Design and Evaluation of SANS TRACAS - A Cross-Platform Tool for Conducting Online EEG Experiments

by

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DEDICATION

This thesis is dedicated to my paternal grandmother

Late Mrs. Manjulaben Ranjitray Desai

And

my maternal grandparents

Late Mr. Arvindbhai Gulabbhai Naik

And

Mrs. Manjulaben Arvindbhai Naik

Thank you for being the strong willed, kind, and generous people that you were and are.

I also want to dedicate this thesis to my parents

Mrs. Nipa Umeshbhai Desai

And

Mr. Umeshbhai Ranjitray Desai

Thank you for always unconditionally loving and supporting me throughout the years and everything that you've done for me.

Finally, to the Master for life itself.

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ABSTRACT

Electroencephalography (EEG) research has been going on for centuries. However, traditional in-lab EEG studies are too complex, costly, and time-consuming for researchers and study participants. Moreover, it leads to increased marginalization and poor generalization of the findings. To solve this problem and driven by a desire to democratize EEG research, the Sans Tracas platform was created. Sans Tracas is a cross-platform web application for running EEG experiments online. A collaborative effort between cognitive neuroscientists and HCI researchers, the platform is designed via a multidisciplinary lens and using a user-centric iterative design approach to be easy to use by researchers and study participants alike. For researchers, the platform allows users to augment any behavioural study deployed on online platforms with EEG data recordings from the commercially-available InteraXon Muse EEG device. For end-users who have access to the Muse, the platform is focused on having them perform entire EEG studies on their own from the comfort of their homes. This thesis discusses the design, development, and evaluation of Sans Tracas. The results of the main study (N = 55), followed by a semi-structured interview of 11 participants, show that participants found Sans Tracas easy to use, useful, and had fun participating in EEG experiments independently and are now more interested in EEG and Brain Computer Interface (BCI) research than before. Additionally, the EEG data collected was of good quality and viable for online EEG studies. Sans Tracas is exceptionally usable for conducting online EEG studies and is a better experience overall than traditional in-lab studies.

LIST OF ABBREVIATIONS USED

EEG	Electroencephalography
BCI	Brain Computer Interfaces
COVID-19	Corona (CO) Virus (VI) Disease (D) – 19
HCI	Human Computer Interaction
ECOG	Electrocorticography
DARPA	Defense Advanced Research Projects Agency
ALS	Amyotrophic Lateral Sclerosis
ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
PD	Parkinson's Disease
BSLEACS	Brain-computer interface-based Smart Living Environmental Auto-adjustment Control System
UPnP	Universal Plug-and-Play
WHO	World Health Organization
EMG	Electromyography
SVM	Support Vector Machine
UCD	User-Centered Design
ISO	International Organization for Standardization
IVR	Interactive Voice Response
SUS	System Usability Scale
NPS	Net Promotor Score
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
GUI	Graphical user interface
iOS	iPhone Operating System
MacOS	Macintosh Operating System
ERP	Event Related Potential
TV	Television
BLE	Bluetooth Low Energy
AUX	Auxiliary Port
LSL	Lab Streaming Layer
JS	JavaScript
API	Application Programming Interface
CSV	Comma Separated Value
EMD	Empirical Mode Decomposition
SSL	Secure Sockets Layer
FTP	File Transfer Protocol
UI	User Interface
PU	Perceived Usefulness
PEOU	Perceived Ease Of Use
ARCS	Attention, Relevance, Confidence, Satisfaction
SD	Standard Deviation
NaN	Not a Number

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CHAPTER 1 INTRODUCTION

1.1 The Problem

Advances in technology have led to the increasing use of physiological sensors such as electroencephalography (EEG) sensors in many disciplines within neuroscience and Brain Computer Interfaces (BCI) research. EEG is a common neuroimaging technique in sensory and cognitive neuroscience. Traditional EEG research studies take place in a laboratory, where the researcher fits the EEG device on the participant's head, verifies the impedance and signal quality of the sensors, explains to the participant the experimental task to be performed, and monitors the incoming signals and the participants' behaviour during the experiment. The placement of electrodes on the participant's head is relatively time-consuming, with some systems requiring the researcher to apply conductive gel under each electrode to obtain a good signal. Therefore, participating in EEG studies in the lab presents some barriers, not only due to the need to travel to the researchers' laboratory but also due to the somewhat cumbersome and uncomfortable nature of traditional EEG headsets. Given the cost of traditional lab-based EEG systems, most labs would not have more than one, so only one participant can be tested at a time, presenting a further bottleneck in data collection.

