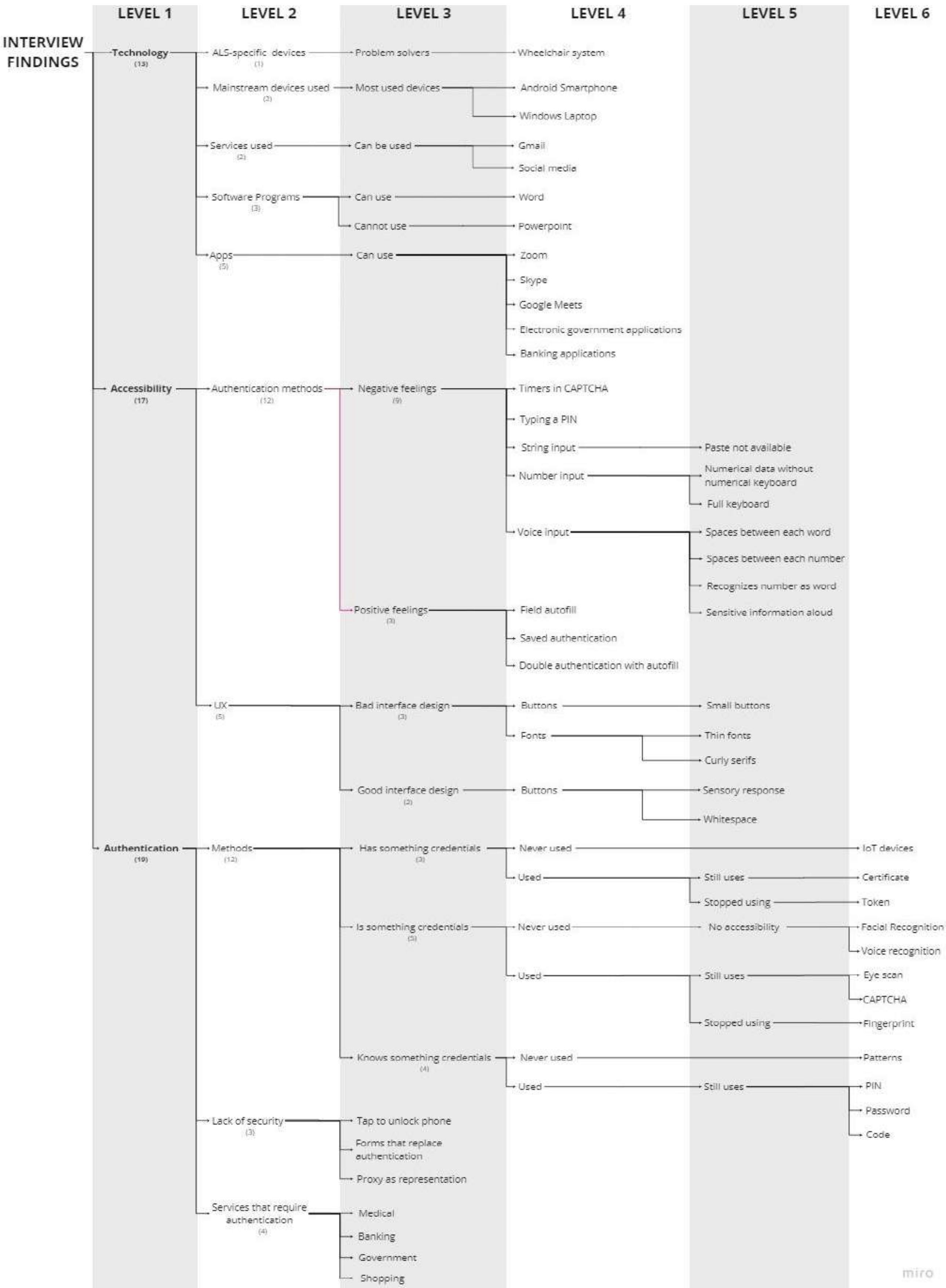

Figure 4.2 - Second interview analysis.

4.2.2. Interview findings

This section reports on the findings of the second interview, which are divided into the three patterns and ordered by how many times they were mentioned during the interview, starting by the most mentioned. The three topics, authentication, accessibility and technology are structured into various key findings which are elaborated and connected to what the interviewee said throughout the interview.

Authentication

The authentication pattern came up 19 times during the interview, where findings were divided into two categories: **authentication methods** and **lack of security**. In the **authentication methods** category, the findings are subdivided into the negative and positive aspects of different types of methods, knows something, has something and is something. The **lack of security** category explains why securing the device/app/software is not always the way to go.

The analysis of the interview shows that ***Is something*** **authentication methods have problems in every phase of the authentication process.** The interviewee stated that without the aid of certain assistive technologies, such as a tablet with eye tracking and a special wheelchair, she simply would not be able to use biometrics. She further explained that the setup phase could never be done by herself alone, since in the early stages of ALS, people lose the ability to keep their head straight due to lack of neck muscle control, which means the person would need a third party holding their head straight, during credential setup.

Into what concerns, the ***credential verification*** **phase**, the participant explained that **fingerprint authentication is very difficult** since hand dexterity is required to hit the sensor and, once all hand movement is lost, it is simply unusable; for facial recognition, *"I do not use facial recognition because I cannot be sure I would always place my head properly."* was the main issue. When the set of biometric credentials is not accepted, the user is prompted with the *failure resolution* procedures. After a few attempts, the user needs to insert a different set of credentials, which are usually of the type *knows something.*

Knows something **methods are used instead of other methods.** Regardless of the other methods being available, PINs, passwords, and codes are the interviewee's first choice. *"Yes, I've used [... pins and passwords...], uh, and I use them on a daily basis. [speaking of knows something passwords]".* This result concurs with statements found in the topic's literature (Lewis & Venkatasubramanian, 2021).

Users do not use authentication when it can be avoided, if unavoidable, a second party is called to authenticate the user. Having to choose between securing private data and being able to use the device is a choice that people who live with disabilities often have to make, as the interviewee stated *"I really, I just have to tap in order to unlock my phone. So I don't have the security."* The participant further stated that this was not merely a matter of convenience. The interviewee explained that, in an event that she has an emergency during the night and was not able to use her voice, she needed to be able to unlock her phone easily. Having to use a *know something* type method instead, would mean that she would need to put her glasses on to see the authentication screen properly, which she might not be able to do, and then she would not be able to call for help.

Accessibility

The accessibility pattern came up 17 times during the interview. The key findings are divided into two categories, **authentication methods** and **user experience (UX)**. The **authentication methods** category is divided in positive and negative aspects of the different processes surrounding authentication. The **UX** category presents a report of what the interviewee finds positive or negative in the overall user experience of multimedia devices/software/apps.

Keyboard input can be a challenge. Two types of issues surfaced regarding keyboard use: string input (password) and number input (PIN and code). The interviewee stores her passwords in a file that she keeps handy, so that whenever she needs to enter a password, she can just copy- paste them. However, not all password fields allow for this procedure Concerning the *number input,* the participant states that a full keyboard should not be provided, when only numbers are to be entered: "*you're asking for a number, why do you give me the full keyboard, where I might not select the correct numbers, that is very weird.*" "*It's tough with a keyboard, whenever you have to put numeric data, and it doesn't give you just the numeric keyboard, it gives you the whole keyboard, that is a pain, a big pain.*"

Voice input is not optimized for authentication. The interviewee currently uses speech-to-text, whenever her voice allows her to. She uses speech-to-text to ease typing, but she reported that she meets a barrier whenever she needs to dictate in password fields. She found that, besides having to give away sensitive information aloud, the keyboard behaves as a simple string field, puts spaces between words/numbers, and recognizes numbers as words: *"let's say I have a username named, one two three four. I would say user, and then it will put a space, or even if I say user one hundred and twenty three it will put a space, or if, uh, if I say user one two three, it will put a space in between, you can say a hundred and twenty three, but if you have nine digits, then it's difficult to say the whole number."*

Automatic processes help ease authentication processes. Saved authentication and double factor text messages that fill automatically are two processes that can help a lot for people with disabilities. Once the username and password are inserted once and saved, the user would only need to click one button instead of going through the whole *credential verification* process. The interviewee stated that *"you have only a very short time, you try to do it in time and it is very stressful"* and, when asked if she used automatic processes to ease the process, she reported that *"Yes, I use that a lot."*

Mistakes are attributed to lack of usability. The interviewee stressed that certain accessibility design rules are not followed and that she often comes across small buttons and buttons which do not have enough whitespace between them, this leading to misclicks, which then lead to errors, which in turn need to be resolved. Another important issue is sensory response to an input, whether that be visual (e.g. change of colour), tactile (e.g. vibration) or auditory (e.g. the button makes a sound when clicked). In this citation, the interviewee is explaining how she overcomes lack of sensory response in her bed controller (Figure 4.3), *"it has a control to put it in five different positions, but the control and it's a big controller. But it has soft buttons, it's a membrane with the touch sensor underneath, then it does not have any lighting underneath, but one led that I tend to vary with, if you play, somehow you might be able to see at night. So in order to bend on my bed, I use my feet, so when I want to go up, because I need to bring my back up or the feet up on those controls on the left side, I use it with my right foot and I used my toes of the left foot and in order to then bring it down, I use my feet."*

Timers are stressful. The interviewee stated that with CAPTCHAs and other types of authentication there is sometimes some kind of timer and that it increases stress, which results in errors and can aggravate the situation *"Because they have a time, and timers, for people who have mobility issues, are difficult. Yeah timers are stressful. So because, you know, you have only a very short time, you try to do it in time and it is very stressful, so you can feel it, and stress is an enemy for us."*

Figure 4.3 - Controller used and described by the interviewee to change her bed's position. Captured by the interviewee.

Technology

Assistive technologies are key for a better experience with devices for people living with disabilities. Certain types of authentication are simply unusable from early stages of ALS without the aid of assistive technologies that are not incorporated in the device, for example, here *"I would have to have my head steady. So it would be placed in a steady position. So if it would be set up in that position, it would work."*. Here the interviewee is referring to a tablet display with an eye tracking software that would be mounted on her wheelchair; without it, it does not make sense to use facial recognition since her head position is key to *credential acceptance* and, in case of *authentication failure*, she could insert the *backup credential* with ease.

Chapter 5

Object Design and Development

This chapter reports on the design and development process of both objects, the authentication scenarios and the prototype. It provides an overview of what choices were made and why, their development and what challenges were faced and how they were overcome. It is divided into two sections, one dedicated to the EMG prototype and another to the authentication scenarios.

5.1. Design and implementation the prototype

Electromyogram

We used electromyograms (EMG) to implement the hardware prototype. Three electrodes were needed: a negative, a positive and a reference electrode. The negative and positive electrode would be placed on the user along the muscle belly, and a reference electrode in a region of low muscular activity (Figure 5.1). The voltage differences of the muscle power were then converted and used as the input method for the authentication scenarios.

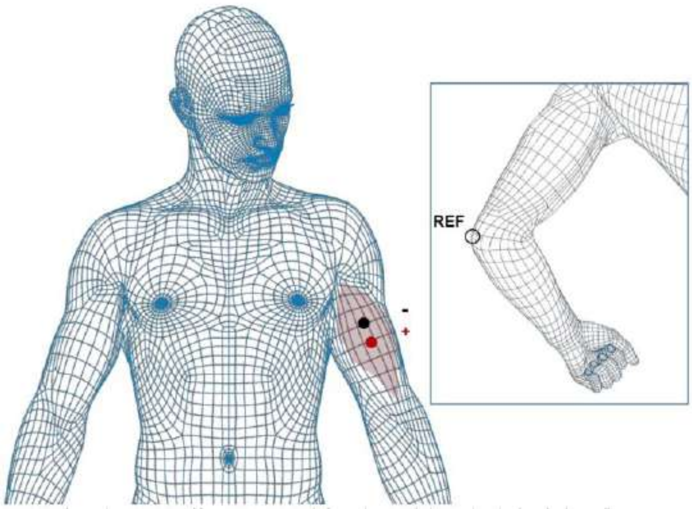

Figure 5.1 - How to place the electrodes to measure the muscle activity of the biceps brachii. The electrode positioning shows the two measuring electrodes placed on the muscle and the reference electrode on the elbow (PLUX Biosignals, 2023).

Hardware

To collect the voltage differences in a muscle, we used a Bitalino Plugged Kit[1], which is a prototyping kit for physiological signals, specifically the Bluetooth connection version. The kit comes with a battery that can be charged through the Bitalino, using a cable. The Bitalino has a built in LED that indicates its state: (i) if here is no light, the Bitalino is off; (ii) if the light blinks slowly, the Bitalino is on; (iii) if it blinks rapidly, the Bitalino is connected to a software.

We connected a Bilatino port to the EMG sensor with a cable, and then the EMG sensor to the electrode cables (Figure 5.2). New electrodes were added at the three ends of the electrode cables, each assigned to as negative, positive, and reference (Figure 5.3)., to ensure a clean muscle power reading.

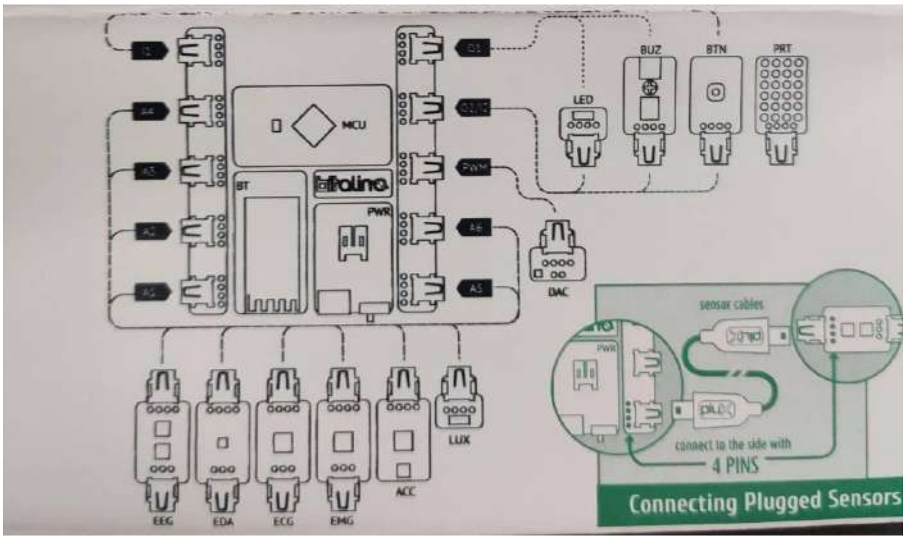

Figure 5.2 - Board map for Bitalino sensor connection.

[1] www.pluxbiosignals.com/collections/bitalino/products/bitalino-revolution-plugged-kit-ble-bt?variant=41622008135871

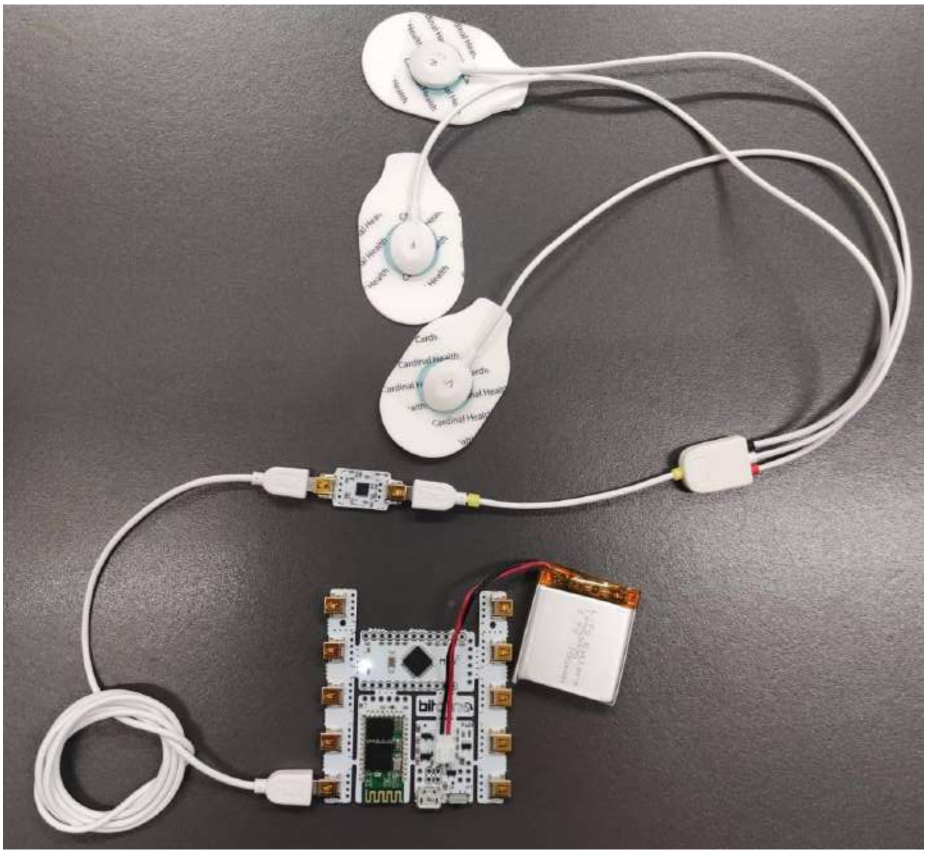

Figure 5.3- Final Bitalino connection.

Software

Concerning our approach to interaction, we used real-time EMG data for our input method.. We used Biocybernetic Loop Engine (BLE) (2017) to (i) receive and process data from sensing devices, the Bitalino to (ii) convert that data into an output, by passing it by conditions defined by us in its visual scripting Biocybernetic Console (this output changed the value of Unity variables); and (iii) send that output to the Unity scene. Figure 5.4 exemplifies how the data is received, processed and sent out.

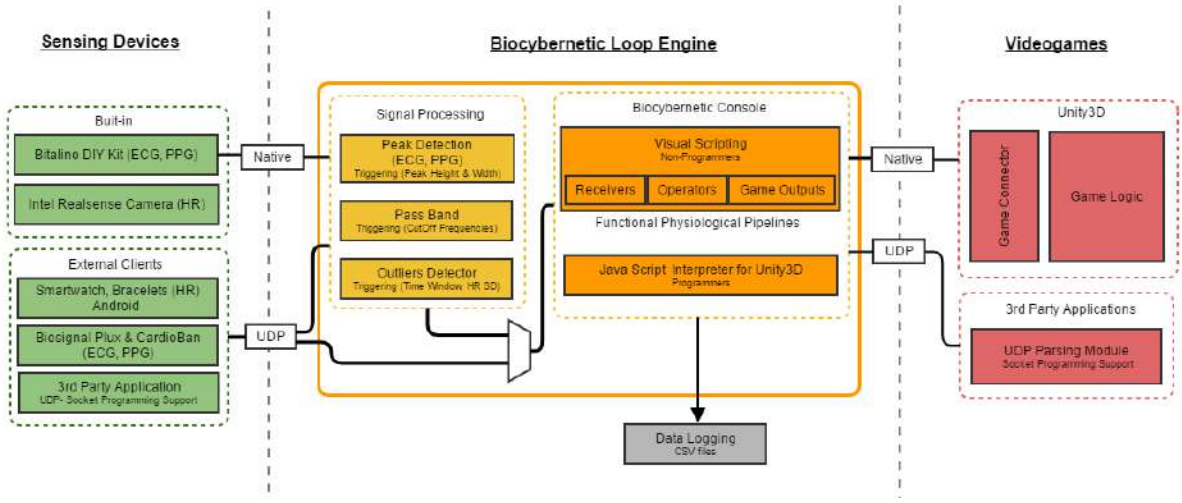

Figure 5.4 - Connection between Bitalino, BLE and Unity.

The BLE exchanges data with Unity through UDP Communication (Figure 5.4). We provided the system with the ports that were sending and receiving the data, and the IP address the data was sent through. We also entered these specifications in a Unity script that enabled us to receive and change the value of our Unity variables.

To receive the data from the Bitalino, we specified the COM port that was being used by the Bitalino and the channel that was collecting the EMG data (Figure 5.5). The BLE also has a Biocybernetic console, which allowed us to create the code, in which our signals would pass through to change their value. This was a low code platform with drag and drop blocks of code that could be connected to create our event system (Figure 5.6).

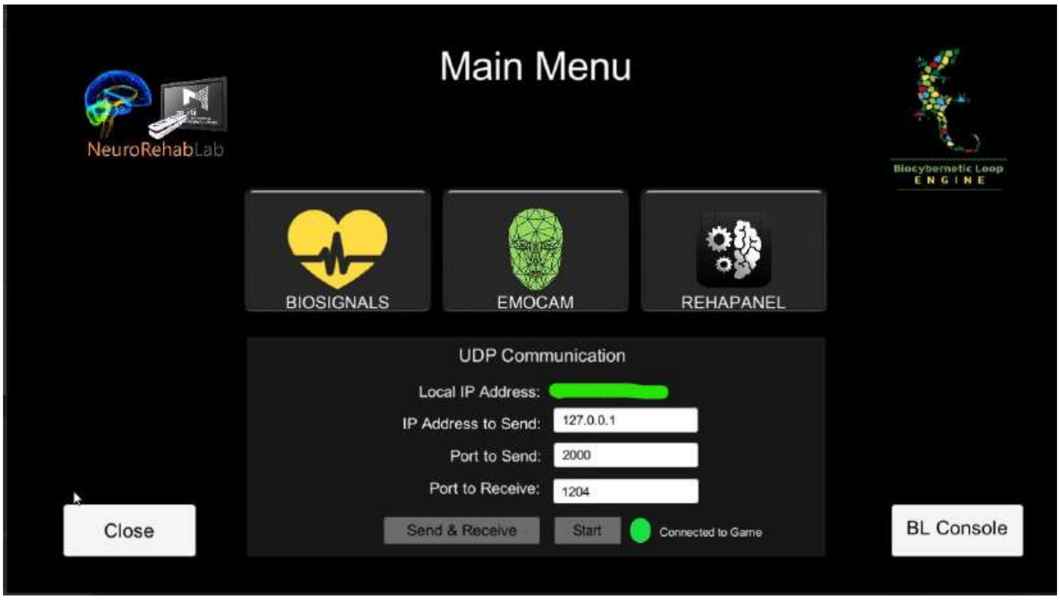

Figure 5.4 - BLE interface with UDP and IP inputs.

Figure 5.5 - BLE receiving the Bitalino signal via Bluetooth.

Code

The Bitalino collects altering current (AC) power signals, which generate a wave with a broad range of amplitudes and frequencies. In AC power signals, the instantaneous value varies and that value cannot be used to calculate the power of the muscle. This means that these raw values could not be used in our system. In order to analyse the signal values, we used a math array code block to calculate the Root Mean Square (RMS) of the value array of the received wave. This value provided us with the equivalent of a DC voltage, which has a constant value for every instant of time. The processing window for signal acquisition was one second and the RMS of that wave was calculated every instant.

The output of the Math Array was then compared to a constant. This constant's value was based on the average of the expected maximum and minimum value outputted by the RMS calculation. If the signal value was higher than the constant, the value of the Click variable would be changed to 1 in Unity, indicating an interaction with the system (Figure 5.6, top). If not, the value of the Click variable would be changed to 0 in Unity, indicating no interaction with the system (FIGURE_5.6, bottom). This value was set to be updated and sent to Unity every tenth of a second.

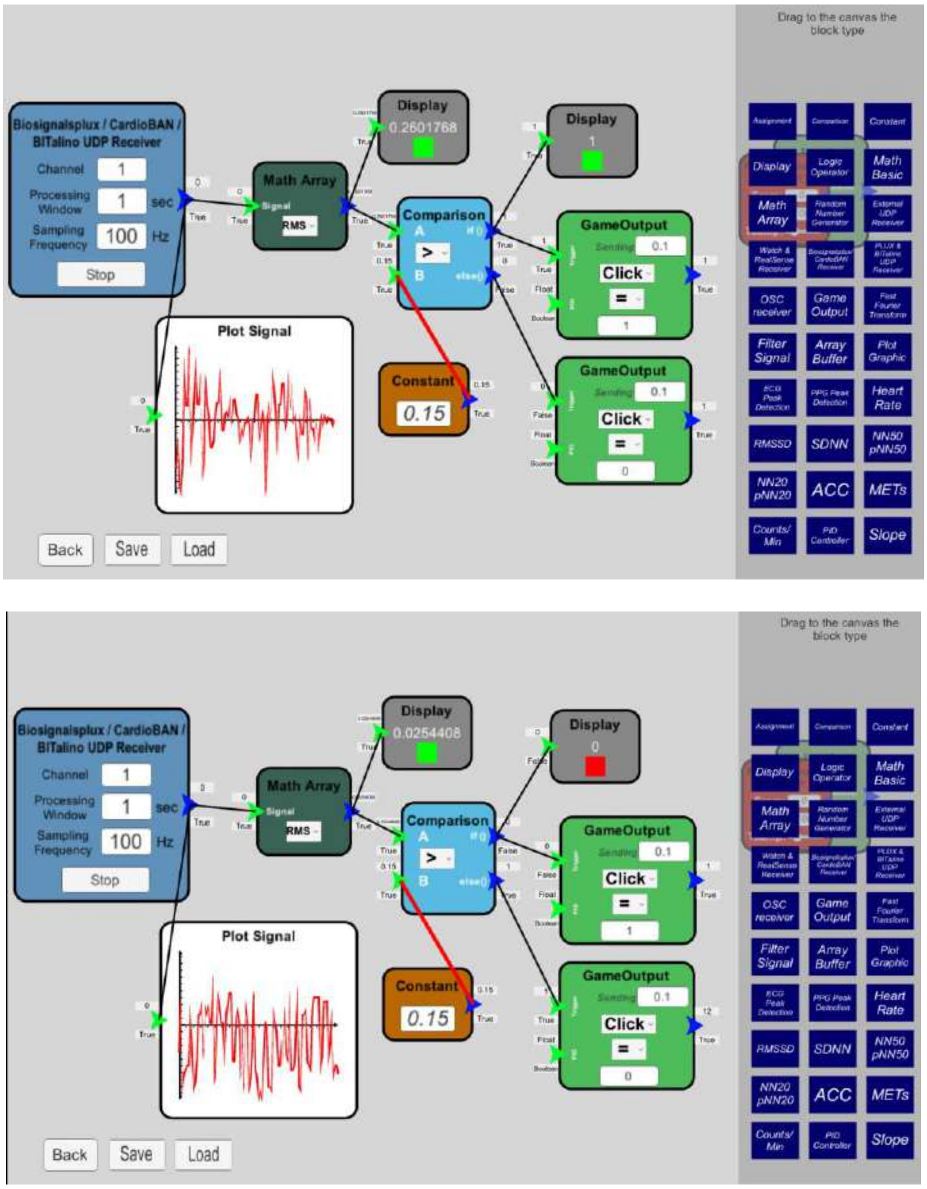

Figure 5.6 - Logic implemented in the BLE GameConsole
receiving an input attempt (top) and no input attempts (bottom).

5.2. Authentication scenarios

This section reports the design process, implementation, preliminary testing and softwares used to create the authentication scenarios. It also details how the authentication scenarios and the prototype were linked to work together.5.2.1.

Software used

Figma (2016) was selected as the main software to design the authentication scenarios. Figma offers simple, yet powerful prototyping capabilities, is open source, has multiple resources and plugins to facilitate the work process, and a big community, which can be helpful in face of an obstacle.

To design the scenarios we followed the Material Design system by Google, third iteration (Google, 2021). This was a useful tool to determine the button size and colour and the scenarios gutter size. The Material Design system by Google was chosen because it was developed with accessibility as a concern, providing a clear, robust and specific interface throughout (Google, 2021) and also because it provides the Material 3 Design Kit, which can be used in Figma.

Authentication methods and keyboards

We applied several criteria when selecting the authentication methods that should be covered in the authentication scenarios: (i) *would it work with the prototype?* (ii) *is it commonly used among most domains* (e.g. medical, governmental, shopping, etc)? (iii) *was it mentioned in the interviews?*. Provided that people need to authenticate themselves various times a day in multiple systems, the tests should also be focused on commonly used authentication methods, like PIN and Password, which are used in banking, governmental and shopping applications and are also used to access devices like computers and smartphones. Finally, since this study is to investigate the experience of the end user, we should work with the crucial information that was provided by them. All the scenarios detailed in Table 5.1 were mentioned in the interviews as an authentication method that was used daily.

Table 5.1 provides an overview of the authentication methods chosen for the scenarios. Figure5.7 illustrates an example for each variation. These methods respond to the three criteria identified above: they work with the prototype, are commonly used amongst all domains and they were mentioned during the interviews. The random keyboard options (A.2 and B.2) were added because when using banking applications, users usually need to authenticate themselves with random keyboards that are displayed inside the page.

Scenario Code	Requirement	Type of Authentication	Authentication Method	Variations
A	know something	Password Based	PIN	Normal keyboard position (A.1)
				Random keyboard position (A.2)
B			Password	Normal keyboard position (B.1)
				Random keyboard position (B.2)
C			Pattern	(C)

Table 5.1 - Chosen authentication methods, and its variations, for the authentication scenarios.

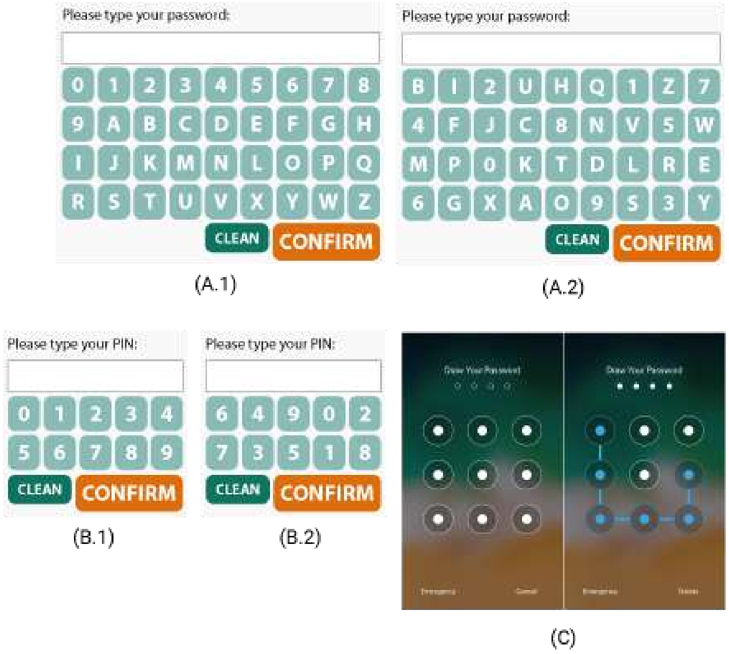

Figure 5.7 - Examples of the authentication methods that were chosen for the authentication scenarios, and its variations.

The keyboard displays selected for the scenarios were QWERTY for Password, and Strictly Numeral for PIN. Then each of those displays would be randomized in *Random keyboard position scenarios* (scenarios A.2 and B.2 in Table OUT_ESC). Figures 5.9 and 5.8 depict both keyboards. The process of choosing which Special Characters was also included in the keyboard involved consulting websites that listed several Special Characters supported by several systems (Oracle, 2018). The final decision was that, besides Special Characters supported for passwords, we should also support several other Special Characters, given that the user, provided a different context, might need to use them.

The *Clear* and *Back* buttons were added into the keyboard keys because they constitute a key element of the PIN and Password input process. They were placed in the final rows of the keyboard due to their usage recurrence. If someone wants to introduce a PIN with six numbers, the expected behaviour is to: (1) not use the *Clear* button, unless they make a mistake; (2) only use the *Back* button once, after PIN introduction; (3) use six times the number keys, if they make no mistakes while typing the PIN number. The same thought process was applied to the *Special Character Key* and the *Caps Lock*, each only needed to be used two times, one to access those keys and one to reverse that choice.

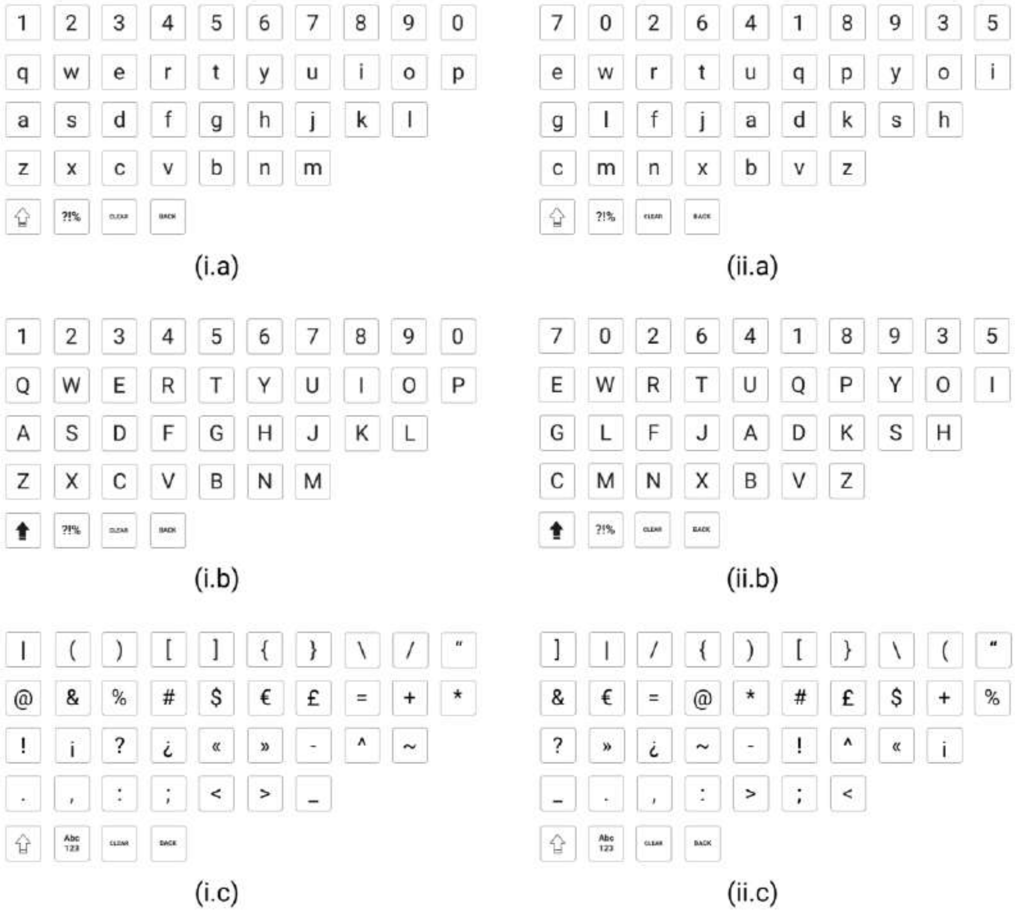

Figure 5.8 - Keyboard dispositions that were designed for QWERTY keyboards.

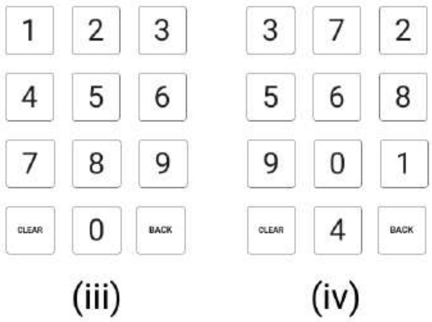

Figure 5.9 - Keyboard dispositions that were designed for number keyboards.

Colour and typography

We made a study on the colour palette to be used for interaction (Figure 5.10) to make sure it was accessible, not only because some people have difficulty perceiving colour bus also because, as discovered in the user research phase, some PLwALS use limited-colour or monochrome displays and browser. The colour palette study was done with the *Designing with accessible colours* kit provided in the figma's *Material 3 Design* kit. We used the (ii.a) version (Figure 5.10), because it was not straining on the eye and the colours that were overlapping passed the *Colour Contrast for WCAG Compliance test* (WCAG, 2023). Figure 5.11 shows the chosen colour palette. The palette addresses: background; containers, for the interaction display; error handling; what colour should the text be, when on top of the previous items.

For the authentication scenarios, we used Roboto (Robertson, 2011), a font that was designed for high legibility, especially for digital screens. Its clean and open letterforms, ample spacing and balanced proportions contribute to its readability across different screen sizes and resolutions. This font is also indicated for users with dyslexia and visual impairment (Zaraysky, 2021).

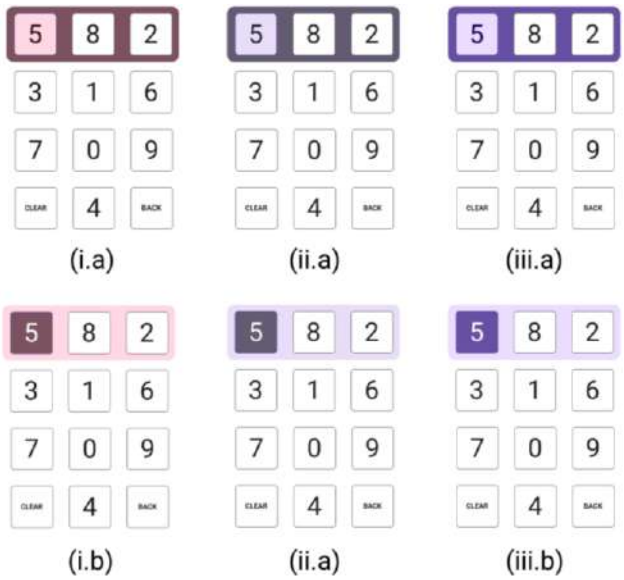

Figure 5.10 - Colour tests for interface interaction variations.

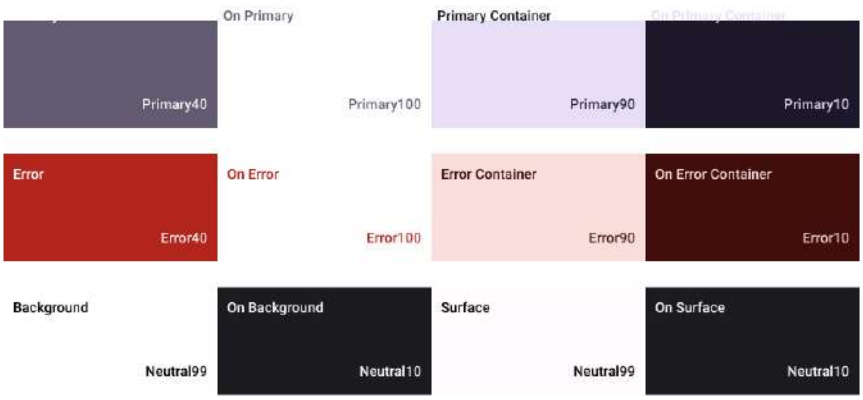

Figure 5.11 - Final colour palette.

Interaction and feedback

As highlighted by the Web Accessibility Initiative (WAI), (WAI, 2023) interactive elements need to be easy to identify. We labelled all our input fields with a placeholder text addressing what needed to be imputed in the field. We also ensured that all buttons were labelled with what they would do when interacted with. Figure 5.12 depicts these choices, for example, the Username input field uses the placeholder text "Enter username..." and the button that submits the user's credentials is labelled as "CONFIRM".

Figure 5.12 - Authentication scenario's input fields.

With regards to attend to the problem exposed in Chapter 2, figure 2.12, for the interaction methods of the intractable elements, i.e. the fields and buttons of the screen, we relied on change of colour whenever an element was intractable and on highlighting whenever a row of elements was intractable:

1. If the elements were displayed in a row, the elements would be highlighted in succession, top to bottom, until the user interacted with one of them (Figure 5.13).
2. If the elements were displayed on a grid, the rows would be highlighted in succession, top to bottom, until the user selected one of them. Then, the elements in the selected row would change colour in succession, left to right, until the user selected one of them (Figure COL_INT).
3. If an input field was selected, they would stay highlighted as the specific keyboard appeared, indicating what the user was interacting with. Then the user would interact with a grid system, the keyboard (Figure 5.15).

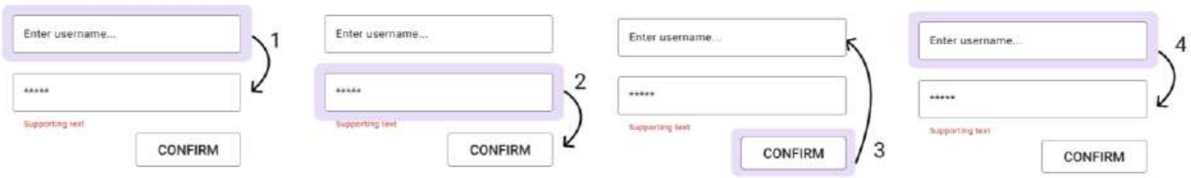

Figure 5.13 - Interaction feedback for row display.

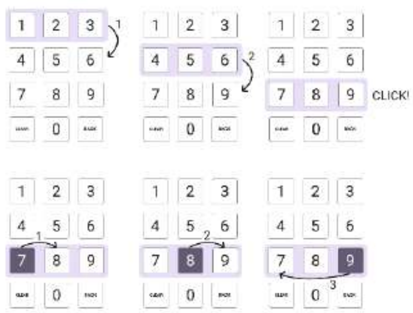

Figure 5.14 - Interaction feedback for column display.

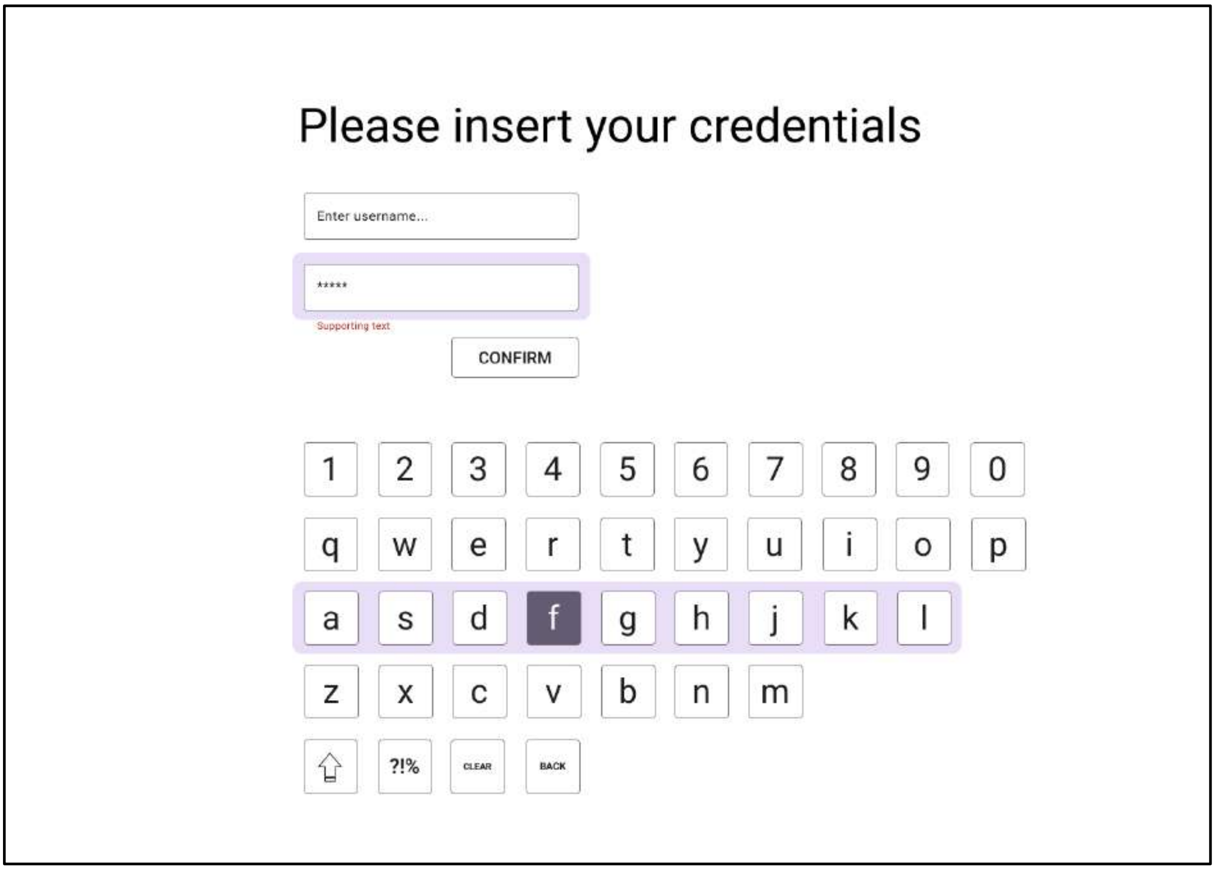

Figure 5.15 - Authentication scenario mockup with interaction display.

Interaction feedback was also taken into account when designing the keyboards. Buttons that, when interacted with would change the keyboard's display, needed to provide visual feedback so that the user could understand what changes had been done and how to revert them (Figure KYB_VAR_INTER). When the user chose to capitalize the keyboard letters, the *Caps Lock* symbol should change its filling from white to black, as shown in the passage from the (i.a) keyboard to the (i.b) keyboard in Figure KYB_FULL. Following that example, when the user chose to use *Special Characters*, the *Special Characters* symbol should change, as shown in the passage from the (i.a) keyboard to the (i.c) keyboard in Figure Figure KYB_FULL.

Error handling was also a concern. To address potential authentication errors, we needed to provide easily identifiable feedback to the user, whenever a credential was incorrect or if there was a mismatch between the username and the PIN/password. According to WAI (2023), feedback should be presented in a prominent style and the instructions about the error should be specific, for ease of error resolution. For this, we applied red coloured error messages under the input fields (Figure ERROR_MESS), and created a list of error messages, presented in Table ERR_MSG. These errors would appear whenever the user submitted incorrect credentials, Table 5.2 can be consulted and crossed with Table 5.3 in order to understand what triggers these error messages. For example, if the user submits their credentials, and both the username and PIN are missing, "Username missing!" should appear under the username input field and "Password missing!" should appear under the Password input field, as illustrated in Figure 5.12.

ERROR MESSAGES		
Error message	**Error output**	**Text**
U.1	Username input field	"Username missing!"
U.2	Username input field	"This username does not exist."
P.1	PIN input field or Password input field	"PIN missing!" or "Password missing!"
P.2	PIN input field or Password input field	"Username and PIN do not match." or "Username and password do not match."

Table 5.2 - Displayed text for each error message.

DISPLAY ORDER OF ERROR MESSAGES				
		Username		
		Missing	**Incorrect**	**Correct**
PIN or Password	**Missing**	Error message U.1 Error message P.1	Error message P.1	Error message P.1
	Incorrect	Error message U.1	Error message U.2	Error message P.2
	Correct	Error message U.1	Error message U.2	–

Table 5.3 - Display of error messages based on PIN and Password input.

5.2.2. Implementation of the authentication scenarios

Software

For the development of the authentication scenarios we used Unity (2016) in combination with Visual Studio Code (2015). Unity was chosen because it has a comprehensive set of tools and features for creating interactive interfaces with a big user community. Unity also allowed us to work with the BLE, which was a requirement. Unity was used to create the screens, manage assets and implement the scenario and component's mechanics. Visual Studio Code was chosen as the source code editor and was used to write the scripts that defined the scenario and the component's mechanics and logic.

How objects work together

Figure5.16 shows a flowchart diagram of how the authentication scenarios work. This diagram details the system's flow and the different output of interacting with its elements. The green elements represent the start/end of the system, the purple elements represent the input elements and the red elements represent error outputs.

The Unity scene also had to work simultaneously with the BLE, which in turn had to receive data from the Bitalino prototype, Figure 5.4 depicts how this is processed. The sensing device, the Bitalino, sends data via UDP to the BLE.

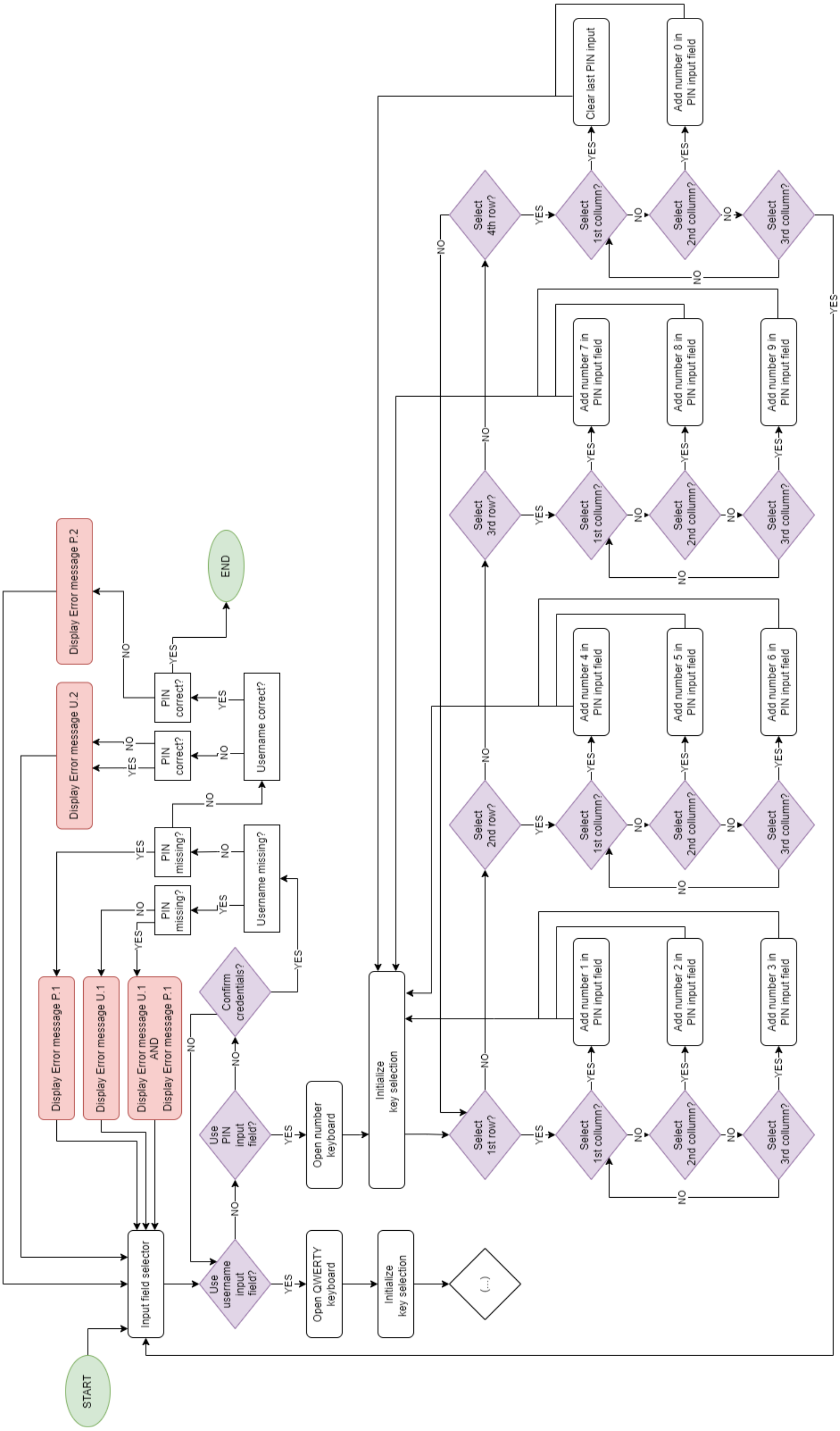

Figure 5.16 - System's flowchart.

Code

The files were arranged inside an "Assets" folder, which contained several other folders that composed the authentication scenes:

- "BLE-Game-Connector" with the files of the unity Package for the BLE-Game-Connector tool;
- "UI Toolkit" with the files of the unity Package for the UI Toolkit tool;
- "TextMesh Pro" with the files of the unity Package for the TextMesh Pro tool;
- "Scenes" with the scenes for each authentication test;
- "Scripts" with all the scripts responsible for interaction;
- "Materials" with the fonts used in the screens; and
- "Data" with the .csv files generated by each test would go to.

Three packages were used when developing the scenarios, the BLE-Game-Connector, the UI Toolkit and the TextMesh Pro. The BLE-Game-Connector provided two scripts that enabled connection between Unity and the BLE. The UI Toolkit provided a collection of features, functionalities, resources and tools for developing user interfaces. The TextMesh Pro provided a system for text appearance and formatting options.

Each authentication scenario is composed of four different scripts, two for receiving and sending the BLE data and two for the scene's interaction behaviors, actions, action flows and visual feedback. The two scripts for interaction behaviors are numberKeyboard.cs and buttonColor.cs, each is composed of a single Class. The numberKeyboard script handles all the interaction, action flows and visual feedback for row buttons. The buttonColor script handles visual feedback for column buttons. The two scripts that receive and send the BLE data are BLEGameSender.cs and BLEGameReceiver.cs, each is composed of a single Class. These scripts came with the unity package BLE_Conector_2020 that are provided in the NeuroRehabLab tools[2].

[2] https://neurorehablab.arditi.pt/tools/

Chapter 6

Experiment Design and Evaluation

This chapter describes the design of the experimental evaluation and its results and is divided into two sections, one dedicated to the design of the experiment and another to the results of the evaluation.

6.1. Experimental evaluation goals and conditions

The previous chapters reported on the design and development process of two objects, from its early stages up until its implementation. The objects consist of a set of a user interface of authentication scenarios and an EMG prototype. The user interface consists of a number of screens that simulate two types of authentication scenarios that the user can interact with through scanning. The EMG prototype is used as the input interaction method, and as such, used to enter user input attempts. To select an item, the user scans through the user interface screen components, displayed on a bidimensional array, first scanning the columns and then the rows. To input a selection, the EMG prototype uses the signals of the user muscle contractions, received from the electrodes placed on the user which are connected to the EMG device.

To evaluate the interaction with the objects, we designed an experiment to assess user performance with the scanning input attempt interaction technique and different types of authentication methods. Participants' subjective preferences were also collected.

The experiment consisted of four tests (Table 6.1) that evaluated user performance with two types of credentials: PIN and Password. Each type of credential was then tested with two different dwell times in each button, 1.2 and 1.8 seconds.

TESTS AND CONDITIONS		
Credential and keyboard type	**Dwell time in each button**	
	1.2 second	1.8 seconds
PIN (ordered key position)	A.1	A.2
Password (ordered key position)	B.1	B.2

Table 6.1 - Set of four tests that were defined.

From the user point-of-view, participants are asked to authenticate themselves with a provided set of credentials, i.e. a username and a PIN/Password. To complete the four tests, participants are asked to enter their credentials four times. The username is generated using the participant's first and last name and remains the same throughout the tests. The PINs and Passwords are generated automatically and are composed of a randomized set of six numbers, for the PIN, and of a randomized set of eight characters for the password: one number, one special character, one capitalized letter and five lowercase letters. A new PIN and password are generated for each test.

By running this experiment, we aim to find out:

- how different credentials and their respective keyboards (PIN - numbers, Password - QWERTY) affect interaction and authentication;
- how different dwell times impact interaction and authentication;
- the errors that occur when using the scanning input method.

Because the username remains the same throughout the experiment, we will also investigate whether there are changes in performance as the user repeats the same task (learning curve).

6.2. Data collection and analysis

6.2.1. Pre- and post-questionnaires

We used a Sociodemographic Questionnaire, as a pre-questionnaire, to gather demographic information about the participants as well as their experience with assistive technologies, keyboard layouts and authentication, that was composed of four sections. One section that gathered **profile** with sex, age, and academic qualifications (Q1, Q2, Q3 Q4). Another concerning **experience with assistive technologies**, regarding previous experience in a yes/no question, and afterwards participants could specify the system and context they used it (Q5, Q6). One about **experience with keyboard layout**, which gathered previous experience with different keyboard layouts in a yes/no question, after which participants could elaborate on the context of usage and specify the frequency of use in a Likert scale. This section included QWERTY (Q7, Q8, Q9), Alphabetical (Q10, Q11, Q12), Numeric (Q13, Q14, Q15) and Numbers Only (Q16, Q17, Q18) keyboard layouts. The final section of the questionnaire concerned **experience with different types of authentication**, and aimed to map previous experience with different types of authentication in a yes/no question, followed by a multiple choice question on the frequency of use, for the several types of authentication methods (Q19, Q20). Participants could then elaborate on the authentication method options and their context of use (Q21).