Not only do these requirements increase the time associated with the study and limit the sample size of participants, but they also make it difficult to achieve high levels of diversity of participants in EEG experiments, hence making the generalizability of findings and democratization of EEG experiments virtually impossible. Participant recruitment is often based on convenient sampling due to the need to have the participants visit the research lab for the experiment. This increases marginalization with respect to who can benefit from the innovation. It also can lead to an inadequate sample test size, resulting in low statistical power, as mentioned by Button et al. [1].

Moreover, with the emergence of COVID-19, it has become difficult for researchers and participants to meet each other in a confined space to conduct studies. Even after about two years of living in the pandemic, researchers are still trying to figure out the most efficient way for them to conduct in-person EEG research [2].

1.2 Motivation

As a result of the abovementioned limitations in the current practices of conducting EEG studies, now more than ever, it has become necessary to pioneer efforts towards democratizing EEG research. Democratizing neuroscience research on a large scale will help advance the field, broaden study sample sizes, and discover new neural interfacing principles while at the same time making neurotechnology accessible to everyone. To achieve such progress, we need to adopt a multidisciplinary approach that would open up participation in basic EEG research by taking it out of the lab and bringing it to people's doorsteps. This can only be possible by connecting neuroscience (BCI and EEG) research with Human Computer Interaction (HCI) research. Thus, it is time now that we must adopt user centred HCI design paradigms for neurotech products and application development. HCI principles could also help us develop a general sense of mutual trust with our target audience and help people adopt the EEG research.

Additionally, with the recent advances in low-cost, portable, and easy-to-use EEG tools such as the Muse [3], Emotiv [4], and OpenBCI [5], EEG equipment is increasingly becoming accessible in many households. These advances make it possible for end-users to participate in EEG experiments from the comfort of their homes. This would help increase the participant database and reduce the marginalization of minorities. It would also bring down the cost of research significantly. However, to date, there is no easy-to-use experimental platform that aids researchers in running EEG experiments remotely.

1.3 The Solution

To bridge this gap, this research presents the design, development, and evaluation of Sans Tracas: A cross-platform tool that lets users conduct online neuroscientific studies and EEG experiments using a simple web browser and a consumer-grade EEG device, such as InteraXon's Muse [3]. Since a platform like this was only possible by combining HCI and neuroscience research, Sans Tracas was developed via a multidisciplinary lens and in an iterative approach via multiple meetings and brainstorming sessions for over a year.

Specifically, this thesis presents a cross-platform application for running large-scale neuroscientific (EEG) studies. Instead of the more traditional way of running neuroscientific (EEG) studies (i.e., in a laboratory), Sans Tracas provides a way to run those studies online from the comfort of one’s own home. Sans Tracas also serves as a web-based EEG data collection tool. Sans Tracas has two target users: cognitive psychology, neuroscience, and EEG researchers (also referred to as ‘researchers’) and people who would be study participants (also referred to as ‘end users’). Sans Tracas was developed via an iterative user-centric design approach, with both target users at the centre of the development process. The goal for the end-users was to allow them to independently run an EEG experiment online without help from researchers or anyone else. The goal for the researchers was to allow them to augment their behavioural experiments by letting them integrate it with Sans Tracas and add an EEG component to their research. Both goals were to be achieved by keeping target users’ ease of use at the centre of the design.

The usability of the platform's initial version was evaluated via an in-lab pilot study with 7 participants. The platform was later refined based on the results from the pilot study. The usability of the final version of the platform was evaluated via an at-home main usability study with 55 participants.

1.4 Contributions

The thesis made three significant contributions:

One; since Sans Tracas lets users run and participate in EEG studies from the comfort of their homes, thereby contributing to the effort towards democratizing BCI (a Brain-Computer Interface is a system that connects the human brain to external technology) and neuroscience (EEG) research, increasing diversity of participants, reducing marginalization, and reducing the associated cost of conducting research in the area.