The post-questionnaires consisted of: i) an Evaluation of the EMG Prototype Questionnaire to assess the user experience with the EMG prototype, and ii) an Evaluation of the Authentication Scenarios Questionnaire to evaluate the user experience of the authentication scenes. The questionnaires included a section about the **credential type** to ask which credential was harder PIN/Password (Q1), on which participants could explain the attributed difficulty (Q2, Q3). Another section regarding which **dwell time** was harder, long/short, where participants could elaborate on their choice. This section covered both PIN (Q4, Q5) and Password (Q6, Q7) tests. Another section that gathered positive and negative **feedback on the scenarios**, as well as the level of agreement of participants with five adjectives (tiresome, fast, stressful, easy, safe) on a Likert scale, for both PIN (Q8, Q9, Q10) and Password (Q11, Q12, Q13). A final section on the **prototype's usability** that collected on a Likert scale, the level of agreement of participants with 7 adjectives (tiresome, comfortable, fast, stressful, easy, efficient, calibrated) (Q15). The participants could elaborate on their answers and provide positive and negative feedback and add further suggestions for the prototype (Q16, Q17, Q18).

The pre- and post-questionnaires were initially planned to be printed and handed out to participants to fill in, but we eventually decided to use Google Forms. This would be easier for participants to fill out and for researchers to analyse. A participant code was provided to each participant that the participant was asked to enter in the first 'question' of the questionnaires. Using Google forms compiled the data automatically in an Excel file, where it was analysed.

6.2.2. Authentication scenarios and EMG prototype tests

For the experimental test assessment, data was recorded both manually and automatically. Whenever the participant selected a button, Unity logged: (a) the total number of input attempts; (b) the position on the interaction tree node; (c) the selected key value; (d) the selected key row and column; (e) the maximum and minimum expected time of selection; (f) the timing of the input selection; (g) the timing of the input selection in relation to the overall test duration. As the test took place, the researcher recorded which password/PIN was generated, the participant's selections and her/his reactions. The data of the tests was automatically generated and compiled in a .csv file by Unity. These files were named after the participant's code and the specific test they had just finished (i.e. Jane Doe, Test A.1 was called JD_A1).

To analyse the data the four .csv files of each participant, generated by unity, were passed to an Excel file and colour coded by input field selection, username insertion, PIN/Password insertion and input errors. In order to decode where the errors were and its type, this data was compared to the data collected manually by the researcher during the tests. Errors were detected by reviewing what had been done before and after using the *Clear* button, by identifying unnecessary interactions and by looking at the delay time on interactions (see Table ERRORS). Some data was also passed to different excel file compiling and comparing every participant's tests: (i) duration of each test; (ii) total number of interactions for each test; (iii) number of interactions done in each field, for each test; (iv) number of interactions with Clear, Back, Special Characters and Caps Lock key selection; (v) number of credential verification attempts. The compiled data was then either passed to GraphPad in order to generate graphs.

6.3. Procedures

6.3.1. Ethical approval

Before proceeding to the testing phase, we submitted our study to the Committee on Ethics and Research Deontology (CEDI) of the Faculty of Psychology and Education Sciences of the University of Coimbra (FPCE-UC) for ethical approval. To submit our study, we had to plan it ahead of time, given we needed to provide the ethics committee with all relevant information about the research, namely: the participants we sought to involve, the methods and measuring instruments, the actions to put in place to protect participants and all data collected. The Form for submission of projects that we filled out included: the information about the study; the information about the participants; the Informed Consent form to be read and signed by participants, if they agreed to participate; the Sociodemographic Questionnaire; the Evaluation of the Authentication Scenarios Questionnaire; and the Evaluation of the EMG Prototype Questionnaire. These forms and questionnaires can be found in Appendix B. The project received ethical approval on 21st September 2022, code CEDI/FPCEUC:67/4.

6.3.2. Recruitment

For this set of tests, participants were recruited from the researcher's personal networks, which means a convenience sample was used. The group selection criteria was that they should be adults without a diagnosis of Amyotrophic Lateral Sclerosis. Participants were informed of the study via a phone conversation, where the researcher would give a brief explanation about the experiment. If they volunteered to participate , we asked for the participant's email so they could be contacted to schedule the evaluation session.

The goal is to run the experiment with both a control group and a study group, where the control group selection criteria was that they should be adults without a diagnosis of Amyotrophic Lateral Sclerosis, while the study group selection criteria was that they should be adults with a diagnosis of Amyotrophic Lateral Sclerosis. Participants for the study group have been recruited through the Portuguese Association for Lateral Amyotrophic Sclerosis (APELA) and the tests with the study group are scheduled to take place at the end of July. The original plan was to run the experiment with the study group on the same week as we ran the tests with the control group, however this was not possible due to scheduling constraints of APELA.

6.3.3. Settings and experimental procedures

Upon recruitment, participants were e-mailed the time, building and room in which the test would take place. In this email, we would also attach the Sociodemographic Questionnaire and the participant was asked to fill it out before the test.

The tests were conducted in a room of the Department of Informatics Engineering of the University of Coimbra reserved for the purpose of the evaluation and where the participants would not be interrupted or distracted by noise, lights or movement. On participants' arrival to the room, the chalkboard displayed the conditions of the test (Figure 6.1), that the researcher used to explain the placement of the electrodes and the test conditions. For the duration of the test, the participant sat on a chair in front of a desk and faced a 23 inch ASUS screen, where the authentication scenarios were presented. The researcher sat behind the screen so as not to interfere with the test and to take any necessary notes concerning the test.

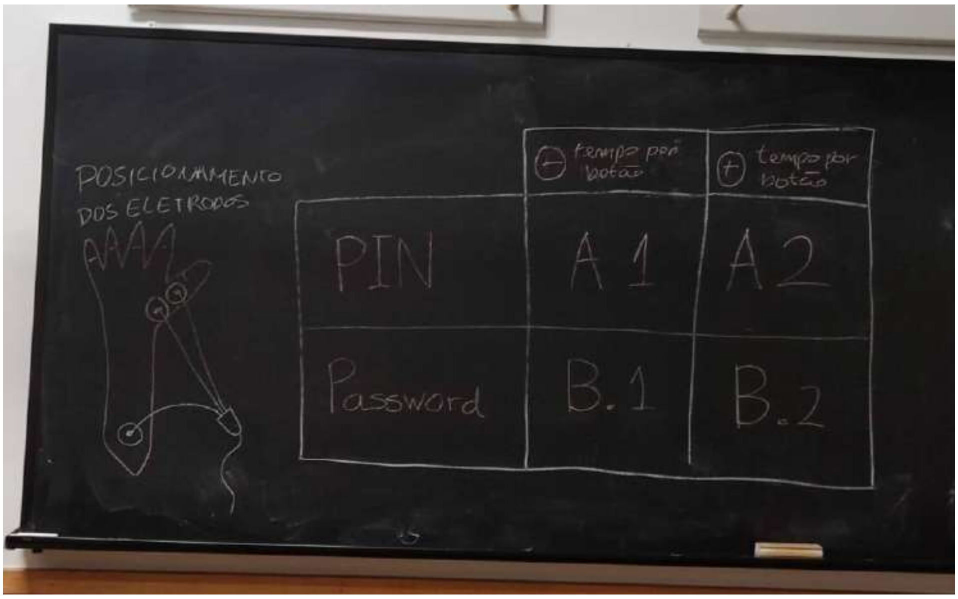

Figure 6.1 - Board displaying some information about the tests,
parallel to the participant and researcher.

Once the participant was in the room, the researcher would greet them and ask them to wash their hands, for better electrode positioning. Once their test started, they were asked to read and sign the Informed Consent form. Afterwards, the researcher asked them to sit in the chair and turn off the sound and vibration of their phones, and put them away, in a place that would not distract them from the test. Then the *Test Script* would be followed by the researcher (APPENDIX B). The participant would be informed that the experiment consisted of 40 minutes of testing authentication scenarios, and 15 minutes of responding to questionnaires. The questionnaires to be filled, the Evaluation of the EMG Questionnaire and the Evaluation of the Authentication Scenarios Questionnaire, and the purpose of the questionnaires was explained. Afterwards, an explanation on how the EMG prototype worked was provided and, after cleaning the muscle zone with rubbing alcohol, the electrodes were placed on the participant's thumb and elbow (Figure BOARD, left). The positive and negative electrodes, responsible for muscle signal acquisition, were placed in the Opponens pollicis (see Figure 6.2). This muscle was chosen because it is the largest of the thenar muscles, the muscle group responsible for the fine movements of the thumb, and it can be activated by medially rotating and flexing the metacarpal on the trapezium (Oliver, 2022). Figure 6.3 exemplifies one thumb movement that can be done to activate this muscle. It was also chosen due to the lack of fatty tissue in the hand and its muscle definition. The reference electrode would be placed near the elbow bone, due to its lack of muscle activity. By using this placement, we could ensure proper electrode placement in each participant with relative ease.

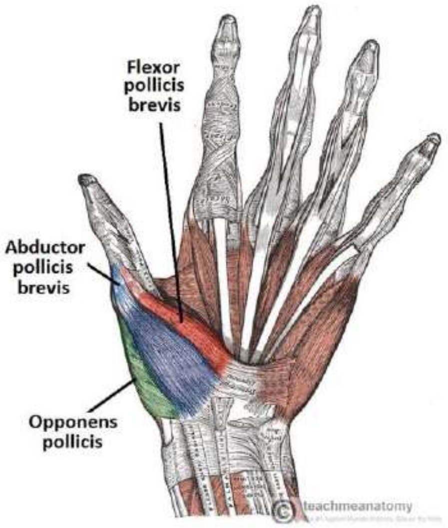

Figure 6.2 - Palmar view of the thenar muscles.

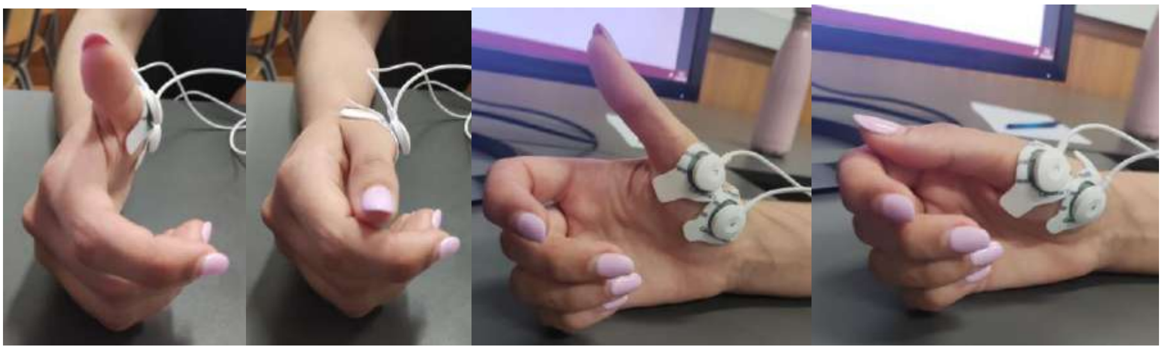

Figure 6.3 - Example activation of the muscle Opponens pollicis, by medially rotating and flexing the metacarpal on the trapezium. Image recorded in one of the tests with a participant.

The researcher would then check for any mistakes in electrode placement by asking the participant to flex their thumb while checking if a click was being made in the BLE. This also ensured that the participant knew how to properly activate the muscles. Then a mock test was presented to the participant, which lasted four minutes, where participants were asked to try and interact with the system, in order to understand how and when to interact. Afterwards, the researcher explained how the authentication scenarios worked: (i) what variables were at play (credential type and dwell time); (ii) what participants needed to do in order to complete the test; (iii) where in the screen they could find their assigned credentials; (iv) the username was always the same; (v) PIN and Password were randomized and what characters they included. Then participants were informed that they could stop the test any time and should explain why afterwards. Finally, they were reminded that the system was being tested and not them, so they needed not be nervous. Before testing began, the participant was given a pen and paper, in case they had some feedback they might forget, and were asked to warn the researcher if they felt an electrode was peeling off. Finally, the tests were initialized in the following order: (A.2) PIN with longer dwell time; (A.1) (A.2) PIN with shorter dwell time; (A.2) Password with longer dwell time; (A.2) Password with shorter dwell time. After the testing was done, the participant filled the two final questionnaires with the researcher present, in case any doubts surfaced.

6.4. Experimental evaluation results and analysis

6.4.1. Participants

Our sample size was of nine participants, of which six females and three males, with two age groups, one between 23 and 26 (P1 to P5 and P8 to P9) and another between 58 and 61 (P6 and P7). None of the participants had previous experience with EMG devices.

Participant	Sex	Age	Academic qualifications	Previous experience with EMG
P1	Female	23	Master's degree (polytechnic or university)	No
P2	Female	25	Bachelor's degree (polytechnic or university)	No
P3	Male	26	Master's degree (polytechnic or university)	No
P4	Female	26	Master's degree (polytechnic or university)	No
P5	Female	25	Master's degree (polytechnic or university)	No
P6	Male	58	Bachelor's degree (polytechnic or university)	No
P7	Female	61	Bachelor's degree (polytechnic or university)	No
P8	Female	24	Bachelor's degree (polytechnic or university)	No
P9	Male	25	Master's degree (polytechnic or university)	No

Table 6.2 - Sociodemographic characteristics of the participants.

Concerning keyboard dispositions, all participants had previous experience with QWERTY and strictly numbers dispositions. QWERTY disposition is by far the most used, with seven participants reporting several uses daily (P1, P3-P6, P8, P9) and two reporting more than 5 times or daily use (P2, P7). Strictly numbers dispositions are the second most used keyboard dispositions with one participant reporting several times a day use (P2, P4), four participants, more than 5 times weekly or daily use (P3, P6, P7, P8), one participant, 2 to 3 times a week (P1), two participants, once a week (P4, P9) and one never use (P5). Only two participants had no previous experience with numeric keyboards (P2, P9) and only five participants use it: several times a day (P5), 2 to 3 times a week (P8) and weekly (P4, P6, P7). Alphabetical disposition had the least previous experiences, only three participants had previous experience (P4, P5, P8) and no participants use it.

Keyboard disposition		Participants								
		P1	P2	P3	P4	P5	P6	P7	P8	P9
QWERTY	Previous experience	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Usage frequency	More than once a day	More than 5 times or daily	More than once a day	More than once a day	More than once a day	More than once a day	More than 5 times or daily	More than once a day	More than once a day
Alphabetical	Previous experience	No	No	No	Yes	Yes	No	No	Yes	No
	Usage frequency	I never use it	I never use it	I never use it	I never use it	I never use it	I never use it	I never use it	I never use it	I never use it
Numeric	Previous experience	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
	Usage frequency	I never use it	I never use it	I never use it	Once a week	More than once a day	Once a week	Once a week	2 to 3 times a week	I never use it
Strictly numbers	Previous experience	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Usage frequency	2 to 3 times a week	More than once a day	More than 5 times or daily	Once a week	I never use it	More than 5 times or daily	More than 5 times or daily	More than 5 times or daily	Once a week

Table 6.3 - Participants previous contact and frequency of use for different keyboard dispositions.

All the participants use authentication. Regarding the credentials used in our tests, PIN and password show about the same usage frequency. The results for password usage are: five participants use it several times a day (P4-P7, P9), one uses it more than five times a week or daily (P3), one uses it 4 to 5 times a week (P1), two use it 2 to 3 times a week (P2, P8). The only difference in the results for PIN usage are that P7 reports only using it once a week. Concerning the other authentication methods, biometric authentication is used by several participants, CAPTCHA and physical devices are used very little and no participants use patterns.

Participant	Do they use authentication	How many times they use credentials						
		Password	PIN	Pattern	CAPTCHA	Facial recognition	Fingerprint	Physical device
P1	Yes	4 to 5 times a week	4 to 5 times a week	I never use it	Once a week	4 to 5 times a week	I never use it	I never use it
P2	Yes	2 to 3 times a week	2 to 3 times a week	I never use it	Nunca uso	2 to 3 times a week	I never use it	I never use it
P3	Yes	More than 5 times or daily	More than 5 times or daily	I never use it	Once a week	I never use it	More than 5 times or daily	I never use it
P4	Yes	More than once a day	More than once a day	I never use it	Once a week	Nunca uso	More than once a day	I never use it
P5	Yes	More than once a day	More than once a day	I never use it	More than 5 times or daily	More than 5 times or daily	Once a week	More than 5 times or daily
P6	Yes	More than once a day	More than once a day	I never use it	2 to 3 times a week	I never use it	I never use it	I never use it
P7	Yes	More than once a day	Once a week	I never use it	I never use it	I never use it	I never use it	I never use it
P8	Yes	2 to 3 times a week	2 to 3 times a week	Once a week	2 to 3 times a week	2 to 3 times a week	2 to 3 times a week	I never use it
P9	Yes	More than once a day	More than once a day	I never use it	More than 5 times or daily	More than once a day	More than 5 times or daily	More than 5 times or daily

Table 6.4 - Participants previous contact and frequency of use for different authentication credentials.

6.4.2. Results and analysis of the tests

6.4.2.1. Completion times and number of input attempts

Figure 6.4 shows the total number of input attempts made by participants to complete each test and the expected number of interactions needed to complete the test. Evey participant was able to complete the four tests except P6, which did not complete A1 because they made too many wrong input attempts and got to tired to continue. Tests A1 and A2 needed 31 interactions to be completed: 14 for the username introductions, 14 for PIN introduction, and 3 for selecting input fields. Depending on the generated password, 39 to 43 input attempts were needed to complete tests B1 and B2: 14 for the username introduction, 22 or 26 for password introduction, and 3 for selecting input fields. Three participants were able to finish test A1 with the least amount of interactions (P4, P5), three participants were able to finish test A2 (P1, P3, P9), four participants were able to finish test B1 (P1, P3, P4, P5) and four participants were able to finish test B2 (P1, P3, P5, P9). Out of the 36 tests, the username was introduced with the least amount of input attempts, 20 times, and the credentials 15 times, 8 times for PIN and 7 times for password. By comparing tests, it is noticeable that shorter dwell times (A1 and B1) require more input attempts than long dwell times (B2 and A2).

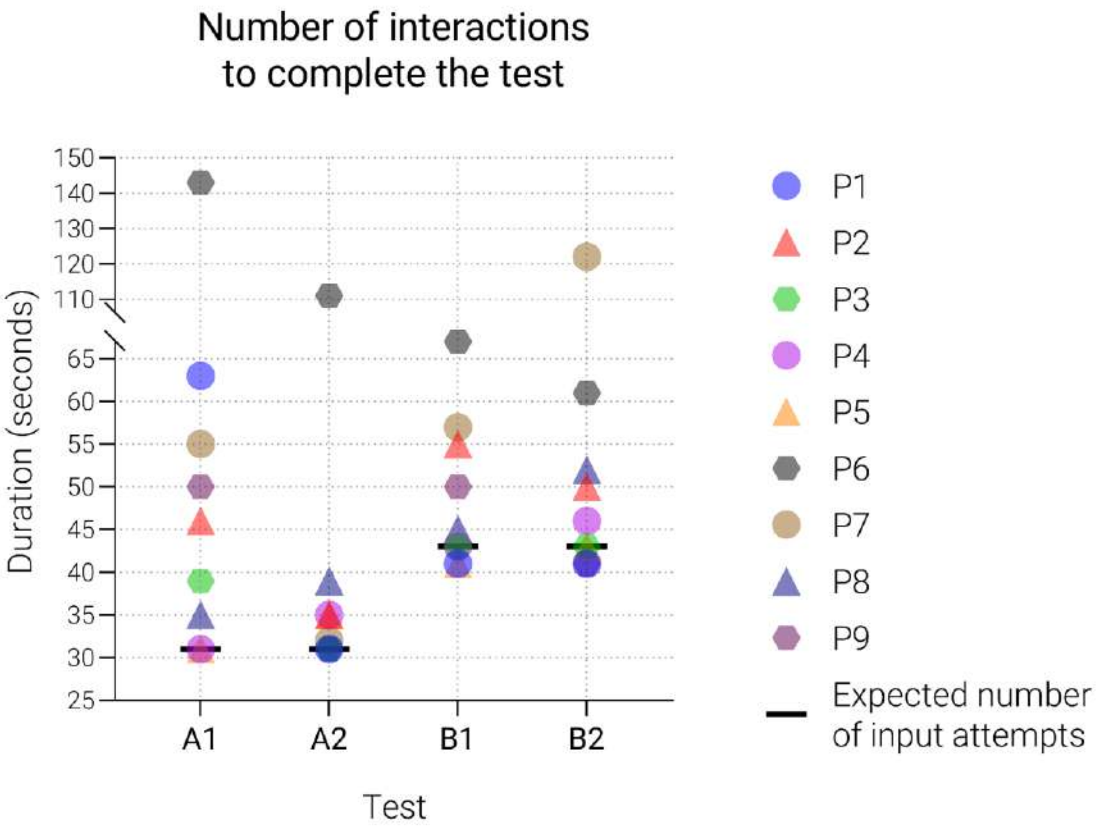

Figure 6.4 - Number of interactions by participants
and expected number of interactions for each test.

Figure 6.5 shows the duration of each test by participant. Two graphs were generated, one with all tests and their average, on the left, and another where participants with very different test durations were eliminated (P6 in A1 and A2, P7 in B2). By removing abnormal test durations, the average of the participants' test duration is more even. Considering the results obtained without discrepancy results, on average, the PIN tests had about the same duration, with a completion time average for A2 of 6.24 seconds for A1 and 6.19 seconds. It was not expected that a shorter dwell time (A1) had a longer test completion average, but if cross examined with Figure 6.4, we observe that the higher number of input attempts increased the amount of time needed to finish the test.

In the password tests, the participants' time completion average is 5.79 seconds for B1 and 8.16 seconds for B2. Although some variation on the number of input attempts can be observed between B1 and B2 (Figure 6.4), shorter dwell times do not seem to impact interaction and authentication.

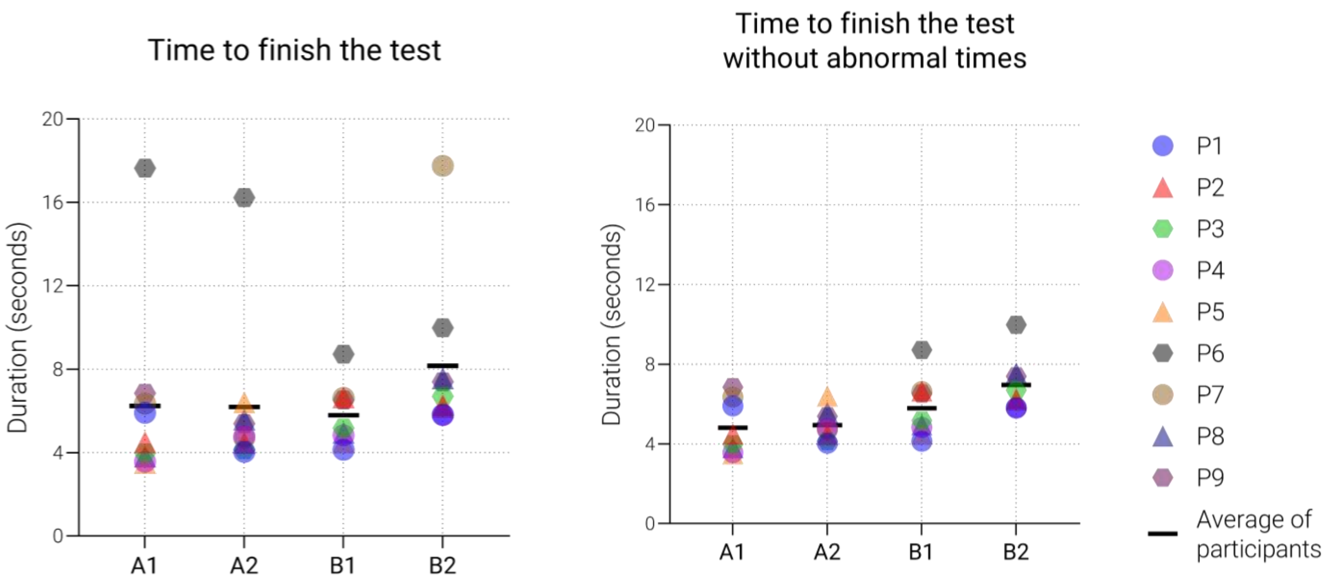

Figure 6.5 - Duration of participant's tests. On the left the average of participants is calculated by using every time, on the right it is calculated by removing tests with abnormal durations.

Figure 6.6 shows the average input attempt timing of every possible input selection, for each participant. The selection options are rows and columns within the username section or the PIN/password section and selections in the input fields. The graphs are grouped by shorter dwell times (A1, B1), on top, and longer dwell times (A2, B2), at the bottom. It is possible to observe a pattern among the four tests, where input attempts on columns were faster than rows, except for the input field rows. This might be explained because the input field and the columns are the final node for key choice, whereas rows in username and credential input are a step to get to the columns, and input the key.

Comparing the short dwell times, in A1 and B1, column and row input attempts are about equal for username input. In A1 we see that row input attempts occur later for the PIN than they do for the username. The opposite happens for B1, with input attempts on rows being done later in the username and faster for the password. When we compare A1 and B2, the input attempt timing inside the credential field is different, B1 column input attempts are a bit faster and row input attempts are much faster than in A1. This might be due to using different keyboard dispositions, as having more choices in QWERTY might rush participants to select the desired key so that they do not need to wait longer than necessary.

With longer dwell times (A2, B2), participants seem to take longer to do an input attempt on each field. Concerning A2, the input attempt timing increases substantially, which might happen because A2 was the first test and participants were still getting acquainted with the systems. On average, row input attempts in A2 were equal in username and PIN fields and column and input field selection times are also similar. In B2 timings were longer for row input attempts for username and password but column and input field input attempts timings were close to the results of B1(≈0.7 seconds). The behaviour of faster row choice in the password compared to the username is maintained.

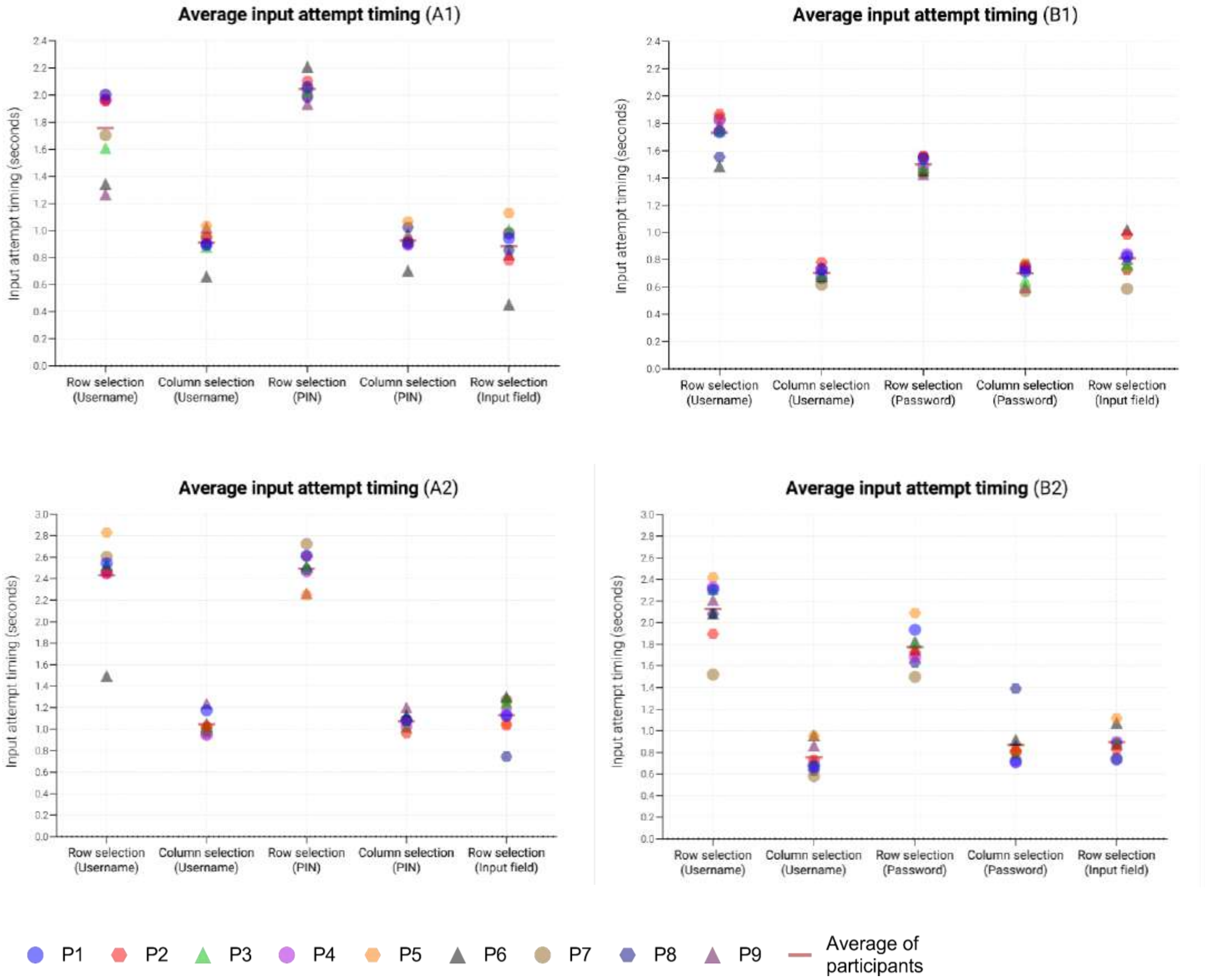

Figure 6.6 - Average of row and column selection, inside each input field (Username, PIN, Password). Shortest dwell times on top (A1 and B1), and longer dwell times on the bottom (A1 and B2).