Two; this thesis contributes to HCI by presenting the design and development of Sans Tracas, a cross-platform application that allows users to run EEG experiments from the comfort of their home and helps in reducing the cost associated with data collection and contributes to democratizing the process of running EEG experiments. It is developed via a multidisciplinary lens and through an iterative user-centric process approach by identifying six design principles. This would benefit the researchers exploring the possibilities of combining HCI and neuroscience research. Upon further refinement and simplification of the integration process, it could also encourage researchers working in the behavioural neuroscience space to add an EEG component to their research, invigorating more researchers to venture into EEG and BCI research.

Third; to evaluate the usability of Sans Tracas, I conducted an in-the-wild at-home study with 55 participants, with one participant evaluating the platform both from an end-user and a researcher perspective. The evaluation results show that Sans Tracas is highly useable for conducting large-scale EEG studies.

1.5 Overview of Thesis

This thesis contains a detailed description of all the work carried out during the design, development, and evaluation of Sans Tracas in a sequence of seven chapters.

CHAPTER 1 INTRODUCTION: This chapter introduces the thesis. It gives an overview of the thesis, the problem and the issues surrounding it, and the solution approach for the problem.

CHAPTER 2 RESEARCH BACKGROUND: This chapter contains a review of research related to this thesis. It explores what EEG and BCI are and goes from their history to their numerous applications over the years. It also discusses various challenges surrounding the field and the need to combine HCI and neuroscience research to tackle those challenges. Finally, it provides detailed reviews of platforms similar to Sans Tracas and their detailed comparisons with Sans Tracas.

CHAPTER 3 DESIGN AND DEVELOPMENT OF SANS TRACAS: This chapter discusses the various stages of the iterative, user-centric design and development of Sans Tracas. It also provides the six design requirements and their solutions implemented in the platform.

CHAPTER 4 EVALUATION PROCESS OF SANS TRACAS: This chapter contains details about the evaluation of Sans Tracas. It also presents the research questions and the detailed pilot study, and the main study evaluations that are part of this iterative user-centric research process.

CHAPTER 5 RESULTS: This chapter answers the research questions by presenting the detailed data analysis and results of the study.

CHAPTER 6 DISCUSSION: This chapter discusses the implications of the research.

CHAPTER 7 CONCLUSION: This chapter summarizes the entire work and presents its limitations and future research directions.

CHAPTER 2 RESEARCH BACKGROUND

Brain-computer interfaces (BCI) are systems that provide direct communication between the brain and a computer or other external devices [6]–[8]. This communication can be "uni-directional", where the computer or external device receives signals from the brain and performs an action based on the interpretation of those signals, or "bi-directional", where in addition to performing an action based on the signals received from the brain, the computer or external device also sends some form of input to the brain [9]. BCI allows communication between the brain and a computer or external device that involves no muscular stimulation (i.e., without moving a muscle or using a peripheral device such as a mouse or a keyboard [10], [11]). BCI can be further classified into three types: (1) non-invasive, (2) semi-invasive, and (3) invasive [10], [12], [13]. Non-invasive BCI records EEG/MEG signals by placing electrodes on the scalp, the most outer part of the brain. Semi-Invasive BCI records ECOG signals by placing electrodes in the duro or the arachnoid. Invasive BCI record intraparenchymal signals by directly implanting electrodes in the cortex. Non-invasive BCI does not require any type of surgery, whereas Semi-invasive or Invasive BCI requires some form of surgery to implant electrodes [14]. Figure 2.1 illustrates the three types of BCI [15].

This chapter discusses the research background that covers the history of BCI and EEG research, its current applications and recent breakthroughs, the limitations of the current research approach, and the trends in moving the research online. This chapter also highlights the lack of available tools and technologies for general all-purpose EEG and BCI research and the need for democratization in the field. The chapter concludes with a discussion and comparison of the current tools/platforms/organizations putting an effort to generate more interest in EEG and BCI research and amplifying existing ones.

2.1 History of BCI and EEG Research

Electroencephalography (EEG) is a century-old method used to record an electrogram of the electrical activities of the brain recorded on the scalp [16], [17]. In 1929, a German scientist, Hans Berger, was the first to ever record an EEG in humans [18]–[21].