6.4.2.2. Input errors

Figure 6.7 shows the real time of input attempts of two participants for the test A1, P5 which finished the test with the minimum amount of input attempts and P6 who decided to stop the test after 17.64 minutes when 143 input attempts had already been made. This analysis shows the instances when participants failed to select the desired key and had to wait another round to be able to do another input attempt. While comparing both participants, it is noticeable that P5 makes later but timed input attempts (average of 2.03 seconds for rows and 1.03 seconds for columns) and P6 makes faster (average of 1.78 seconds for rows and 0.68 seconds for columns) but untimed input attempts. When looking at the times of interaction of the two, we can observe that unlike P5, which is steady in the input attempts timings (≈2 seconds for username and PIN rows and ≈1 second for username and PIN columns), P6 is not (1.3 seconds for username rows, 2.2 seconds PIN rows and ≈0.7 second for username and PIN columns).

When looking specifically at the results of P6, we see that the participant had to wait several rounds for several keys. These types of results might be due to slow reaction or a misunderstanding on how to activate the muscle. They could also be due to bad electrode positioning but, given that the electrodes were not changed throughout the tests, and B1 and B2 seem to have fewer delays on selection, we ruled out this option. While still looking at P6, results in Figure 6.6 show that, on average, the participant usually made a selection faster than the other participants. This might be due to frustration, where a participant, having failed to successfully select the desired key several times, tries to input a selection as fast as they can in order not to miss another selection. For a further analysis on how participants input selection timings compared, please refer to Appendix C that shows the results of participant's tests side by side, for each test.

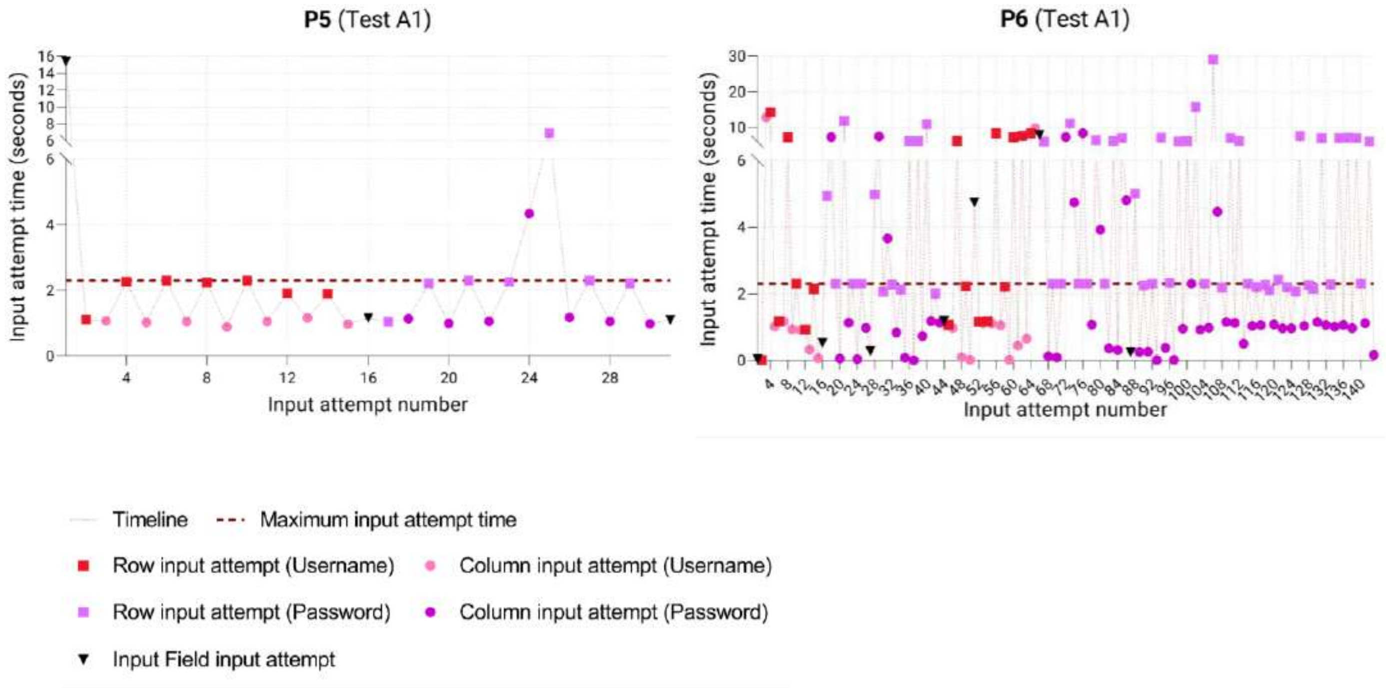

Figure 6.7 - Comparison of the real time of input attempts of two participants, P5 on the left and P6 on the right, for the test A1.

The errors made throughout the tests were analysed by type and field. Input errors could be of five types, where the user: (E1) selected the previous row; (E2) selected the next row; (E3) selected the previous column; (E4) selected the next column; (E5) misunderstood the user interface. When a participant selected the “clear” key, we could infer what kind of error they made. For example: if a participant was expected to select “4”, but instead selected “5”, they had made an error type of “Selected the next column” kind; if they were expected to select “a” and selected “v”, the error was of type “Selected the next row” kind; if the input attempt was not added in username/PIN/password, but still generated extra input attempts, it was of the type “User interface misunderstanding” kind. If the participant tried to authenticate, but received an error message concerning the bad PIN/Password, although they often needed to clean the whole input field, only the wrong input would be accounted for (this happened for P1 in A2 and P7 in B2). Figure 6.8 and Figure 6.9 show descriptive statistics of the errors made throughout the tests, by all participants.

Figure 6.8 shows input selection errors for PIN tests, A1 on top and A2 at the bottom. In PIN tests, participants made 21 errors overall, 16 errors in A1 (12 in the username and 4 in the PIN) and 5 in A2 (2 in the username and 3 in the PIN) (Figure 6.8). In A1 only two participants made no errors (P4, P5) and three in A2 (P1, P3, P9).

Figure 6.8 shows input selection errors for password tests, B1 on top and B2 on the bottom. In password tests, participants made 23 errors overall, 8 in B1 (2 in the username and 6 in the password) and 15 in B2 (6 in the username and 9 in the password). Both password tests had four participants finishing the test without input errors (P1, P3-P5 in B1; P1, P3, P5, P9 in B2).

When cross-analysing the values it is noticeable that the username field is prone to fewer errors than the credentials (PIN and password). We also observe that errors where the previous item was selected only occur in long dwell time tests (A2 and B2). When we leave out user interface misunderstanding errors, it is possible to analyse errors in the two keyboards. In the PIN keyboard, a shorter dwell time is more prone to selecting the next column but longer dwell times are prone to selecting the next row.

The fact that A1 had 12 username input errors and A2 only had 2 might be due to being the first time participants were interacting with the shorter dwell time, given that participants almost always selected the username first (except P7 in A2). The number drops again to half (6 username errors), if we look at the username input in B1. This confirms that participants make more errors the first time they are exposed to the shorter dwell times, which may also be due to the participant being used to the previous dwell time.

One type of user interface misunderstanding mistake was recorded, the users did not know how to remove the special characters after activating them, and tried to use the “back” button. After realizing that this did not work, they understood that they should select the same key used to activate the special keys.

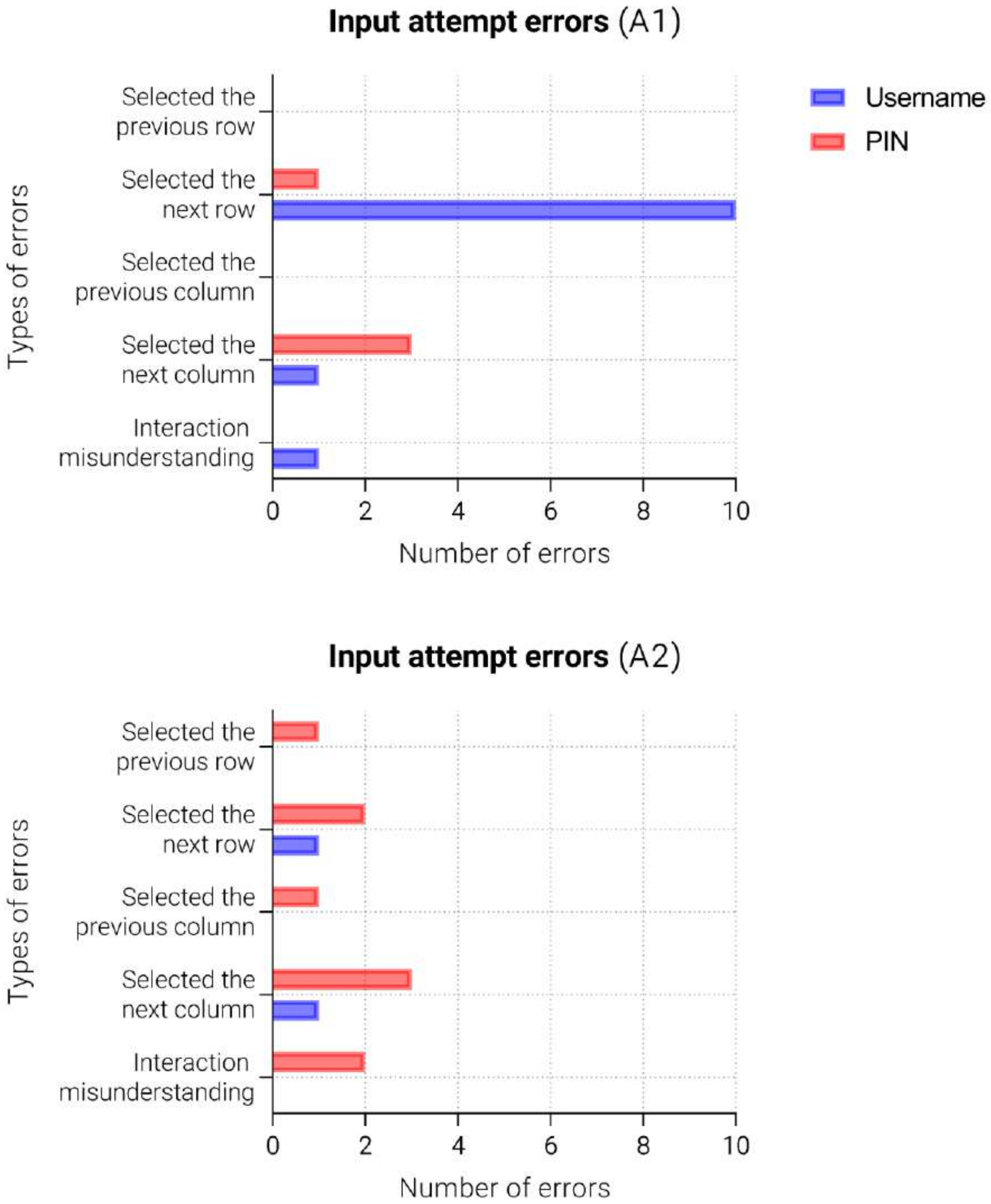

Figure 6.8 - Number and type of errors in PIN tests.

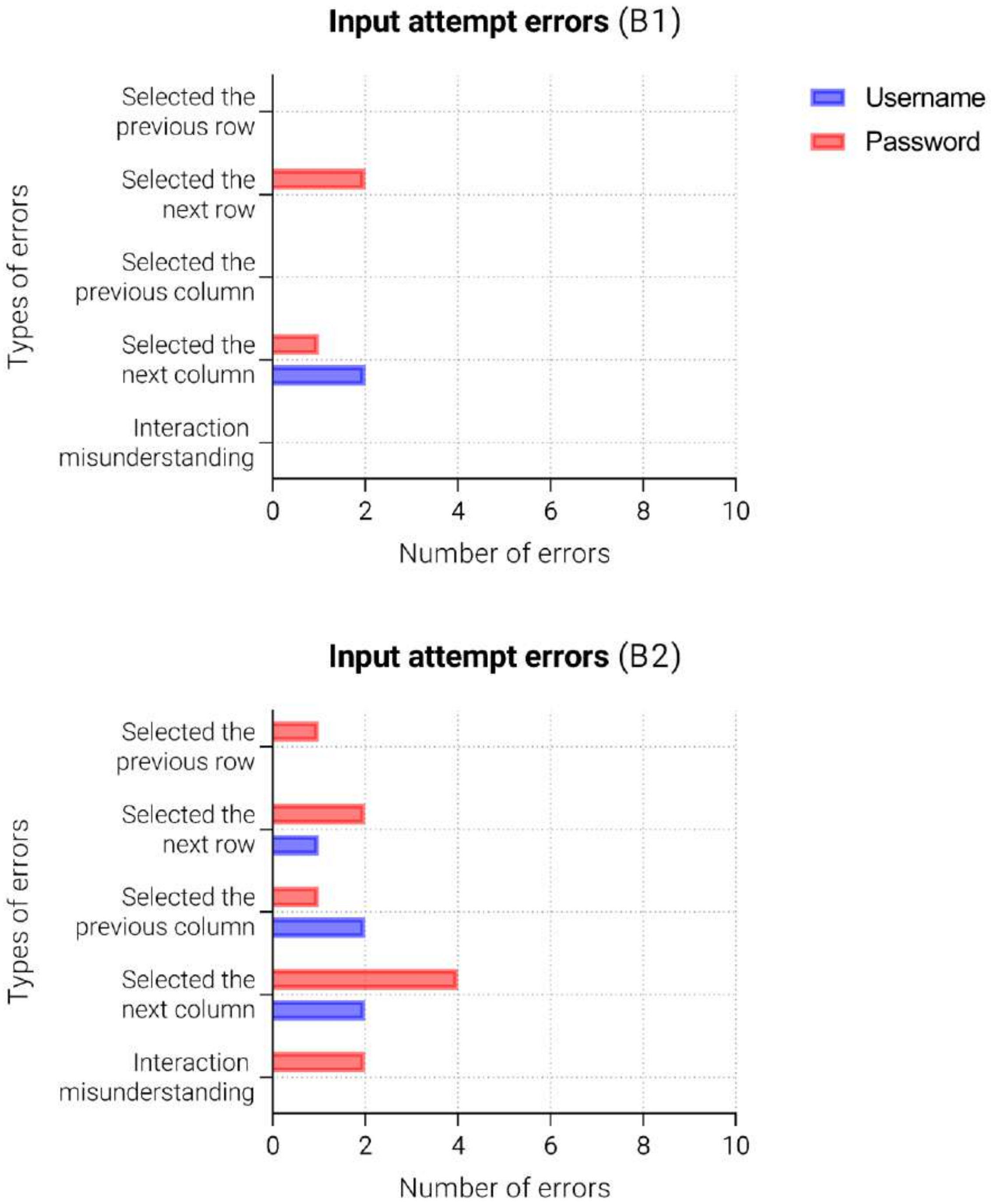

Figure 6.9 - Number and type of errors in Password tests.

6.4.2.3. Performance changes across time

By having the participant insert the same username across tests, it was possible to analyse changes in performance across time. Figure 6.10 shows how many input attempts each participant made inside the username field, in each test. The tests are ordered from first (A2) to last (B1). We can see that from A2 to A1, the amount of input attempts increased, which, as mentioned before, might be due to the change in the dwell time, from longer to shorter, and the participants having to get used to the new timing. From A1 to B2 we see a drop in the number of input selections, even though the number is still higher than A2, which has the same dwell time. However, when we compare A2 to B1, we can see that the amount of input attempts is about the same even though B1 has a shorter dwell time. This may mean that, with experience, participants get better at inputting their username and making fewer mistakes, even when presented with a shorter dwell time.

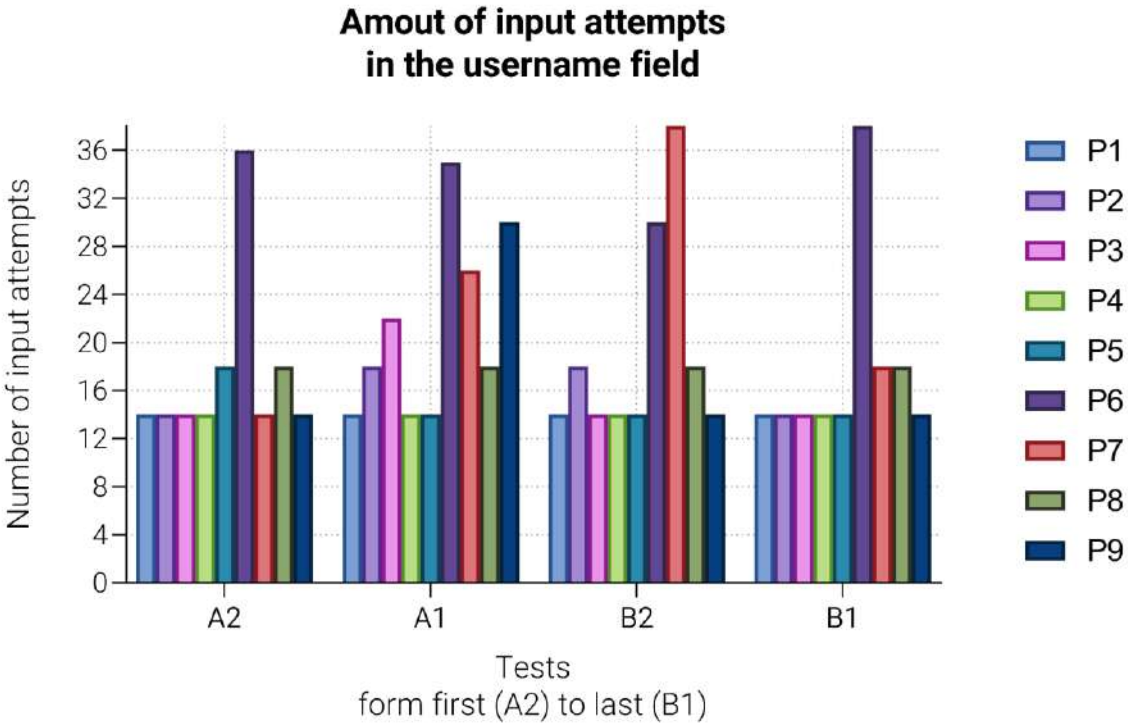

Figure 6.10 - Amount of input attempts made by each participant inside the username field, for each individual test.

Figure 6.11 shows the average of the participant's input attempt timings, distinguished in rows and columns, for each test. Again, the tests are ordered from first (A2) to last (B1). We can see that the column input attempt timing drops with each new test, regardless of the dwell time of each test. This shows that participants become faster at inputting a key in columns, as they become more experienced. With rows the drop in timing is larger for the longer dwell times and stable for shorter dwell times.

Looking at Figure 6.8 and Figure 6.9, we can see that for longer dwell times (A2, B2) becoming faster did not affect the number of errors recorded. Even though there was not much of a difference in the username row input attempt timing in the shorter dwell time tests (A1, B1), we see a significant drop in the number of errors of the type “Selected the next row” type from test A1 to B1, indicating that the participants had learned how to input a key. For further analysis of the learning curve of each participant please refer to Appendix C, Section II, that shows the four tests side by side, for each participant.

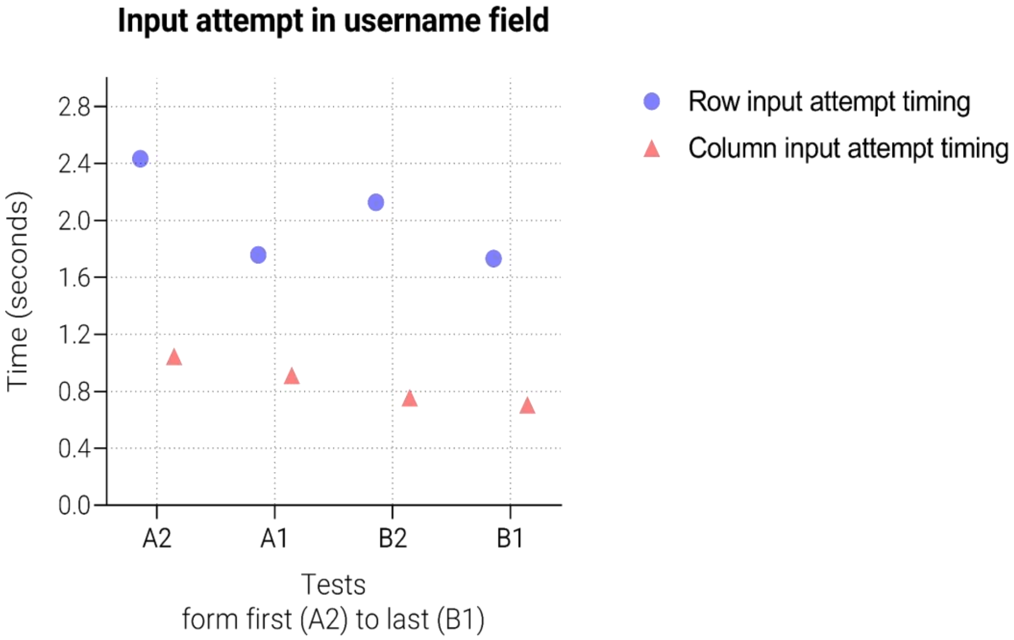

Figure 6.11 - Average of participants input attempts timings inside the username field, for each individual test.

6.4.3. Results and analysis of the questionnaires

After finishing the tests, participants were asked to respond to the post-questionnaires. Figure 6.12 shows what credentials participants found more difficult. Only P1 found PIN harder, whereas all other participants found it easier because the keyboard is simpler and they have to select fewer keys. They also stated that typing the password was harder, because the password was longer, had more selection options, and had to input a special character and a capitalized letter. This answer was provided in response to multiple selection questions with two options, the participant could elaborate upon.

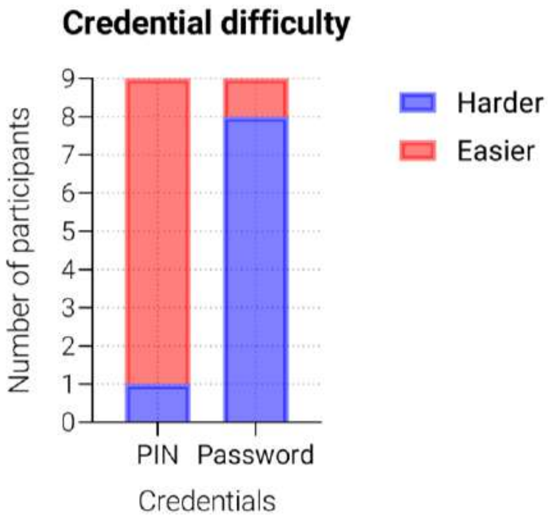

Figure 6.12 - Difficulty of credentials according to participants.

Regarding the dwell times difficulty, Figure 6.13 shows the analysis for each credential, PIN on the right and password on the left. Longer dwell times do not seem to affect how participants perceive the difficulty of PIN authentication. P3, P6-P9 reported that the shorter dwell time did not allow them enough time to react and make a selection and that they did not mind a longer time in PIN because they had fewer characters to type. The remaining participants found it too long, with P4 stating that they found the longer time distracting. For password introduction, it seems that longer dwell times are harder. P5 stated that shorter dwell time was harder because it incited to click more than once and P3 stated that even though a longer dwell time was less tiresome, it led to fewer mistakes and less interactions with the "clean" button. Six participants (P1, P2, P4, P 7-P9) found shorter dwell times easier because it was faster and less tiresome.

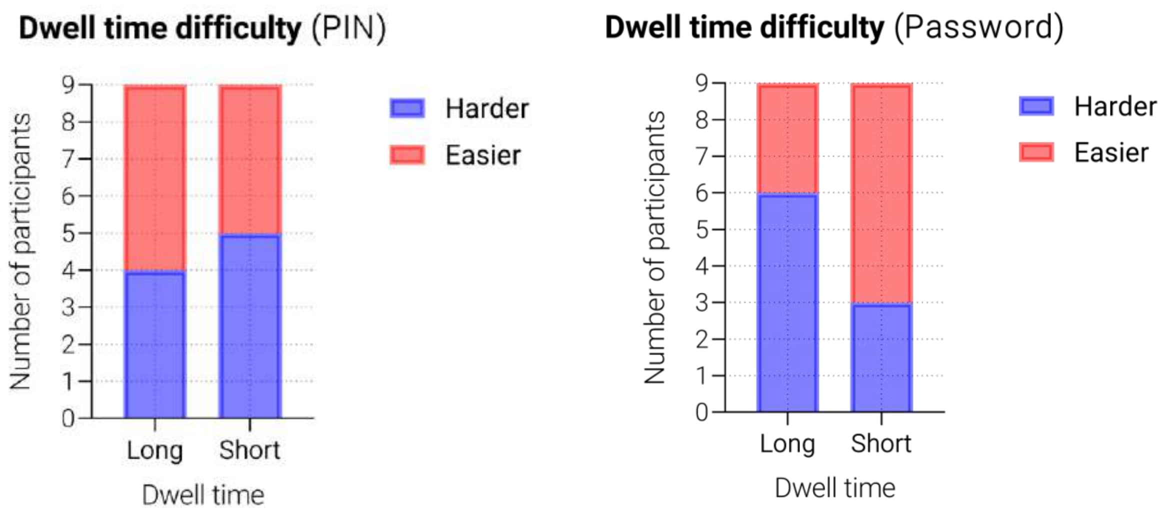

Figure 6.13 - Difficulty of dwell times for each credential, PIN (left) and password (right), according to participants.

Figure 6.14 shows participants' assessment of both credentials with regards to five adjectives answered in a 6-items Likert scale, PIN on the left and password on the right. We can see that participants found passwords more tiresome and slower than PIN, with P5 to P8 and P9 reporting that it was more complex, but safer (P3 to P6, P9, P10). Participants also stated for both authentication methods that the inserted character should be visible a few seconds before inserting and that there should be a button to view the imputed credentials. P5 and P6 suggested a "clear" button that would clean the whole input field.

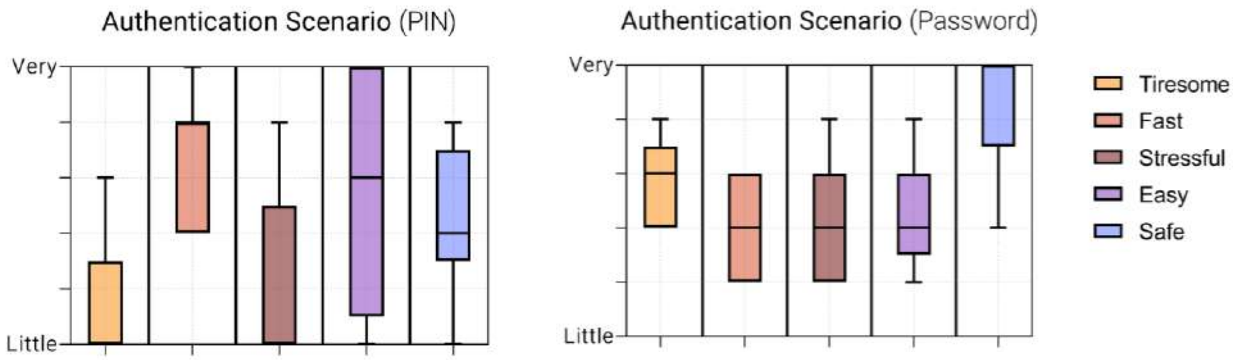

Figure 6.14 - Participants' assessment of both credentials, PIN (right) and
Password (left), with regards to five adjectives answered in a 6-items Likert scale.

Concerning the EMG prototype, Figure 6.15 shows that participants had a positive response to it. Overall they did not find it tiresome, with P2 stating that it depended on the positioning of the thumb, P4 saying that they tried several thumb positions that worked and that minimized the strain on it and P8 reported that it caused slight discomfort due to an old injury. Most participants found it comfortable but P4 stated that some people might be allergic to the electrodes glue, P7 had a slight allergic reaction. P5 thought that there should be an alternative to single-use electrodes, making it a more sustainable alternative. On average, they found it somewhat fast. They also found it easy to understand (P5, P8, P9) and not stressful, with P8 stating that they felt some stress at first, but it went away after getting used to it. It was also considered fast and calibrated, P3 found that even though they never used this type of interaction, they felt it was responsive and P5 stated that more gestures could be added to improve the efficiency of the input method.

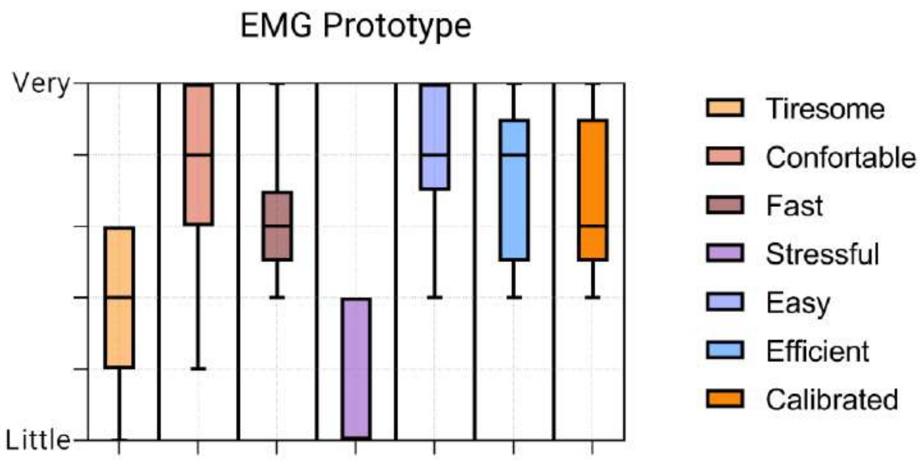

Figure 6.15 - Participants' assessment of the prototype with
regards to five adjectives answered in a 8-items Likert scale.

Chapter 7

Conclusions, discussion and future work

7.1. Conclusion

This work stresses the importance of the accessibility of authentication methods as a key aspect of participation for people who have neurodegenerative diseases, namely people living with ALS. In order to achieve equity in societal participation and include people with different spectrum of abilities, it is important to design with accessibility in mind.

Throughout the work of this dissertation, we designed and implemented two objects to assess the accessibility of different authentication. We developed an EMG prototype that uses muscle contraction as an input method and designed and implemented a set of authentication scenarios. The objects worked with each other in order to study the accessibility of different authentication methods, PIN and password. The EMG prototype was used as the input method of interaction with the authentication tests. This enabled us to structure an experiment and evaluate: (i) how credentials and their respective keyboards, numbers for PIN and QWERTY for password, affect interaction and authentication; (ii) how different dwell times impact interaction and authentication; (iii) what errors occur when using a scanning method; (iv) changes in performance by repeating a task.

A key result and finding of our work is that it is possible to use the EMG prototype as an input method for a scanning-based user interface. This by itself provides an alternative to mainstream interaction, the selection input method. By structuring interfaces in a tree node disposition, this type of interaction can be enabled.

Our results revealed that participants find **PINs easier and less tiring** than passwords and that they found **passwords safer and more customizable**. We found that **shorter dwell times lead to more input errors in number keyboards** but that the same does not happen in QWERTY. Even though shorter dwell times can lead to faster input attempts, if the input attempt is an error, this results in more overall time trying to authenticate oneself. In both keyboards, columns are selected faster than rows, with both **rows and columns being imputed faster in QWERTY keyboard dispositions and slower in number keyboard dispositions**. We also found that **reaction timing is affected by the tree node of the overall choice** instead, with deeper nodes being faster. We also found that different age groups might have different reaction timings, with older users reacting less timely and younger making input attempts more timely.

Concerning input errors, we found that making a larger number of incorrect input attempts might lead to making input attempts earlier, and that prior knowledge on the information to input (as was the case with the password information), allows users to be more efficient and make fewer mistakes. Errors where the previous item is selected only happen in longer dwell times and errors where the next item is selected happen less in deeper tree node choices.

Concerning performance change across time we found that reaction time decreased with experience and users make faster input attempts when repeating a task. We also found that participants started to make fewer input mistakes when using the same dwell time and that input errors on short dwell times decreased and started to match the number of input errors made in long dwell times. Finally, the learning curve for farthest node choices is significantly higher than for deeper nodes, proving that users get more confident in their knowledge of the key positions.

7.2. Discussion and future work

This study further reinstates, as presented in the reviewed literature, that both assistive technologies and mainstream software and services should always be adaptable to the user and not the other way around. If a user can alter an artifact to fit their needs it becomes more accessible, so more users use it. For example, if users are able to select a specific dwell time which accommodates and is adjusted to their needs, they will likely make fewer mistakes, thus need less time to complete a task. Different tasks and nodes can also benefit from this adaptability, if deeper input tree nodes need less time for reaction, their dwell time could be faster than shallow nodes. The same applies to the number of selectable items displayed. To exemplify, QWERTY keyboards displays have more column items and users input them faster than number keyboard displays, so more options might benefit from shorter dwell times. Because users can learn a system as they use it, it might be expected that the learning curve is even steeper for people who have ALS given that sometimes they use buttons as an input method, therefore are acquainted with the scanning method. One thing that we also took from this work is that most people use credentials and, given that nowadays most interfaces and services have authentication as a requirement, if people are not able to authenticate themselves, they are not able to participate.

It was not possible to run the experiment with our study group nor with a bigger and more diverse control group. By not testing with our study group, people with ALS, we are not able to evaluate whether our end users are able to use the prototype, thus not allowing us to determine which kinds of credentials are more accessible to them. Still, we have run the experiments with a group of healthy volunteers, and we have been able to identify differences in performance, especially among those with different age ranges. For example, participants in their early to mid-twenties seemed to make fewer input attempts and fewer errors than those in their late fifties and early sixties. Older participants made more input attempts and took longer to finish tests. By not having a bigger and more diverse sample size in our control group we cannot conclude that age affects performance, however this warrants future research given that 90-95% of ALS diagnoses are of the sporadic type, which tends to appear in the mid-to-late fifties, and only 5-10% are of the familial type, which tends to appear in a person's teens and early adulthood (Hulisz, 2018).

Having a small sample size in our study means that, even though we can draw conclusions, the results are fragile and that they might not hold up with a bigger or different sample. By only doing only one round of tests, we were also not able to improve on the authentication scenarios which were designed. Participants made several statements about changes that should be done in the tests in order to improve their experience. This was positive, because now we have feedback on what needs to be iterated in the tests in order to eliminate shortcoming in the user interface design choices, and thus make the authentication process straightforward.

7.2.2. Future work

In the near future, we will run the experiment with the prototypes with our study group. This will allow us to effectively learn how people with ALS use the prototypes and, in this way, have a more robust and reliable study. These tests are scheduled to take place in August 2023 with participants from APELA.

Because we learned that our user interface could be tweaked to improve the overall experience of the tests, after implementing minor changes, we will recruit a new set of participants for a control group. A new experiment with the tweaked user interface will involve not only the participants from APELA, but also a larger and more diverse set of participants in the control group.. The findings of this new evaluation experiment will allow us to determine the effective value of the authentication alternative we designed and implemented. It will also allow us to explain why some interface and interaction design choices should or should not be applied and why types of credential are more accessible than others for people that live with ALS. After doing the second round of tests we will thoroughly analyse the data and report on it. We aim to write a scientific article which we intend to publish.

In the beginning of this dissertation, we aimed to design and implement an eyetracking alternative to the expensive devices which are currently available in the market. It was defined that we would use Mediapipe to develop the eyetracking prototype. We also designed the authentication scenarios for this type of selection input method, however due to time constraints, we were not able to implement this alternative, leaving unstudied an input method that is often used by people living with ALS. In the future, it would be interesting to develop the eyetracking-based prototype, so it can be assessed in relation to the one we developed.

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Appendices

Appendix A

Section I

Context study research

Figure A.1 - List of nonprofit organizations dedicated to ALS, on the right, and blogs created by people living with ALS or by their relatives/caregivers, on the left.

Figure A.2 - List of videos created by or for people living with ALS.

Context study analysis

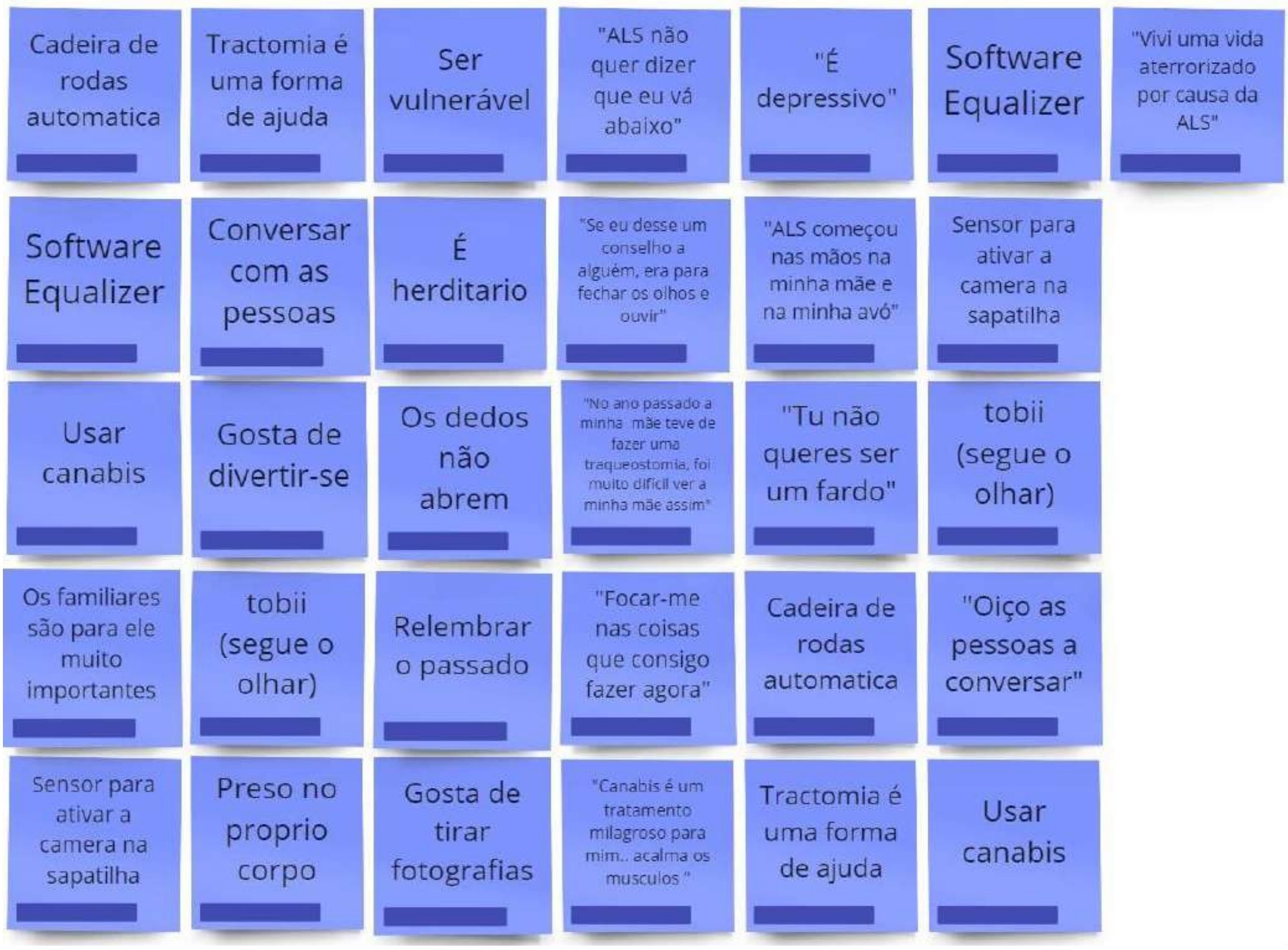


Figure A.3 - Unstructured data, for the affinity diagram, from videos of a person living with ALS.

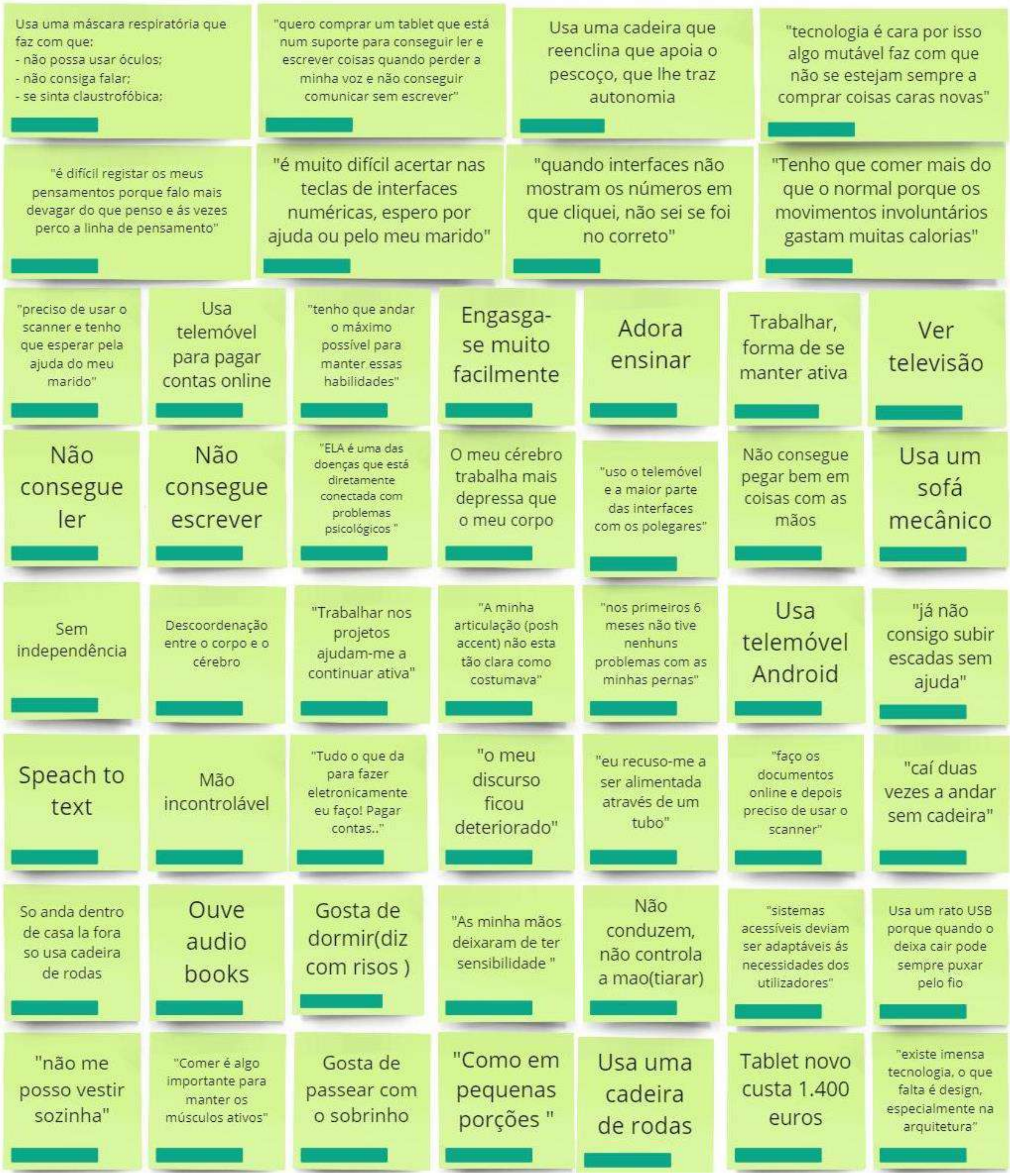


Figure A.3 - Unstructured data, for the affinity diagram, from the first interview with the participant.

Figure A.4 - Unstructured data, for the affinity diagram, from research in blogs, nonprofit organizations and r/ALS.

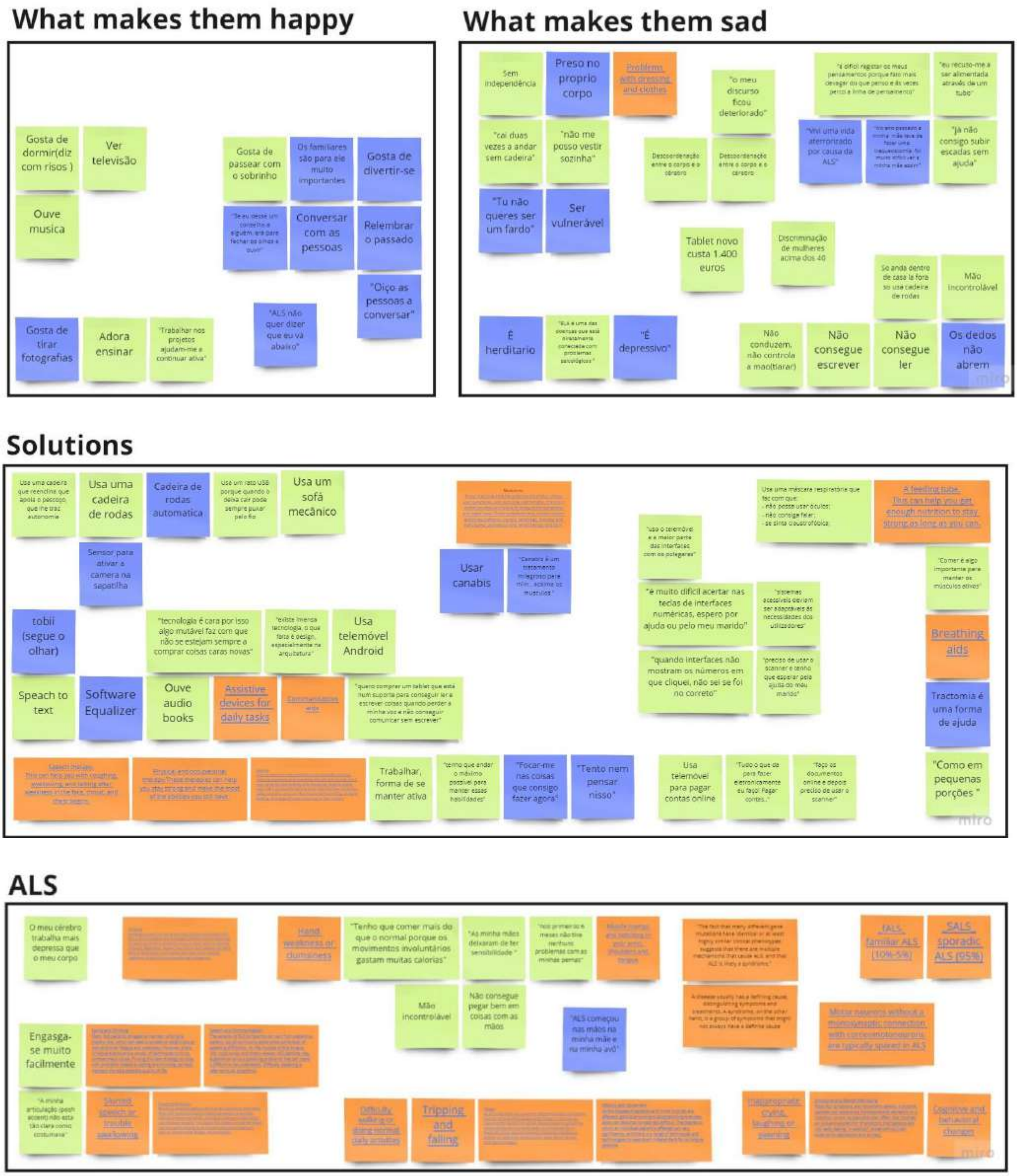


Figure A.5. - Affinity diagram with data displayed by group and subgroup.

Section II

First interview's script

Topic guide:

- ➔ Personal attitudes and experience
- ➔ Personal goals
- ➔ Daily routines
- ➔ Technology use
- ➔ Personal relationships
- ➔ Disease progression

Questions:

1. Tell us a little bit about yourself personally and professionally.
2. What's your big goal, your mission, at the moment? Anything you're working towards and would like to do/achieve any time soon, let's say in a year?
3. How do you go about your day in general? Who shares the day with you and is there anything you enjoy the most and the least in your day? Is there some kind of routine, or can every day be different?
4. How and when did you find out you had ALS? Did your attitude towards life change after you have been diagnosed with ALS? Did you notice changes in the way people look at you?
5. What role does technology play in your daily life and what types of technology do you use? For which purposes?
6. What challenges do you face when interacting with technology? Could you please give us a really good and a really frustrating example of these technologies? What interaction modalities do you prefer to interact with technologies?
7. What advice/recommendations would you give to researchers/developers to make technology more accessible to people with ALS?

Second interview's script

Topic guide:

- ➔ Devices used
- ➔ Software or application usage
- ➔ Authentication methods
- ➔ Adaptation to disease progression

Questions:

1. What do you use your devices for (eg. pc, computer, phone, ...)?
   1.1. What softwares, apps and services do you use on a daily basis?
   1.2. Which of those need authentication in order to be used, and how often do you need to authenticate yourself (eg. leisure, work, bills, medical);
   1.3. What types of authentication credentials have you used throughout your life;
   1.4. If you want, I can highlight some credential types (eg: Password, PIN, facial recog);
2. Since you started using digital devices that require authentication, have you changed the authentication method you used? For eg. when we had only simple cell phones we protected them with pin codes. Now we have smartphones and we can use pins, patterns, biometric info. Have you changed the authentication methods you us.
   2.1. If so, could you specify what those changes were?
   2.2. What about after being diagnosed with ALS?
3. Have you ever used any assistive technologies while authenticating in your devices?
   3.1. If so, which ones?
4. We've talked a bit about the authentication methods you've used. Now, can we go through each authentication phase with me? These are the steps reported in the literature, I suggest we go through them one by one. Would that be alright?
   - ➔ Phase 1 - setting up the method;
   - ➔ Phase 2 - authenticating your credentials;
   - ➔ Phase 3 - resolving an authentication failures;

   4.1. Keeping those phases in mind, what do you think are some positive and negative aspects of each, according to your experience?
5. Considering the various services, apps, and devices you use, which ones do you consider essential protecting through authentication?
6. Considering your expertise and your personal experience, how do you think authentication methods and their stages could be more accessible?

Appendix B

Section I

Sociodemographic Questionnaire

Questionário Sociodemográfico

Caro participante,

Agradecemos o seu interesse e disponibilidade para participar neste estudo. Este questionário tem como objetivo recolher informações importantes sobre características a fim de compreender melhor a diversidade e as particularidades da nossa amostra.

As questões apresentadas neste questionário abrangem uma variedade de tópicos, como idade, gênero, educação e contacto prévio com tecnologias assistivas, teclados e credenciais de autenticação. Essas informações são cruciais para traçar um perfil completo dos participantes e obter uma compreensão aprofundada das relações entre diferentes fatores.

Gostaríamos de ressaltar que todas as suas respostas serão tratadas com a mais estrita confidencialidade e serão utilizadas exclusivamente para fins académicos. As informações coletadas serão analisadas de forma agregada e anonimizada, garantindo a sua privacidade e segurança.

Ressaltamos que a sua participação neste estudo é voluntária, e pode interromper o preenchimento do questionário a qualquer momento, sem qualquer penalidade ou prejuízo.

Se houver alguma dúvida ou preocupação durante o preenchimento do questionário, por favor, não hesite em colocar questões. Estamos à disposição para auxiliá-lo no que for necessário.

Agradecemos sinceramente pela sua colaboração.

Questionário Sociodemográfico

Preencha com o código que lhe é fornecido:

A sua resposta

Sexo: *

◯ Feminino

◯ Masculino

◯ Sexo não atribuído à nascença

Idade: *

Colocar apenas a idade (exemplo: 24)

A sua resposta

Habilitações literárias: *

Selecione o nível de escolaridade mais elevado que completou:

◯ 1.º ciclo do ensino básico (4.º ano)

◯ 2.º ciclo do ensino básico (6.º ano)

◯ 3.º ciclo do ensino básico (9.º ano)

◯ Ensino secundário/técnico-profissional (12.º ano)

◯ Ensino superior (bacharelato ou licenciatura) (politécnico ou universitário

◯ Mestrado (politécnico ou universitário)

◯ Doutoramento

Experiência prévia/contato com tecnologias assistivas

Figura 1 - Exemplo de pessoa a utilizar um sistema de EMG

Tem experiência prévia/contato com tecnologias assistivas com base em EMG (eletromiograma)? *

(Ver Figura 1)

◯ Sim

◯ Não

Se sim, por favor, especifique com que sistema/em que contexto:

A sua resposta

Experiência prévia/contato com disposição de teclado QWERTY

Figura 1 - Exemplo de teclado com disposição QWERTY

Tem experiência prévia com teclados com disposição QWERTY? *

(ver Figura 1)

◯ Sim

◯ Não

Se sim, por favor, especifique em que contexto:

A sua resposta

Com que frequência usa teclados com disposição QWERTY?

Selecionar ▾

Experiência prévia/contato com disposição de teclado ABCD

Figura 2 - Exemplo de teclado com disposição ABCD

Tem experiência prévia com teclados com disposição ABCD? *
(ver Figura 2)

- ◯ Sim
- ◯ Não

Se sim, por favor, especifique em que contexto:

A sua resposta

Com que frequência usa teclados com disposição ABCD?

Selecionar ▾

Experiência prévia/contato com disposição de teclado Numérico

Figura 3 - Exemplo de teclado com disposição Numérico

Tem experiência prévia com teclados com disposição Numérica? *
(ver Figura 3)

- ◯ Sim
- ◯ Não

Se sim, por favor, especifique em que contexto:

A sua resposta

Com que frequência usa teclados com disposição Numérica?

Selecionar

Experiência prévia/contato com disposição de teclado Apenas de Números

Figura 4 - Exemplo de teclado com disposição apenas de números

Experiência prévia com teclados com disposição apenas de números? *
(ver Figura 4)

- Sim
- Não

Se sim, por favor, especifique em que contexto:

A sua resposta

Com que frequência usa teclados com disposição apenas de números?

Selecionar

Credenciais de autenticação

As próximas questões são relativas a experiências prévias/contactos com diferentes tipos de credenciais de autenticação.