However, the first attempt to implement an EEG-based BCI was done by J. J. Vidal in 1973 [22]. In 1934, English scientist Lord Adrian and American researcher Hallowell Davis independently confirmed Hans Berger’s findings [16]. Their research and the fact that EEG is a non-invasive method served as a prelude to the development of BCI systems we know today [12], [17], [23].

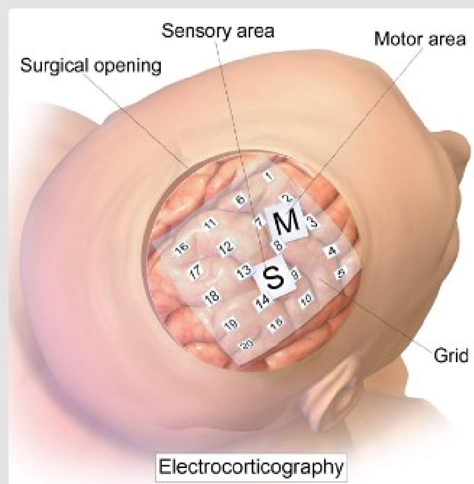
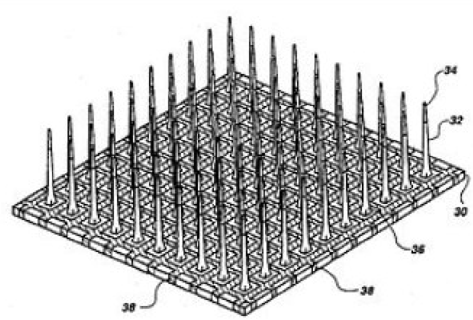
Non-invasive	The sensors are placed on the scalp to measure the electrical potentials produced by the brain (EEG) or the magnetic field (MEG).	
Semi-invasive	The electrodes are placed on the exposed surface of the brain(ECoG).	
Invasive	The micro-electrodes are placed directly into the cortex, measuring the activity of a single neuron.	

Figure 2.1: Types of BCI [15].

In the 1950s, Jose Delgado infamously implanted wet electrodes in live animals and humans to prove that “signals” can be sent to the brain [24]. In the 1970s, the USA's

Defense Advanced Research Projects Agency (DARPA) initiated programs to explore brain communications using EEG [25]. In 1976, UCLA Professor Jaceques J. Vidal coined the term BCI and provided the first evidence that BCI can be used for communication by using single-trial visual-evoked potentials to effectively control a cursor via a two-dimensional maze [26], [27]. In 1998, the first (invasive, non-EEG) BCI was implanted in the human brain by Philip Kennedy that recorded high-quality signals [28]. In 1999, researchers were able to decode a cat's brain signals [29], [30], and another team of researchers led by Hunter Peckham at the Case Western Reserve University were able to return limited hand movements to a person with quadriplegia Jim Jatich [7]. In 2002, monkeys were trained to control a computer cursor [28]. In 2003, a biotech company, Cyberkinetics, in collaboration with Brown University, developed the first publicly demonstrated BCI game 'BrainGate' [15]. In 2005, as a part of the first nine-month human trial of the BrainGate chip implant, tetraplegic Matt Nagle became the first person to control an artificial hand using a BCI [7]. In the same year, at the annual meeting of the American Association of the Advancement of Science (AAAS), a study was presented which showed a monkey feeding itself using a robotic arm electronically linked to its brain [31].

In 2008, at a TI developers conference, Ambient demoed an 'in-development' product called "The Audeo" which would be used to make voiceless phone calls [32]. In 2009, a Spanish company called Starlabs developed a wireless 4-channel EEG system, 'ENOBIO', for research purposes and provided a platform for application development [33]. However, in the same year, the first totally wireless BCI was detailed by Guenther et al. [34], wherein they used the system to turn brain waves into FM radio signals and decode them as sound. In 2010, the world's first personal EEG-based spelling system, 'intendiX', came to the market [35]. In 2014, Rao et al. [36] achieved direct brain-to-brain communication by transmitting EEG signals over the internet. Figure 2.2 shows the number of BCI-related publications over the years [9]. The statistics was based on a search in the PubMed journal with the keyword "brain computer interface". Figure 2.2 shows that there has been a significant increase in the number of BCI publications in the last decade compared to earlier years. This implies that there has been a larger interest in

BCI in recent years and it has helped the engagement of a greater community in the field, and thus increasing the importance of BCI technology.