Costuma utilizar autenticação? *

- ◯ Sim
- ◯ Não

Se sim, por favor, especifique que tipos de autenticação costuma utilizar e com que frequência: *

	Nunca uso	1 vez por semana	2 a 3 vezes por semana	4 a 5 vezes por semana	Mais de 5 vezes por semana ou diariamente	Mais do que uma vez ao dia
Password	◯	◯	◯	◯	◯	◯
PIN	◯	◯	◯	◯	◯	◯
Padrão	◯	◯	◯	◯	◯	◯
CAPTCHA	◯	◯	◯	◯	◯	◯
Reconhecimento Facial	◯	◯	◯	◯	◯	◯
Impressão digital	◯	◯	◯	◯	◯	◯
Dispositivo físico	◯	◯	◯	◯	◯	◯

Caso tenha selecionado que utiliza Passwords, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza PIN, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza Padrão, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza CAPTCHA, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza Reconhecimento Facial, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza Impressão Digital, por favor especifique com que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Caso tenha selecionado que utiliza Dispositivo Físico, por favor especifique co que sistemas e em que contexto:

(Exemplos de sistema: telemóvel, computador, edifício, etc)
(Exemplos de contexto: aplicação bancária, e-mail, entrar numa sala, etc)

A sua resposta

Figure B.1 - Sociodemographic Questionnaire

Evaluation of the Authentication Scenarios Questionnaire


Questionário de Avaliação dos Cenários de Autenticação

Caro participante,

Agradecemos o seu interesse e disponibilidade para participar neste estudo. Este questionário tem como objetivo recolher informações importantes sobre os cenários de autenticação que acabou de realizar, a fim de compreender melhor os pontos positivos, negativos e falhas dos mesmos.

Se houver alguma dúvida ou preocupação durante o preenchimento do questionário, por favor, não hesite em colocar questões. Estamos à disposição para auxiliá-lo no que for necessário.

Agradecemos sinceramente pela sua colaboração.

[redacted]

Não partilhado

* Indica uma pergunta obrigatória

Preencha com o código que lhe é fornecido: *

A sua resposta

Seguinte

Limpar formulário

Ordene os cenários de autenticação, apresentados nas secções em baixo, por grau de dificuldade de execução. Selecione dentro de cada linha a opção mais fácil/difícil.

Cenários: *

(por favor não repita a mesma opção [mais fácil/mais difícil])

	Mais fácil	Mais difícil
PIN	○	○
Password	○	○

Pode, por favor, explicar as razões pelas quais considerou os cenários de autenticação mais difíceis? *

A sua resposta

Pode, por favor, explicar as razões pelas quais considerou os cenários de autenticação mais fáceis? *

A sua resposta

Anterior | Seguinte | Limpar formulário

Ordene agora os testes por grau de dificuldade de execução, tendo em conta o intervalo de tempo de permanência em cada botão individual. Selecione dentro de cada linha a opção mais fácil/difícil.

PIN *

(por favor não repita a mesma opção [mais fácil/mais difícil])

	Mais fácil	Mais difícil
Curto (menos tempo)	○	○
Longo (mais tempo)	○	○

Pode, por favor, justificar o grau de dificuldade atribuído aos diferentes tempos de permanência em cada botão, nos <u>cenários de PIN</u>?

(exemplo: Longo: acho que é/não é porque ...)

A sua resposta

Password *

	Mais fácil	Mais difícil
Curto (menos tempo)	○	○
Longo (mais tempo)	○	○

Pode, por favor, justificar o grau de dificuldade atribuído aos diferentes tempos de permanência em cada botão, nos <u>cenários de Password</u>?

(exemplo: Longo: acho que é/não é porque ...)

A sua resposta

Anterior Seguinte Limpar formulário

Tendo em conta a suas interações anteriores com cenários de autenticação, que aspetos positivos ou negativos gostaria de sublinhar para cada cenário de tipo de autenticação?

Aspetos positivos dos cenários com PIN:

A sua resposta

Aspetos negativos dos cenários com PIN:

A sua resposta

Aspetos negativos dos cenários com PIN:

A sua resposta

Aspetos positivos dos cenários com Password:

A sua resposta

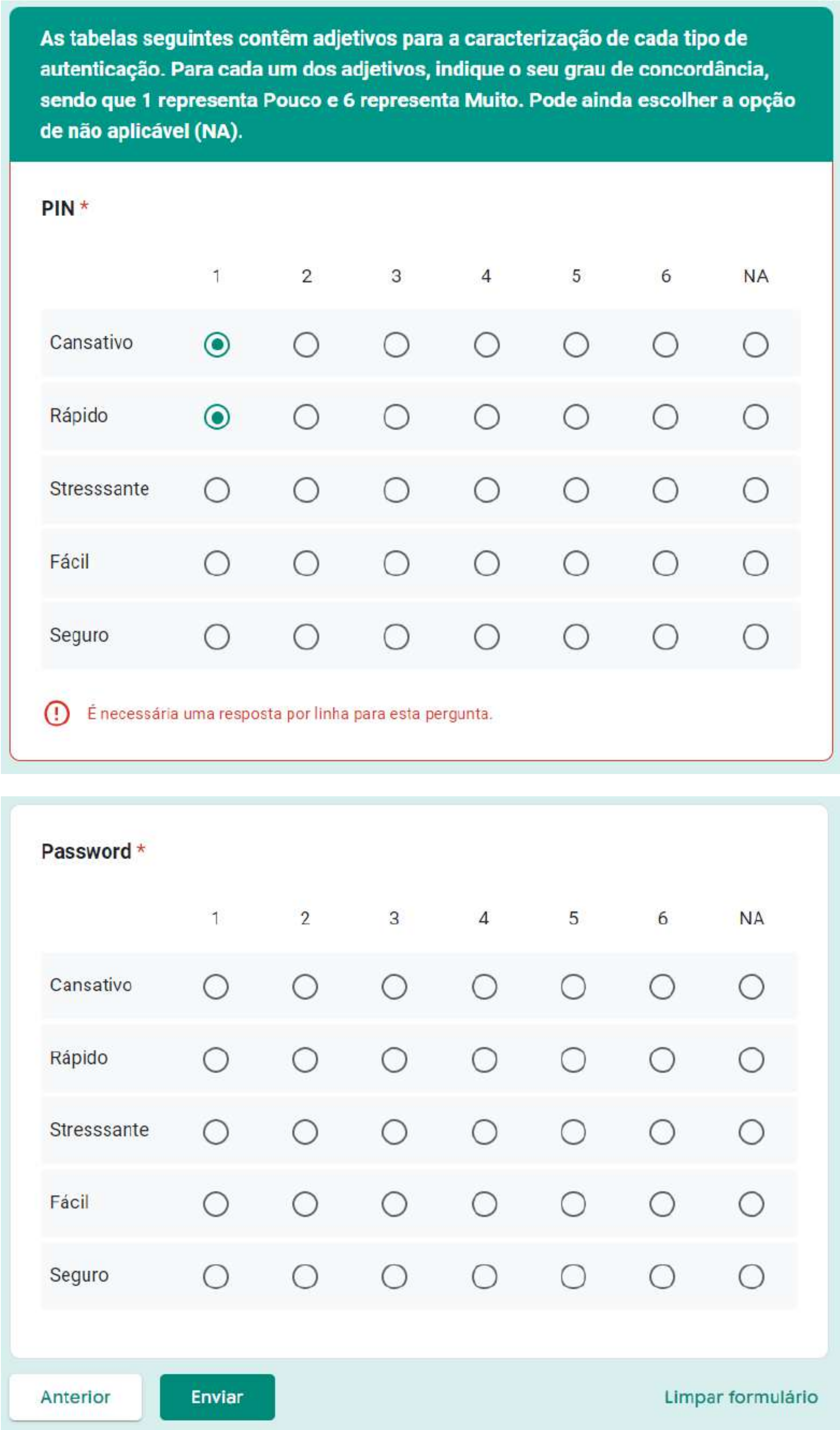
Aspetos negativos dos cenários com Password:

A sua resposta

Utilizaria algum destes tipos de autenticação no seu dia-a-dia como substituto aos mé

A sua resposta

Anterior Seguinte Limpar formulário



As tabelas seguintes contêm adjetivos para a caracterização de cada tipo de autenticação. Para cada um dos adjetivos, indique o seu grau de concordância, sendo que 1 representa Pouco e 6 representa Muito. Pode ainda escolher a opção de não aplicável (NA).

PIN *

	1	2	3	4	5	6	NA
Cansativo	◉	○	○	○	○	○	○
Rápido	◉	○	○	○	○	○	○
Stresssante	○	○	○	○	○	○	○
Fácil	○	○	○	○	○	○	○
Seguro	○	○	○	○	○	○	○

É necessária uma resposta por linha para esta pergunta.

Password *

	1	2	3	4	5	6	NA
Cansativo	○	○	○	○	○	○	○
Rápido	○	○	○	○	○	○	○
Stresssante	○	○	○	○	○	○	○
Fácil	○	○	○	○	○	○	○
Seguro	○	○	○	○	○	○	○

Anterior Enviar Limpar formulário

Figure B.2 - Evaluation of the Authentication Scenarios Questionnaire.

Evaluation of the EMG Prototype Questionnaire

Questionário de Avaliação dos Protótipo de EMG

Caro participante,

Agradecemos o seu interesse e disponibilidade para participar neste estudo. Este questionário tem como objetivo recolher informações importantes sobre os protótipo de EMG que acabou de utilizar, a fim de compreender melhor os pontos positivos, negativos e falhas dos mesmos.

Se houver alguma dúvida ou preocupação durante o preenchimento do questionário, por favor, não hesite em colocar questões. Estamos à disposição para auxiliá-lo no que for necessário.

Agradecemos sinceramente pela sua colaboração.

* Indica uma pergunta obrigatória

Preencha com o código que lhe é fornecido: *

A sua resposta

A tabela seguinte contém adjetivos para a caracterização do protótipo, com recurso a eletromiograma. Para cada um dos adjetivos, indique o seu grau de concordância, sendo que 1 representa Pouco e 6 representa Muito. Pode ainda escolher a opção de não aplicável (NA). *

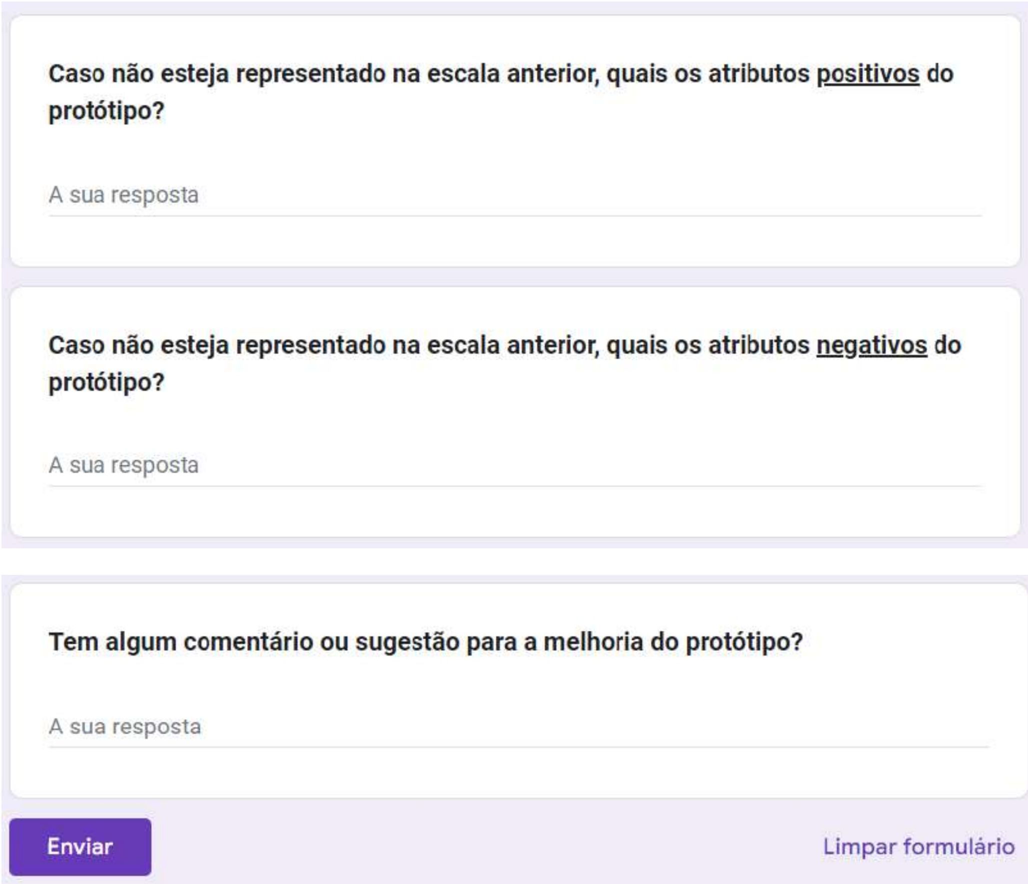
	1	2	3	4	5	6	NA
Cansativo	○	○	○	○	○	○	○
Confortável	○	○	○	○	○	○	○
Rápido	○	○	○	○	○	○	○
Stressante	○	○	○	○	○	○	○
Fácil	○	○	○	○	○	○	○
Eficiente	○	○	○	○	○	○	○
Calibrado	○	○	○	○	○	○	○

Se achar que deve comentar sobre a classificação de algum(s) adjetivo(s), por favor escreva o seu comentário:
(exemplo: Seguro: acho que é/não é porque ...)

A sua resposta

Caso não esteja representado na escala anterior, quais os atributos positivos do protótipo?

A sua resposta



Caso não esteja representado na escala anterior, quais os atributos positivos do protótipo?

A sua resposta

Caso não esteja representado na escala anterior, quais os atributos negativos do protótipo?

A sua resposta

Tem algum comentário ou sugestão para a melhoria do protótipo?

A sua resposta

Enviar

Limpar formulário

Figure B.3 - Evaluation of the EMG Prototype Questionnaire.

FACULDADE DE PSICOLOGIA E DE CIÊNCIAS DA EDUCAÇÃO UNIVERSIDADE DE COIMBRA

Informed Consent

Consentimento informado

Prezado/a participante,

O presente estudo, inserido num projeto de Dissertação do Mestrado que tem como principal objetivo avaliar a acessibilidade de técnicas de autenticação de tecnologias interativas, por meio de eletromiografia, por parte de pessoas diagnosticadas com Esclerose Lateral Amiotrófica. O estudo está a ser realizado por uma equipa de investigação da Universidade de Coimbra, da qual fazem parte as investigadoras Ana Felício, Carla Carvalho e Paula Alexandra Silva.

A realização deste estudo só é possível através da sua participação, completando uma atividade que consta de alguns desafios de autenticação que lhe irão ser apresentados. A duração da atividade é de aproximadamente 30 minutos. Em seguida, ser-lhe-á apresentado um questionário acerca dos desafios da atividade anterior, cuja preenchimento será de aproximadamente 10-15 minutos.

Toda a informação recolhida será anónima e confidencial, pelo que as respostas obtidas serão agrupadas e trabalhadas estatisticamente em conjunto com as dos demais participantes. As informações recolhidas serão utilizadas para fins de divulgação científica, de acordo com a ética em investigação científica em vigor em Portugal. Salientamos que que todos os dados serão tratados de acordo com as Diretrizes da Universidade de Coimbra para a proteção de dados, que estão alinhadas com o Regulamento Geral de Proteção de Dados Pessoais (RGPD; Regulamento nº 2016/679 do Parlamento Europeu e do Conselho, de 27 de abril de 2016 – aplicável desde 25 de maio de 2018). Note que a sua participação é voluntária, pelo que pode desistir do estudo a qualquer momento, sendo para tal necessário não concluir o preenchimento do questionário e, assim, nenhuma das suas respostas será utilizada.

Agradecemos a sua colaboração! Se tiver algum comentário ou dúvida sobre o estudo em questão, por favor, entre em contato com a equipa de investigação, através de um dos e-mails margfelicio@gmail.com, ccarvalho@fpce.uc.pt, paulasilva@dei.uc.p.

Atenciosamente,
A equipa de investigação

Data:	Assinatura do participante:
___________________________	____

Section III

Experiment script

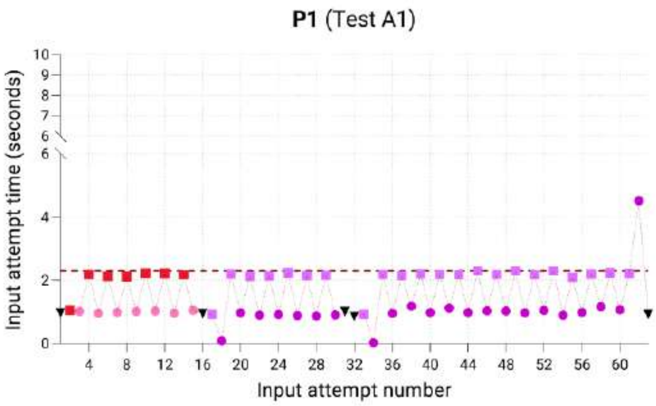
1. Good [morning/afternoon], this procedure will consist of performing a sequence of 4 tests, which last about 40 minutes, and filling in 3 questionnaires, which last about 15 minutes.
    a. The tests consist in the realization of authentication scenarios;
    b. To perform the tasks it will use an EMG prototype as a means of interaction with the system;
    c. The questionnaires are: a sociodemographic questionnaire (to be carried out before the test) and the following two are evaluation questionnaires, of the prototype and of the authentication scenarios (both to be carried out after finishing the tests).
2. I will now explain the prototype better:
    a. I will place 3 electrodes on your skin, one control and two associated with a specific muscle group;
    b. In this case I will place the two electrodes on the muscle associated with the movement of the thumb (specify the muscle);
    c. By using this muscle you will be able to simulate a click, similar to a mouse:
        i. When the muscle is active, it has made a click and is interacting with the system;
        ii. When the muscle is at rest, you are not interacting with the system.
    d. Now I'm going to put the electrodes on your skin
        i. Would you prefer me to put the electrodes on your left hand or your right hand?
        ii. Which is your dominant hand?
        iii. If you ever feel that the electrodes are disaloging from your skin and it is affecting your click ability, please warn me and I will change them.
    e. Now I will start a fake test, and you will try out the system for 4 minutes:
        i. Please note that this test will not be accounted for and exists only for the sake of you understanding the click and system;
        ii. Try to feel how you prefer to move your muscle in order to click, you can try several positions;
        iii. I will ask you to look at the system, try and understand it, during these 4 minutes, try to focus a button of your choice and try to click on it; do this several times;
3. Now I will put you through the four different tests:
    a. The scenarios consist of two variations of credentials: PIN and Password. Each variation has two variations on the amount of time you have to click in the buttons;
    b. You'll notice a gray area on the right side of the screen. There you will see the credentials you have to enter to perform the test.
    c. The username is always the same, but the PIN/Password are automatically generated and are always different.
    d. Please note that the PIN consists of 6 numbers;
    e. Please note that the Password consists of 8 characters: (1) capital letter; (1) number; (1) special character; (5) lowercase letters; This is important for the correct input of credentials;
4. There is no time limit for the tests.

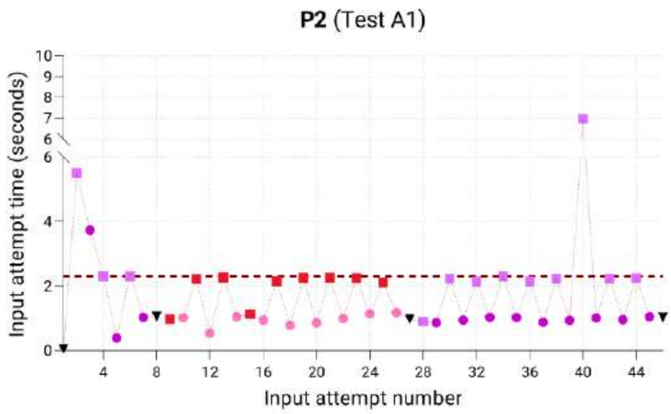
5. Note that if you feel you cannot finish the test, you can always ask to stop the test and I ask you to explain why, this is important for a coherent analysis of the tests;
6. I want to remind you that the tests are not made to test you, but to test the system. Knowing this, there is no need to be nervous. Any frustration or shortcomings are not due to your ability but to something that should be rethought in the design of the prototype and/or authentication scenario

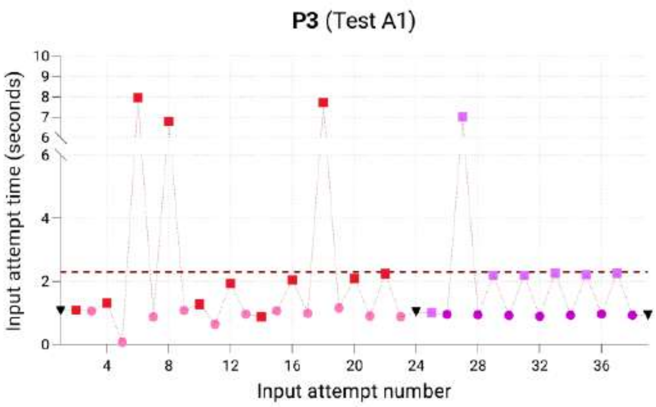
Appendix C

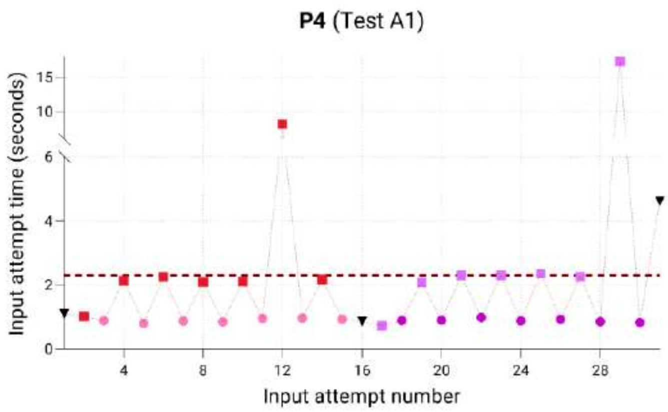
Section I

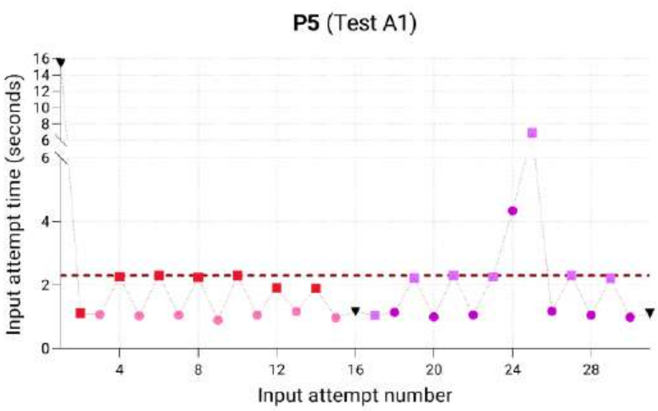
Real timing of each selection for the duration of test A1, by participant

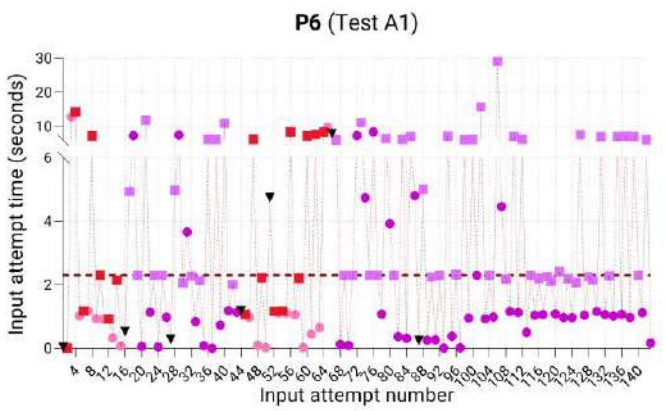












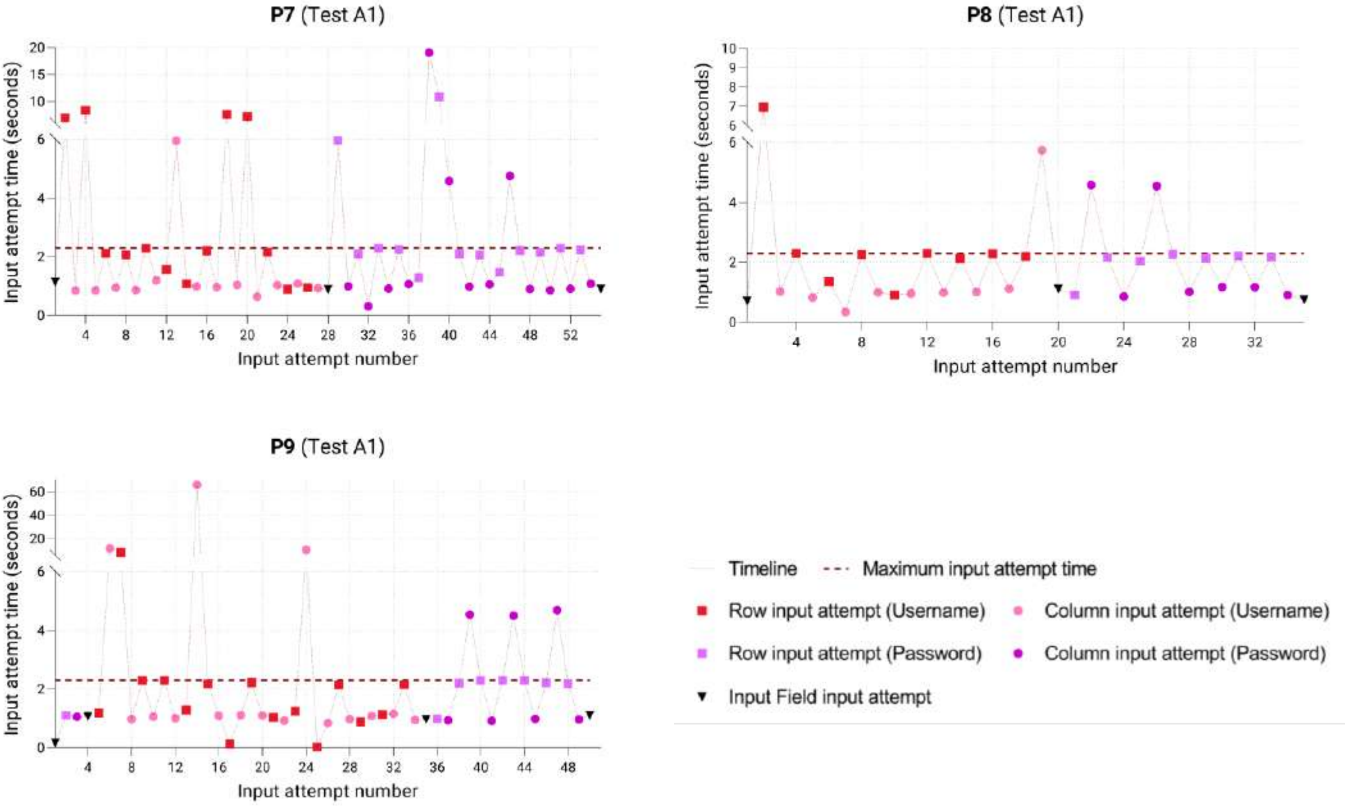
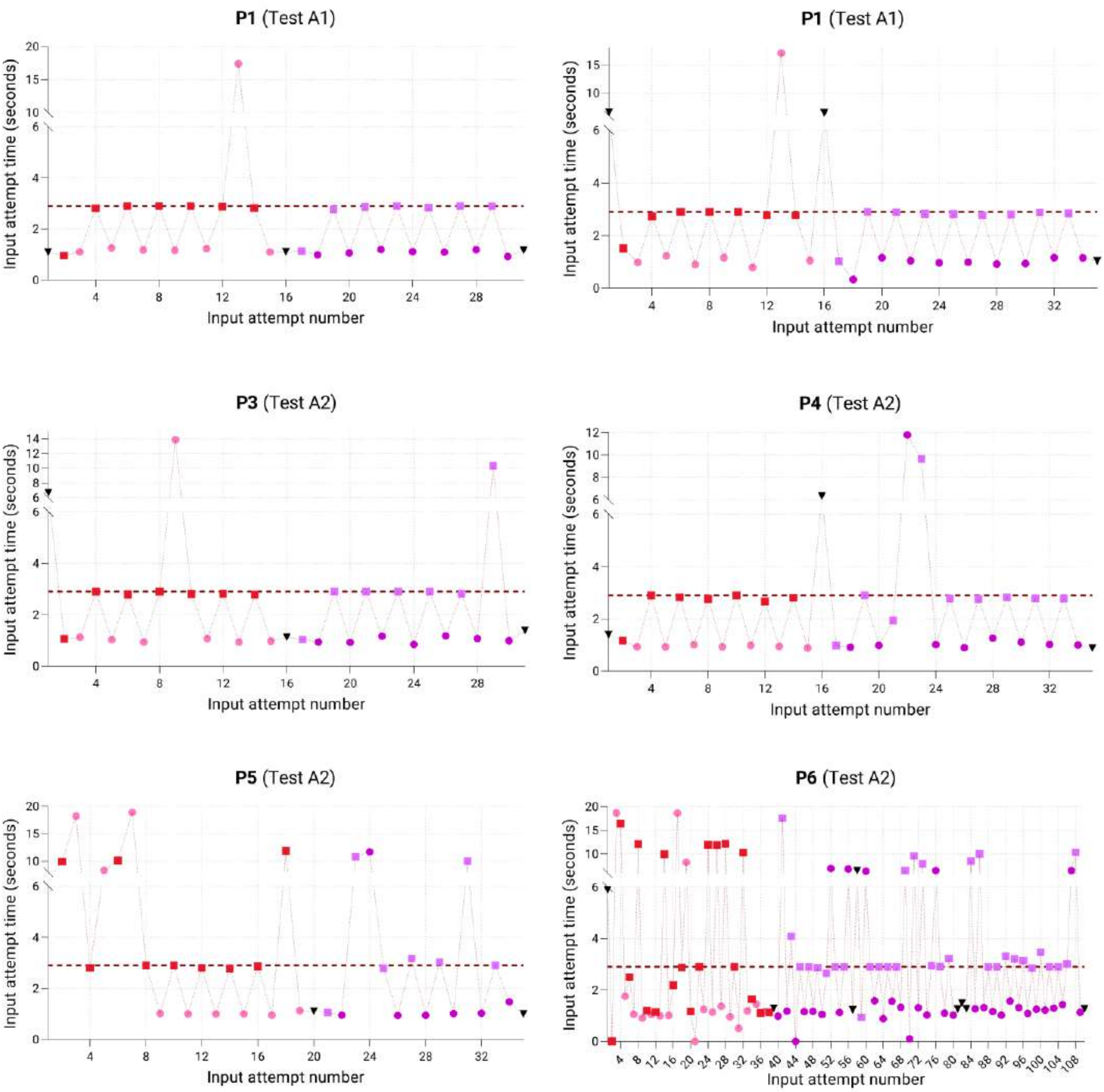