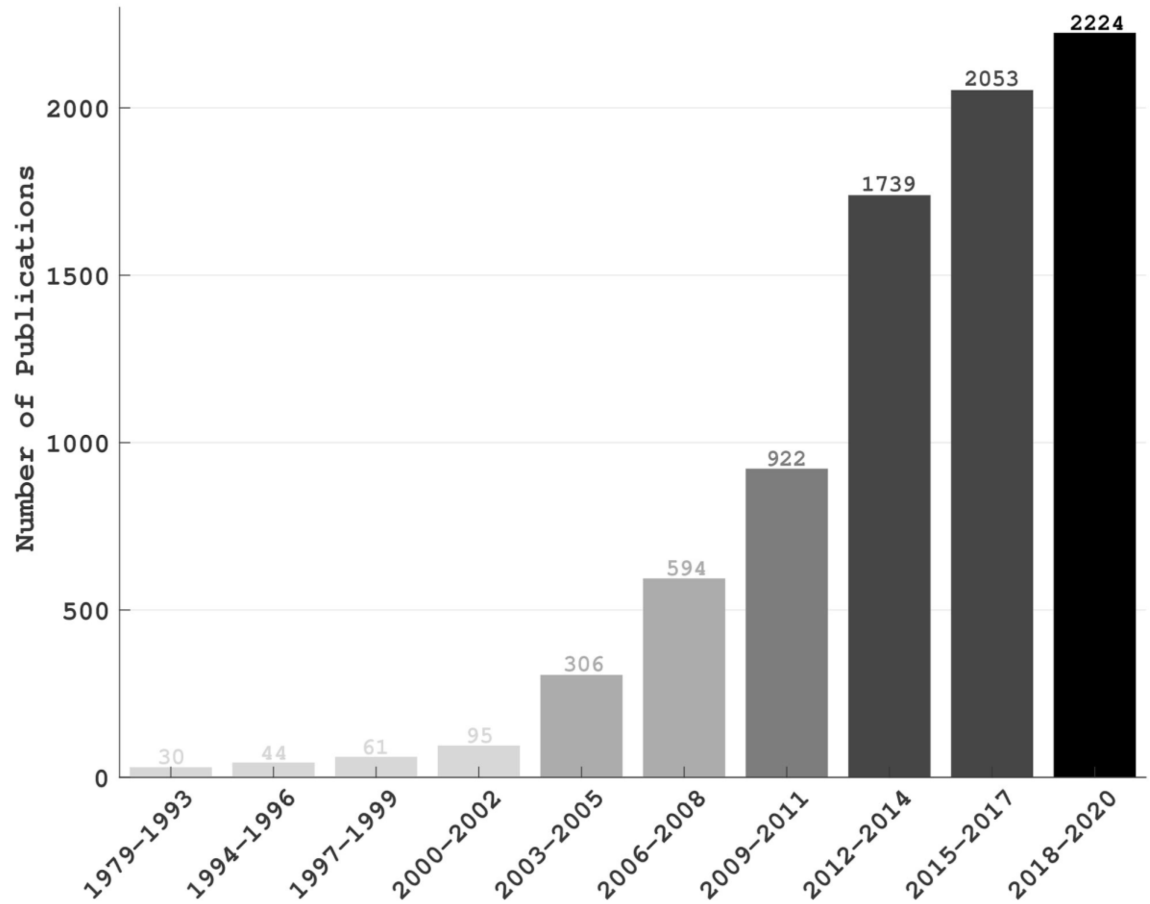


Figure 2.2: Number of BCI publications over the years [9]

2.2 BCI Applications and Recent Breakthroughs

Historically, BCI was always envisioned as a potential technology for replacing or augmenting existing neural pathways or serving as an assistive device which is directly controlled by the brain [22], [37]–[39]. BCI have primarily focused on helping disabled people live everyday lives again. However, they also have potential applications in various fields such as rehabilitation, affective computing, robotics, gaming, and neuroscience [9]. The research applications of BCI technology have evolved significantly over the years, including but not limited to using brain fingerprinting for lie detection [40], detecting drowsiness to improve human working conditions [41] and keeping task workload demand in check using Adaptive Automation triggered EEG systems [42], using EEG to estimate human reaction times [43], using BCI to control Virtual Reality to help rehabilitate chronic stroke patients [44], using BCI to control an Augmented Reality quadcopter [45], improving cognition using BCI video games [46], using BCI to control and navigate a humanoid robot [47], and using a BCI controlled humanoid robot to help empower Locked-in Amyotrophic Lateral Sclerosis (ALS) patients independently reach and grasp a glass of water [48]. Figure 2.3 shows the various fields of research where BCI has been applied [49].

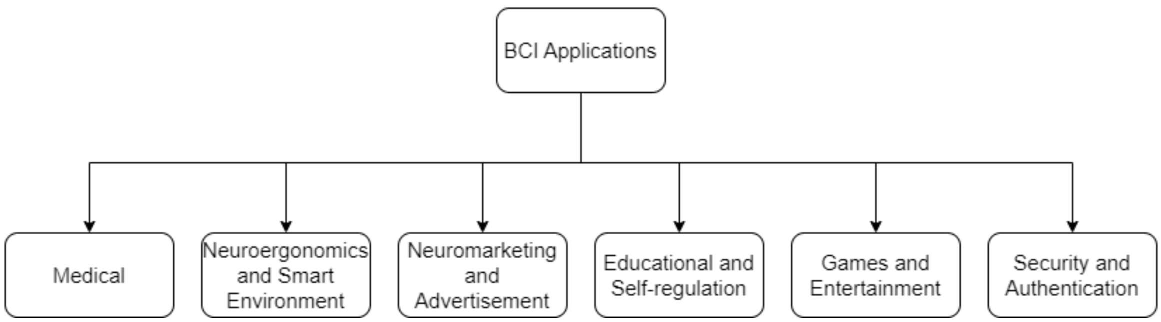


Figure 2.3: BCI application fields [49]

EEG and BCI have seen their most heavy usage in the medical field. The healthcare field takes advantage of EEG and BCI in all associated phases, including prevention, detection and diagnosis, rehabilitation and restoration, as shown in Figure 2.4 [49]. Using EEG, researchers have thoroughly studied the effects of smoking, alcohol, and motion sickness on the brain and how it affects the brain's attentiveness to prevent various accidents and injuries [50]–[56]. Researchers have always been interested in using EEG for brain tumour detection [57], [58], while also concentrating on identifying breast cancer using EEG signals [59]. Nowadays, EEG examination is one of the most popular diagnostics methods for disorders such as Epilepsy, Attention Deficit Disorder (ADD), Attention-Deficit/Hyperactivity Disorder (ADHD), concentration problems, Parkinson's Disease (PD), Multiple Sclerosis, sleep problems, and various mental disorders [60]–[65]. BCI has also been heavily used in neurological rehabilitation [66]. BCI has helped restore motor functions for post-acute stroke patients [67]–[69]. It has also been applied in using a mobile robot to help locked-in people complete daily life activities [70], [71].

Apart from their primary usage in the medical field, EEG and BCI are also used in various smart environments as they smoothly integrate with Internet of Things (IoT) to help people with disabilities [72]. For example, Lin et al. [73], [74] developed a cognitive controller system called Brain-computer interface-based Smart Living Environmental Auto-adjustment Control System (BSLEACS) to monitor user's mental state and adapt to the surrounding accordingly. Since then, it has further extended its functionality by involving universal plug-and-play (UPnP) home networking. As mentioned earlier, EEG and BCI have also been used in improving workplace conditions by measuring the cognitive load of the operator (the driver's brain).

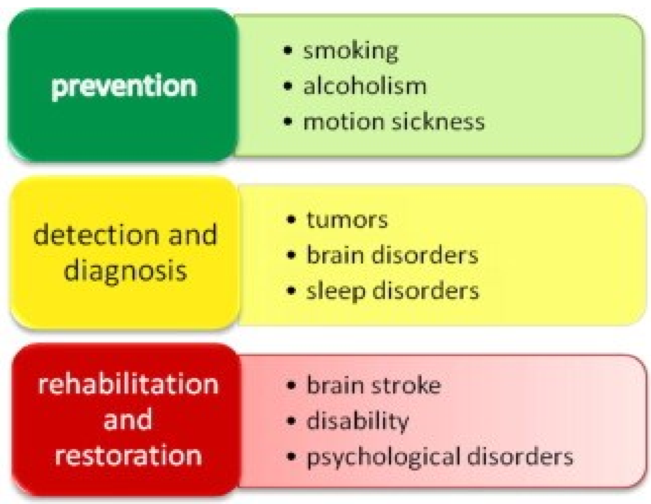


Figure 2.4: The usage of EEG and BCI in various healthcare phases [49]