Figure C.1 - Real timing of each selection for the duration of test A1, by participant

Real timing of each selection for the duration of test A2, by participant



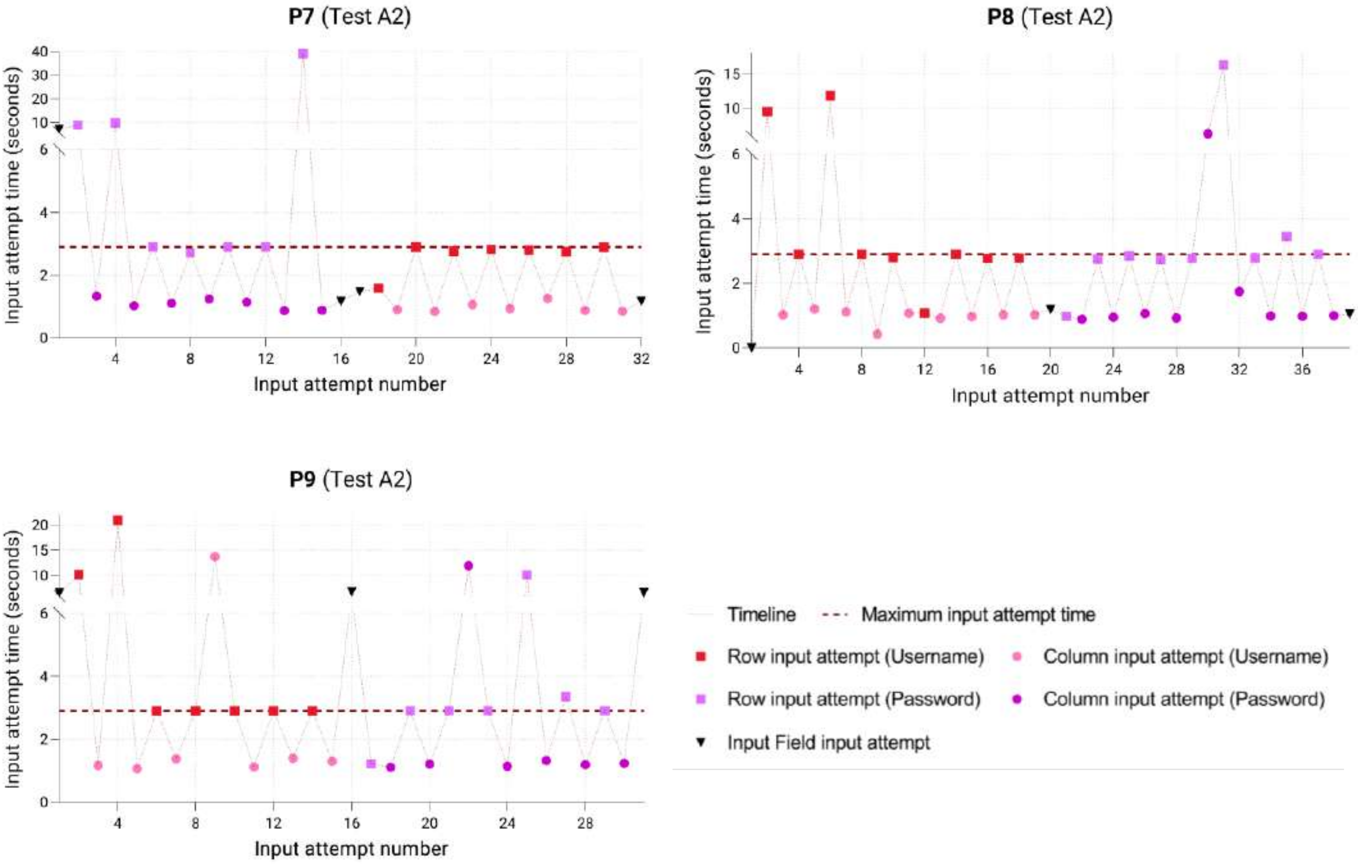
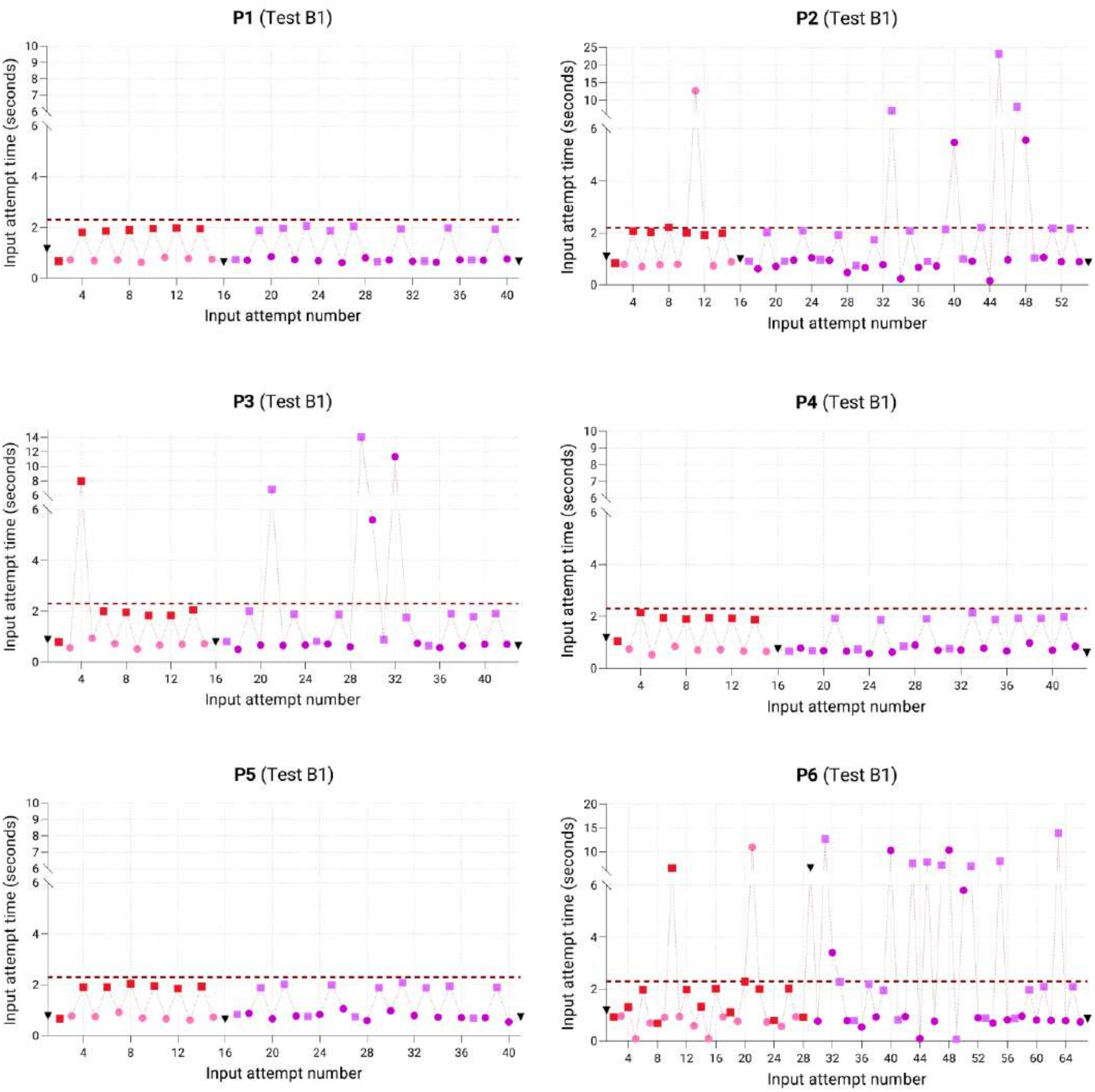


Figure C.2 - Real timing of each selection for the duration of test A2, by participant

Real timing of each selection for the duration of test B1, by participant



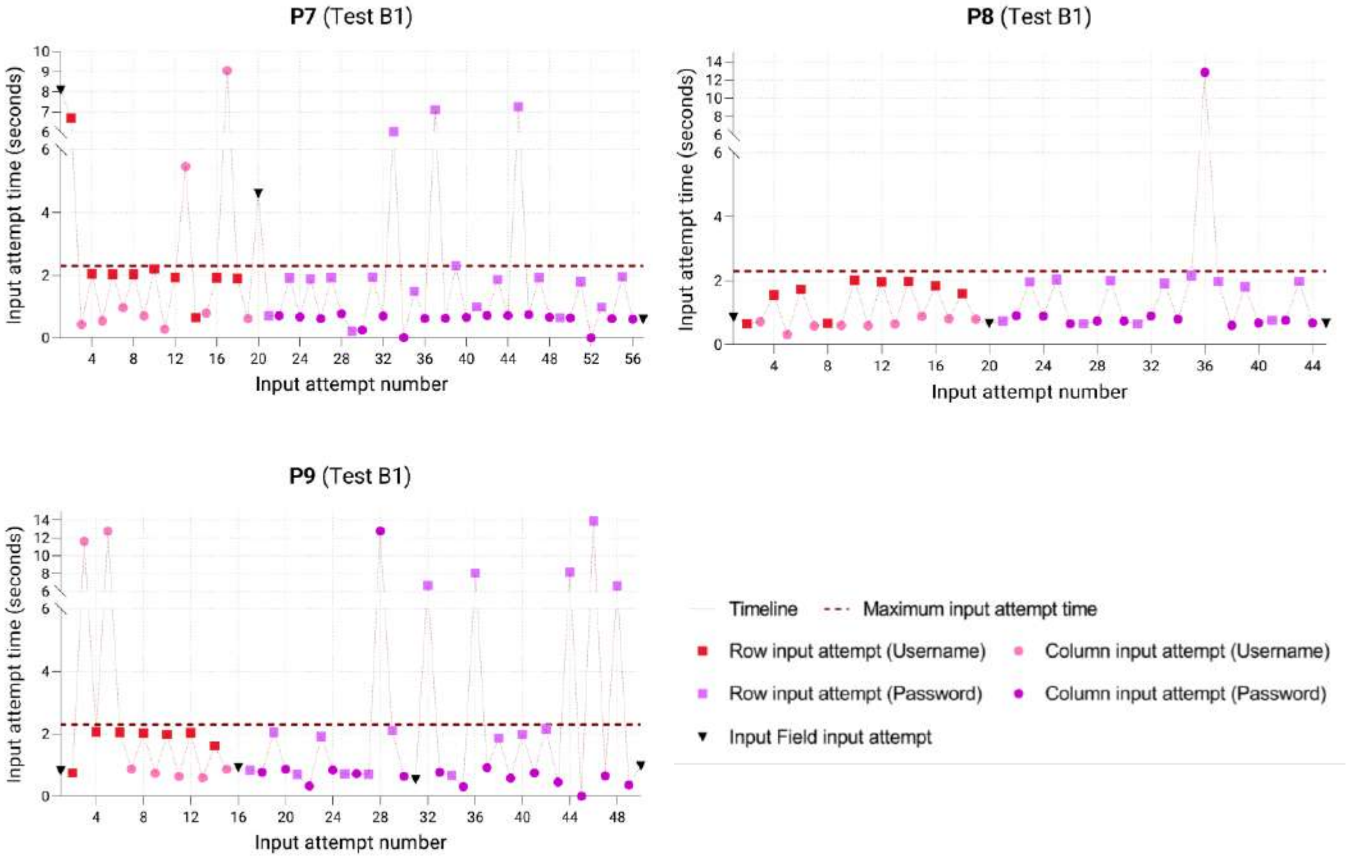
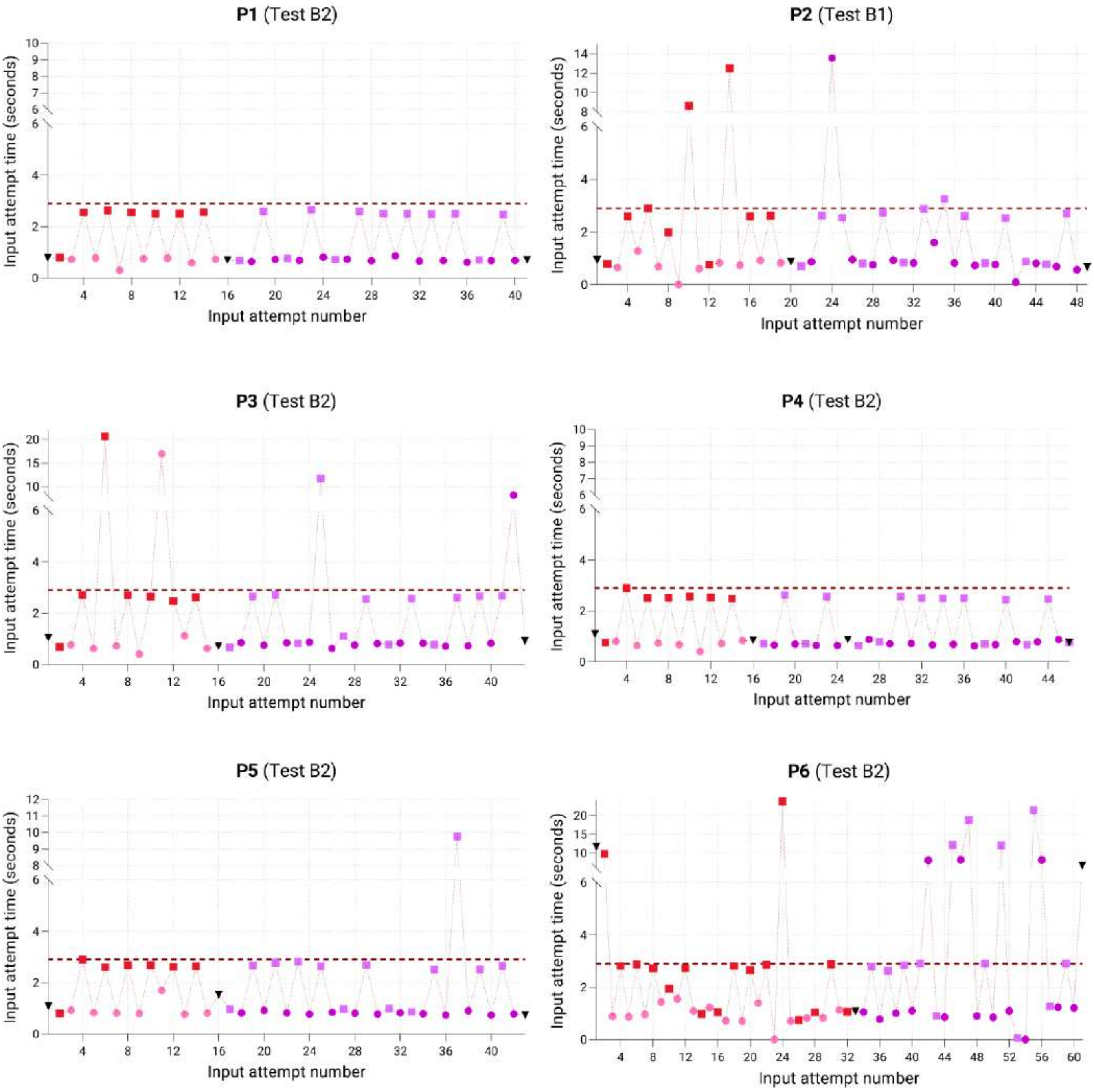


Figure C.3 - Real timing of each selection for the duration of test B1, by participant

Real timing of each selection for the duration of test B2, by participant.



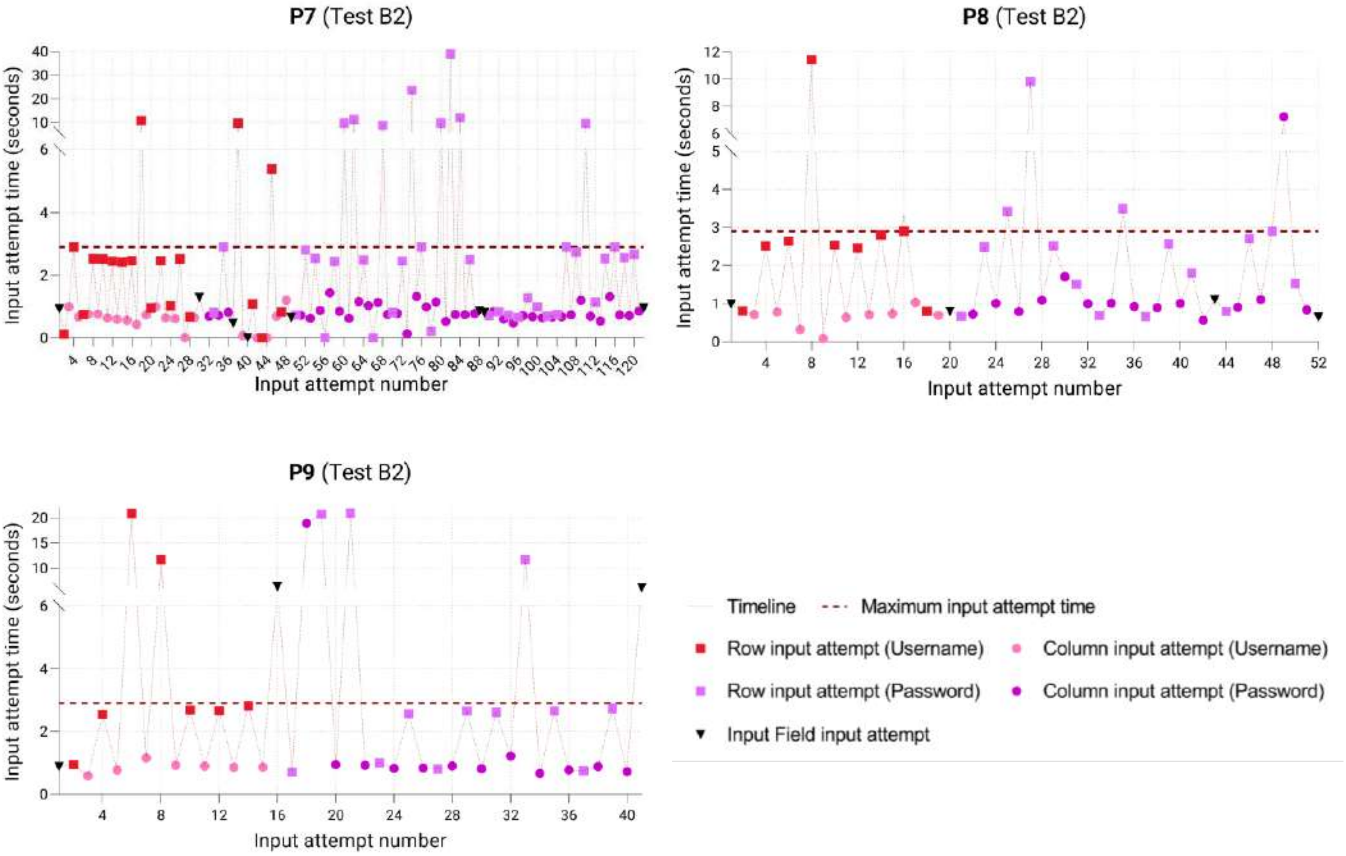


Figure C.4 - Real timing of each selection for the duration of test B2, by participant

Section II

Real input attempt timing of P1 tests

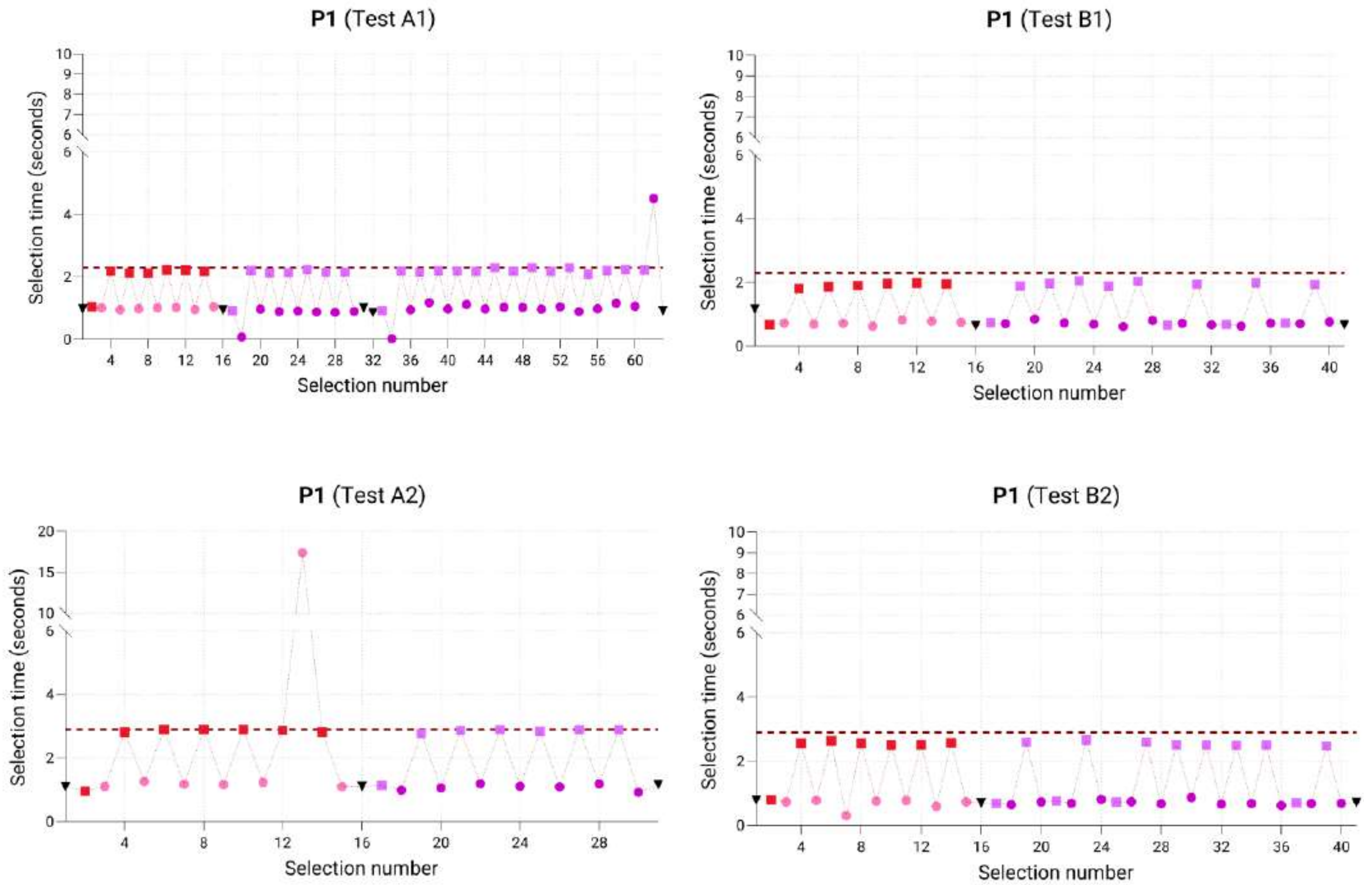


Figure C.5 - Real input attempt timing of P1 tests.

Real input attempt timing of P2 tests

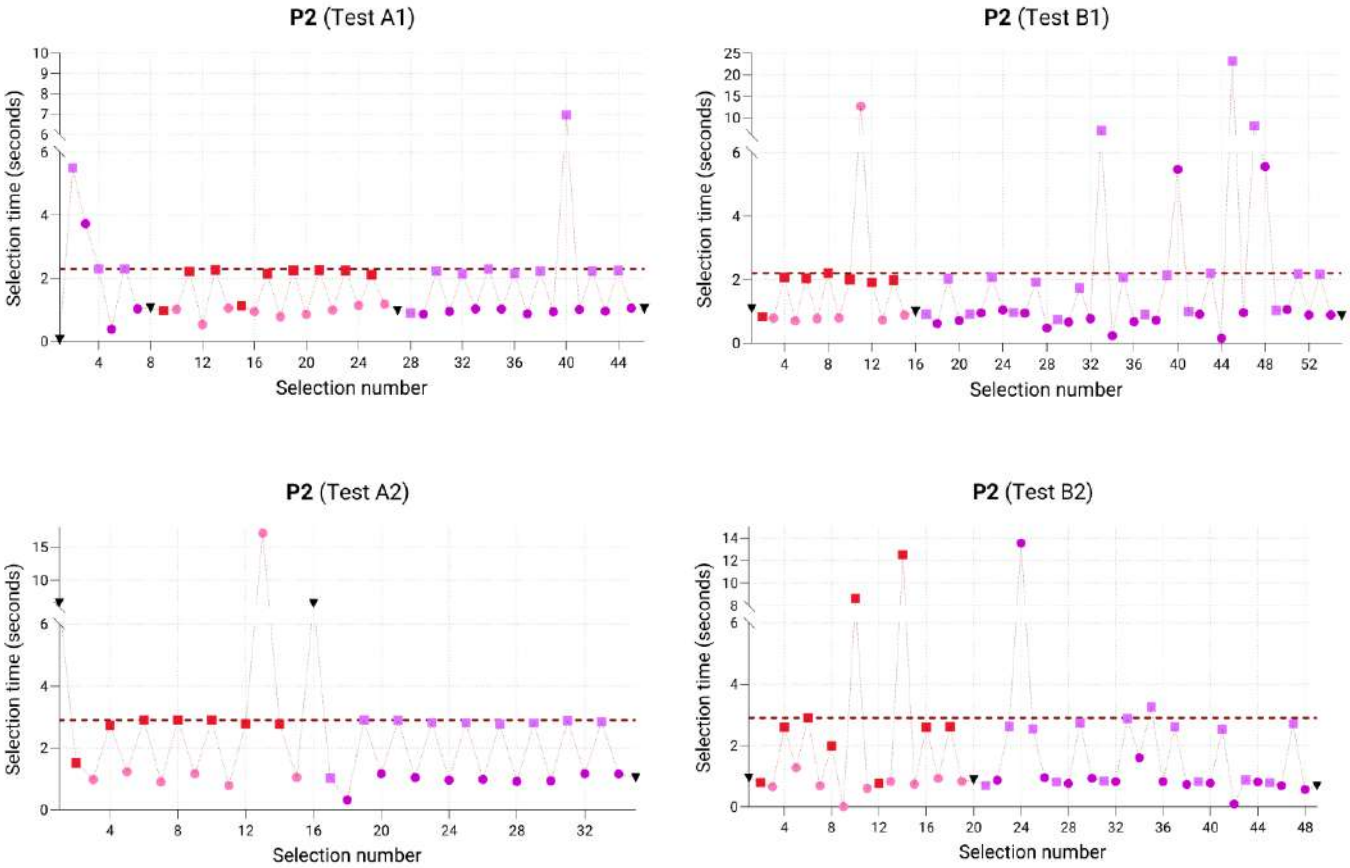


Figure C.6 - Real input attempt timing of P2 tests.