In the field of Neuromarketing and advertisement, Vecchiato et al. [75] have studied the effect of commercial advertising on brain activity using high-resolution EEG techniques. Vecchiato et al. [76] also considered the impact of other cognitive factors in neuromarketing, whereas Yoshioka et al. [77] measured the generated attention accompanying watching activity. Sorudeykin et al. [78] have established personalized interaction to each learner based on their resultant response experiences in the education and self-regulation field. Márquez et al. [79] applied EEG-based emotional intelligence in sports competitions to control the accompanying stress. In the games and entertainment field, Bonnet et el. [80] provided a multi-brain entertainment experience by combining the features of existing games with brain controlling capabilities in a video game called BrainArena.

As mentioned earlier, techniques such as EEG brain fingerprinting have been used in the security and authentication field. Contrary to this, Tan and Nijholt [81] designed an EEG serious game called Brainball. The purpose of the game was to reduce the user's stress level by allowing the user to move a ball only by relaxing their mind. Nakanishi et al. [82], [83] used a simplified driving simulator with mental-tasked condition to verify the driver's identity on demand. In their other work, Nakanishi et al. [84], also performed unconscious driver authentication. BCI and EEG have been widely applied in many different domains and have been shown to be successful to varying degrees.

Figure 2.5 demonstrates a schematic illustration timeline of the evolution of the BCI applications and the current advances of BCI in diverse applications [9]. As shown in the figure: in 1995, Cognitive & Perceptual Learning/Rehabilitation by McMillan et al. [85], in 2000, Orthosis Control by Pfurtscheller et al. [86], Music BCI by Rosenboom et al. [87], in 2004, Robotics by Millan et al. [88], in 2008, Drowsiness Detection by Lin et al. [89], in 2009, Wheelchair Control by Iturrate et al. [90], in 2009, Affective Computing by Zander et al. [91], in 2014, Brain-to-Brain interface by Rao et al. [36], in 2016, Multiplayer gaming by Nijholt et al. [92], in 2017, Brain Racers by Perdikis et al. [93].