Real input attempt timing of P3 tests

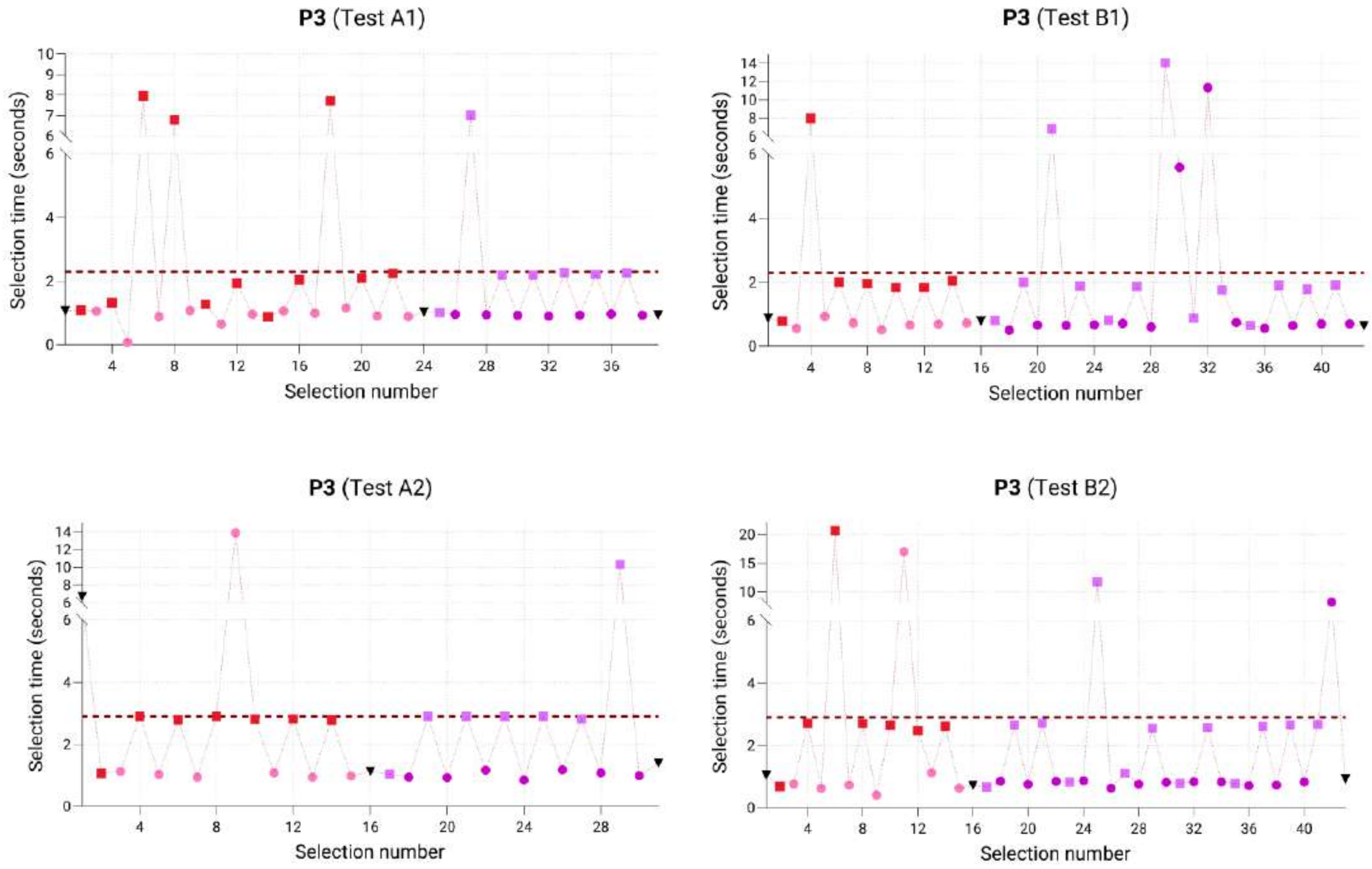


Figure C.7 - Real input attempt timing of P3 tests.

Real input attempt timing of P4 tests

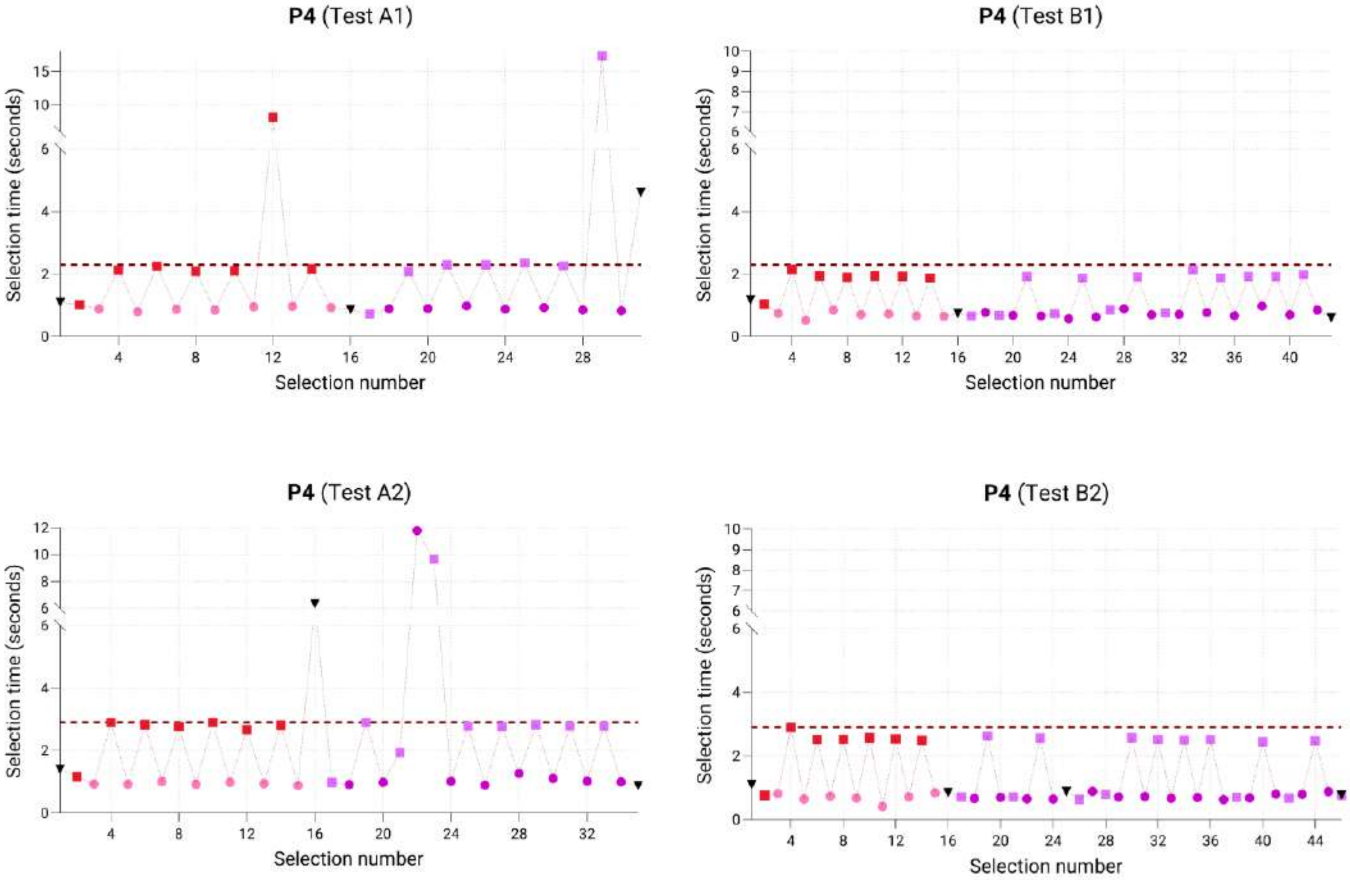


Figure C.8 - Real input attempt timing of P4 tests.

Real input attempt timing of P5 tests

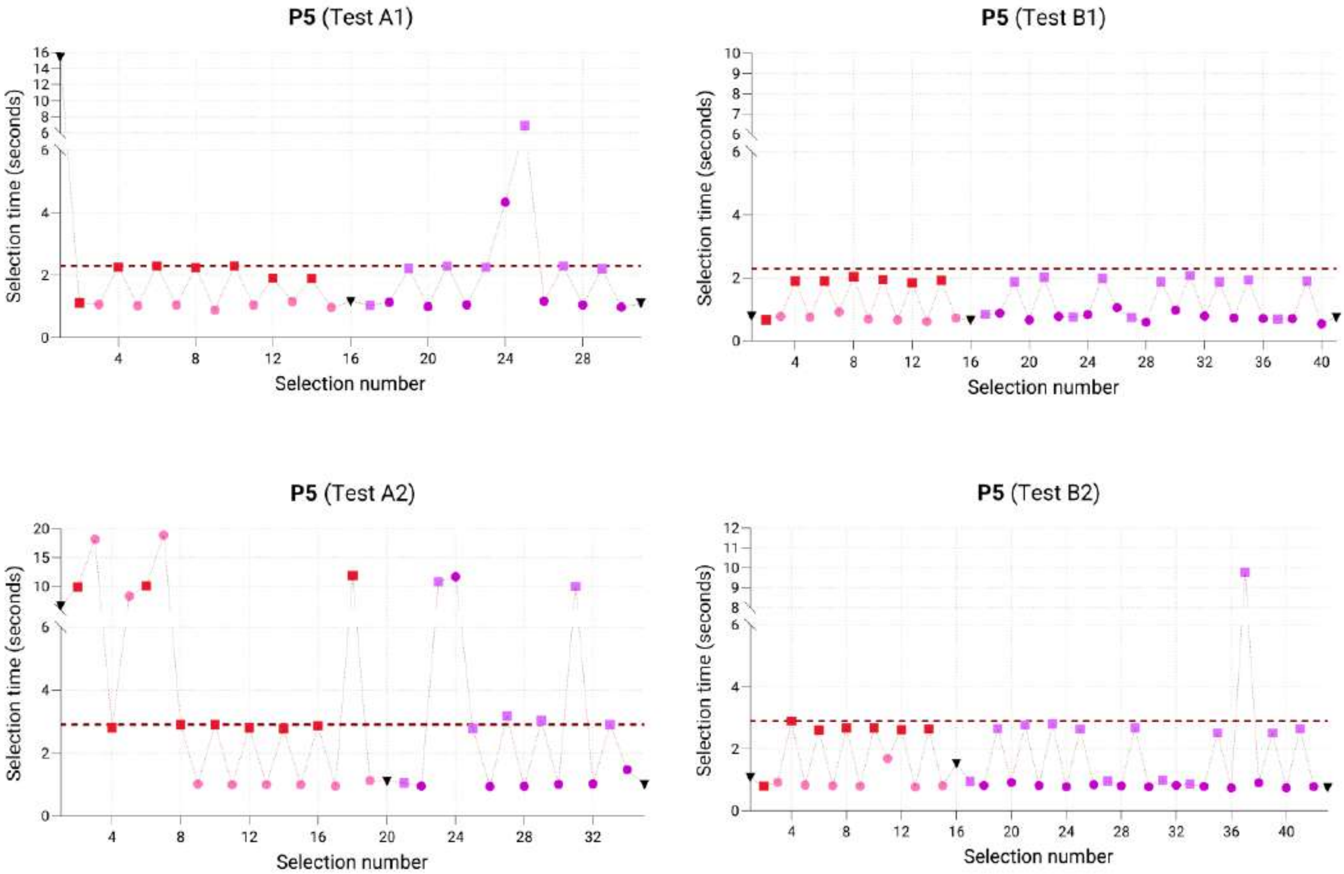


Figure C.9 - Real input attempt timing of P5 tests.

Real input attempt timing of P6 tests

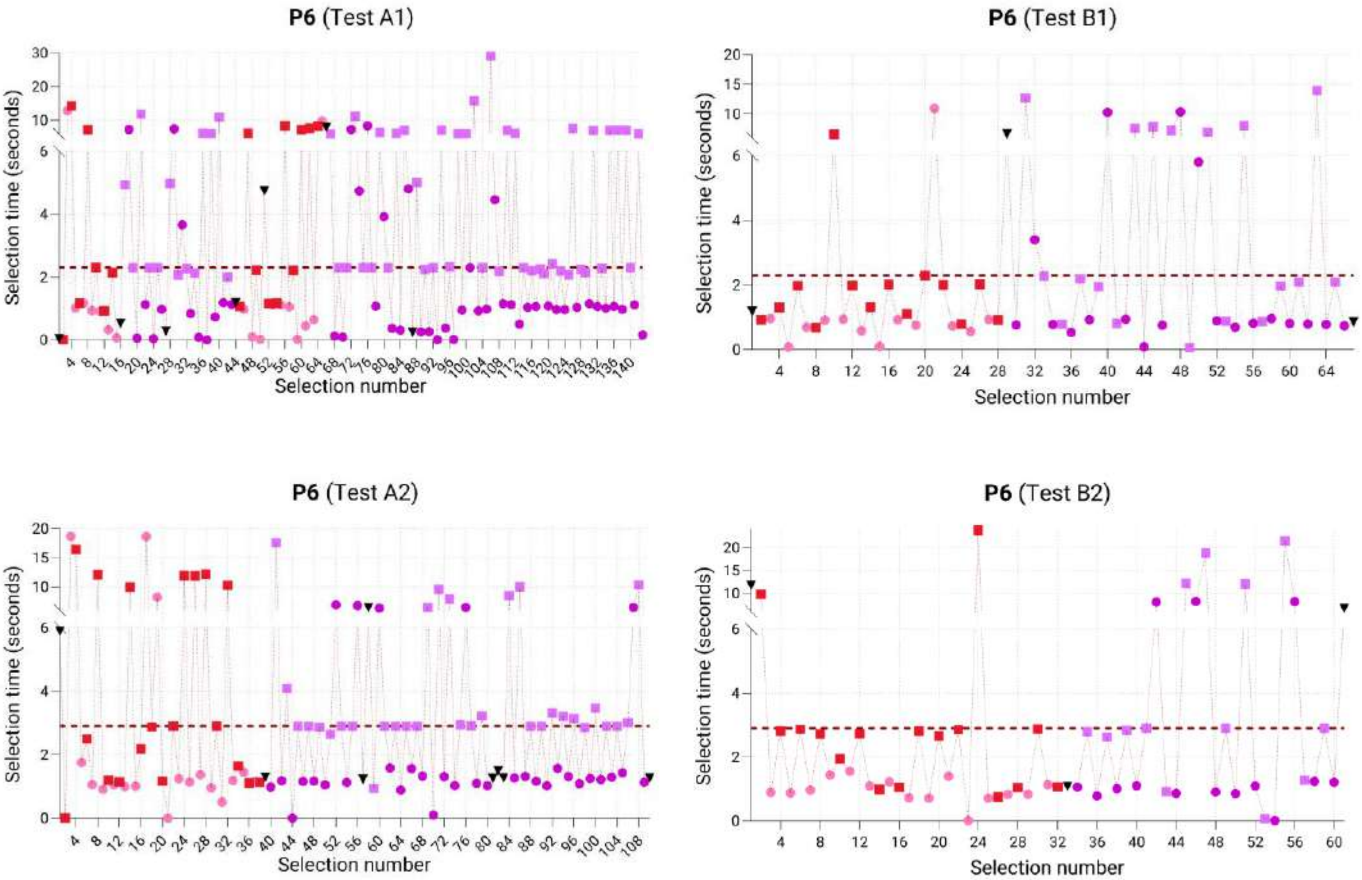


Figure C.10 - Real input attempt timing of P6 tests.

Real input attempt timing of P7 tests

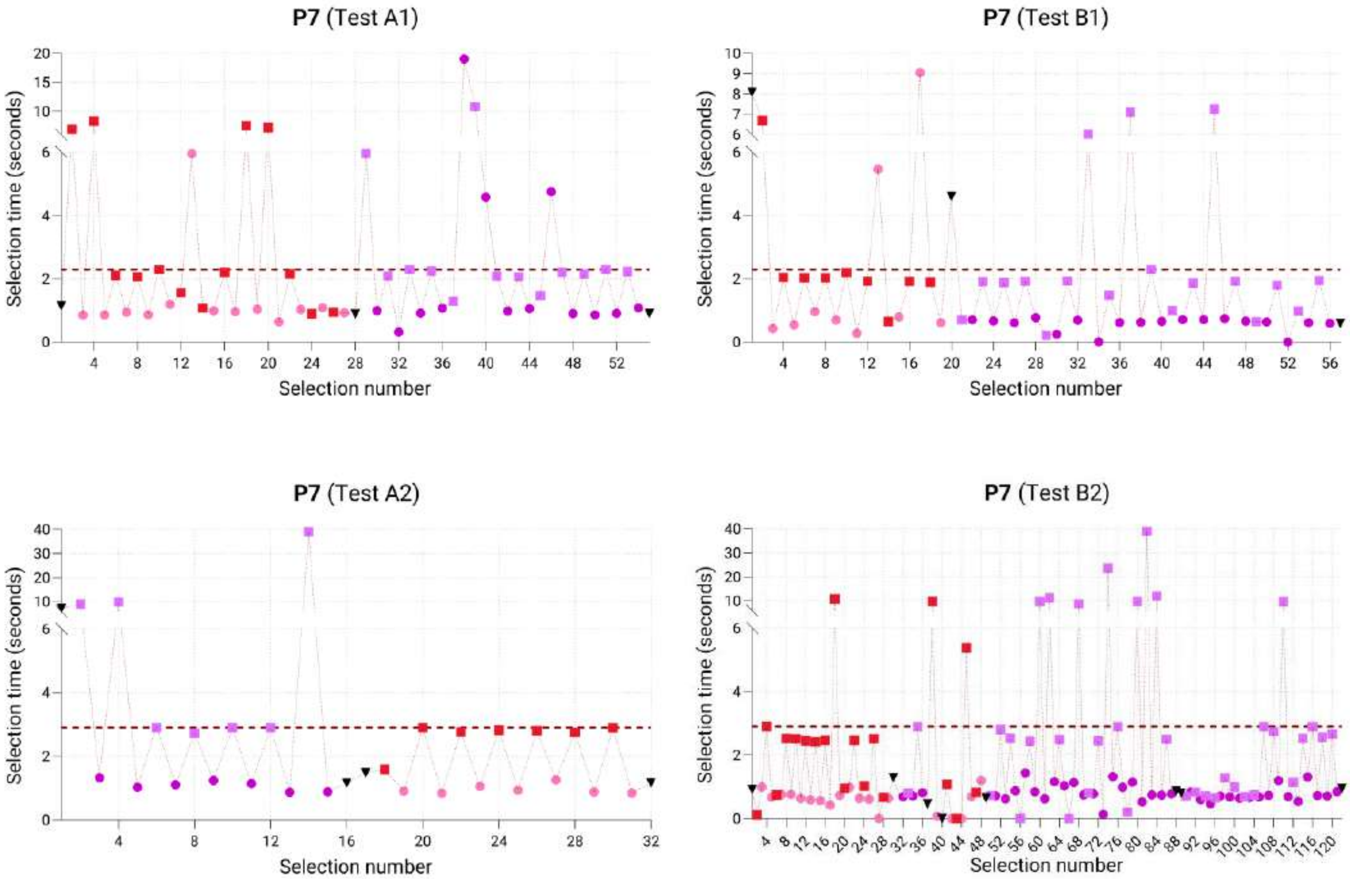


Figure C.11 - Real input attempt timing of P7 tests.

Real input attempt timing of P8 tests

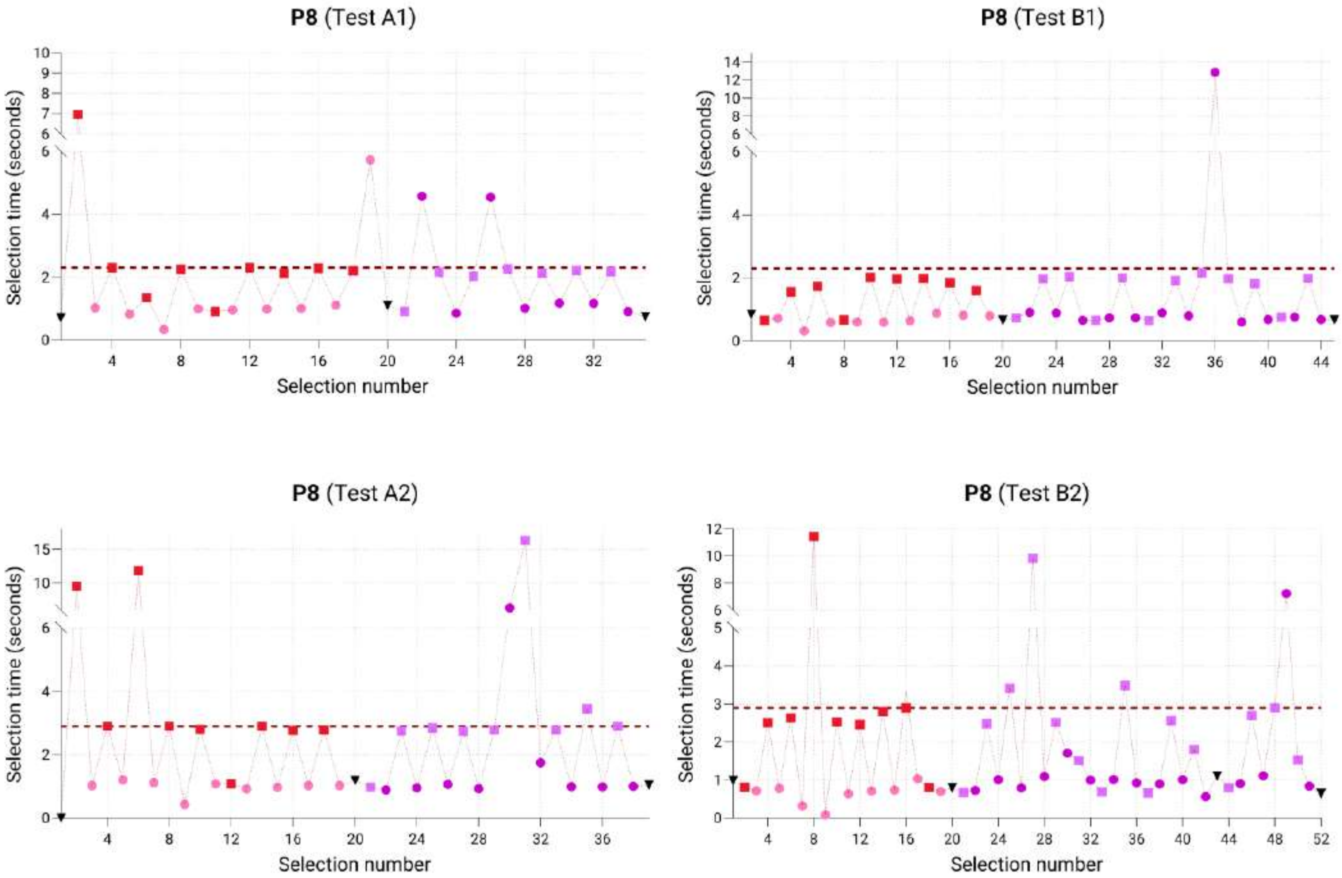


Figure C.12 - Real input attempt timing of P8 tests.

Real input attempt timing of P9 tests

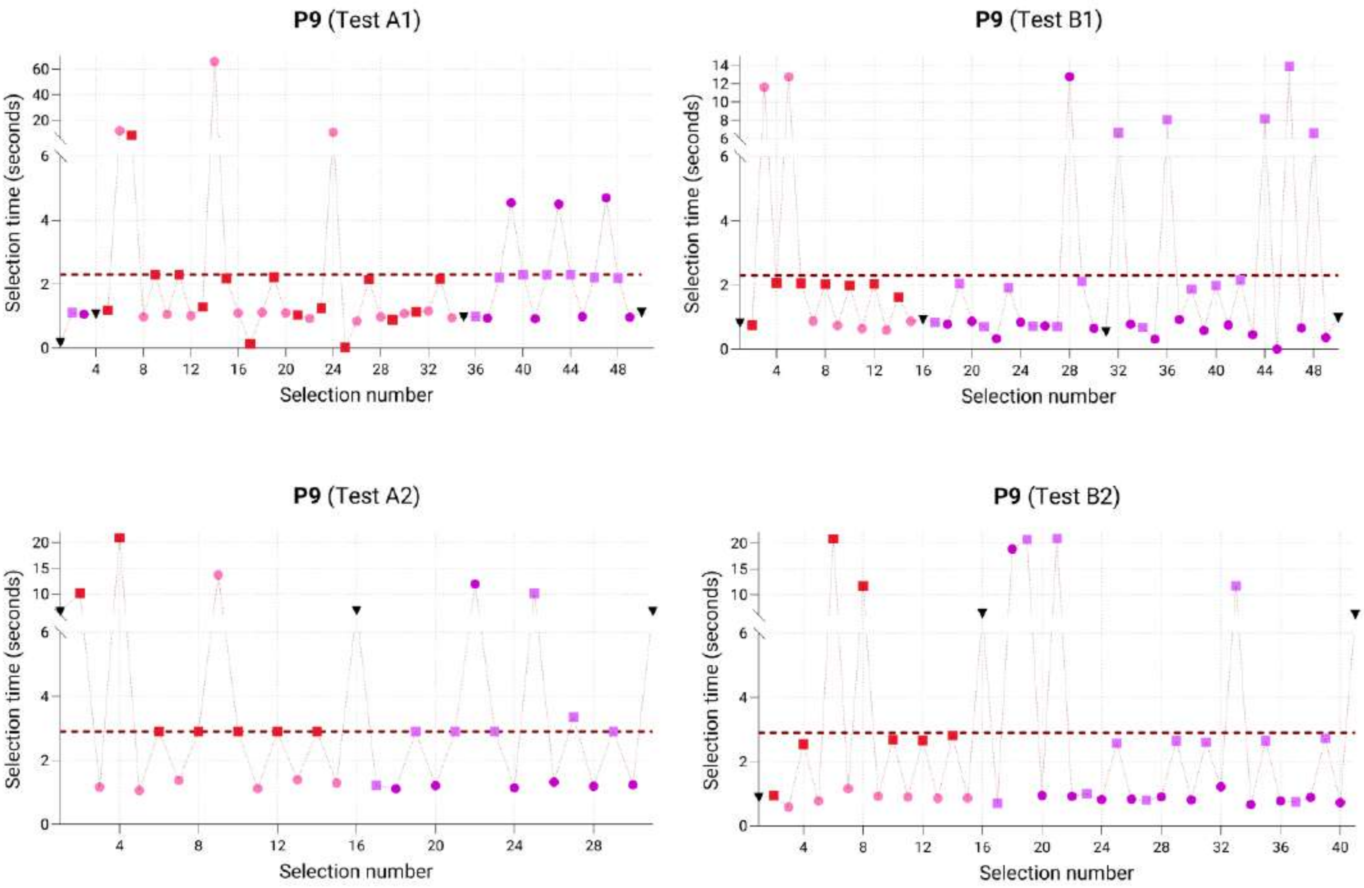


Figure C.13 - Real input attempt timing of P9 tests.