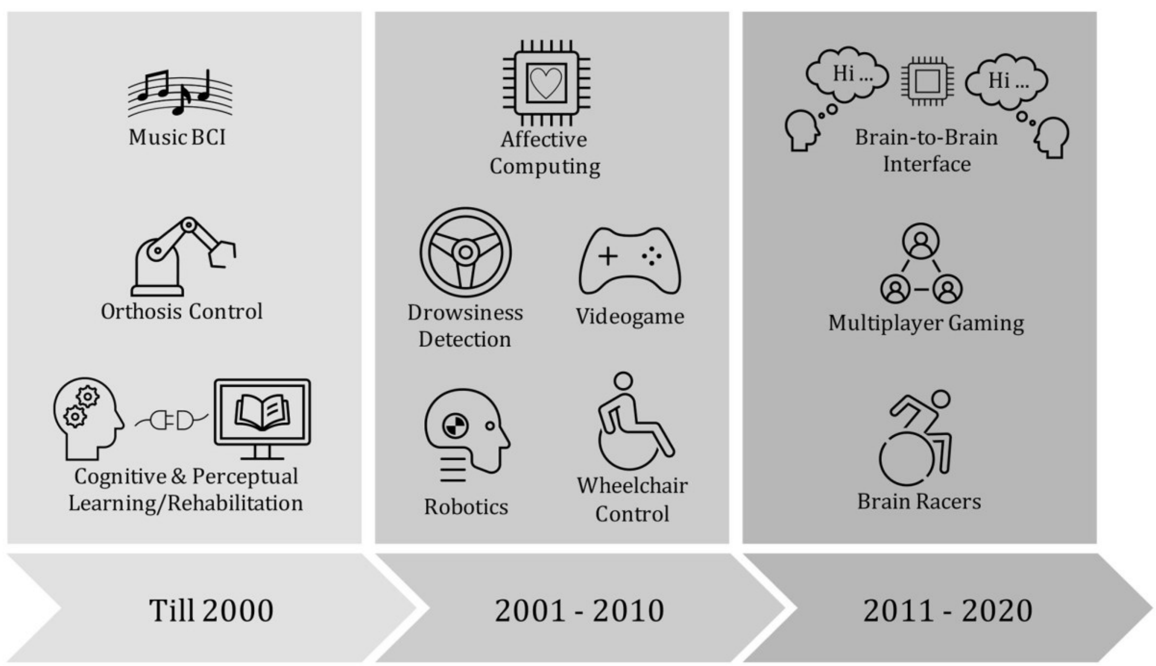


Figure 2.5: Evolution of BCI applications [9]

2.3 Challenges and Limitations

Despite the many different and critical potential applications, BCI has its fair share of limitations. In this section, the limitations of BCI, in particular, EEG research will be examined. This section also identifies what major areas we need to focus on to improve the current state-of-the-art in EEG and BCI research. Besides the apparent disadvantages of EEG compared to other Invasive-BCI, we also need to consider the current ethical, ergonomic, technical, and usability challenges of EEG and BCI.

2.3.1 Usability Challenges

Usability can be described as a measure of how well a specific user in a specific context can use a product or design to achieve a defined goal [94]. It is about the quality of user's experience while interacting with the product or design. It involves methods for improving the ease-of-use during the design process and includes qualities such as efficiency, effectiveness, and satisfaction [95]. Lotte et al. [96], [97] highlighted that usability challenges describe the limitations that affect the level of acceptance for general EEG and BCI research. Furthermore, Van Erp et al. [98] observed that these usability challenges also address the limitations facing the user acceptance of BCI and EEG technology utilization. Based on their extensive research studying different types, processing, perspectives, and applications of BCI, Panoulas et al. [99] concluded that training the user is an extraordinarily lengthy and daunting task. The researchers must guide the users through the entire process multiple times and need to take numerous test recordings before the actual experimental sessions can begin to improve accuracy. The users must also be taught how to deal with the system and how to control their brain feedback signals during the training and calibration phase. Mak et al. [100] argues that some EEG and BCI applications also require an exhaustive series of user commands (e.g., different mental activation tasks).

Moreover, Kübler et al. [101] argues that most BCI requires extensive efforts to set up, calibrate, and operate. Wolpaw et al. [102] suggest that there are still a number of crucial issues associated with the commercial use of BCI such as the ease and convenience of daily use, cosmesis, safety, reliability, the usefulness of the BCI applications in the user's daily life, and the need for ongoing expert technical oversight ought to be addressed in order to successfully transfer BCI technology from laboratory to clinical applications. Moreover, the cost of ongoing technical support is high and is only available from a small number of research groups.

As highlighted by Desai et al. [103], predominately, all traditional EEG research studies take place in a laboratory setting, where the researcher fits the EEG device on the participant's head, verifies the impedance and signal quality of the sensors, explains to the participant the experimental task to be performed, and monitors the incoming signals and the participants' behaviour during the experiment. Moreover, placing electrodes on the participant's head is relatively time consuming, with some systems requiring the researcher to apply conductive gel under each electrode to obtain a good signal. Therefore, participating in EEG studies in the lab presents some barriers, not only due to the need to travel to the researchers' laboratory, but also due to the somewhat cumbersome and uncomfortable nature of traditional EEG headsets. Additionally, given the cost of traditional lab-based EEG systems, most labs would not have more than one system. So only one participant can be tested at a time, presenting a further bottleneck in data collection. Not only do these requirements increase the time associated with the study and limit the sample size of participants, but they also make it challenging to achieve high levels of diversity of participants in EEG experiments, hence, making the generalizability of the findings and democratization of EEG experiments virtually impossible. Besides, participant recruitment is often based on convenience sampling techniques due to the need to have the participants visit the research lab for the experiment [104]–[106]. This increases marginalization with respect to who can benefit from the innovation. It can also lead to an inadequate sample test size, resulting in a low statistical power, as mentioned by Button et al. [1]. Thus, the customization of EEG and BCI systems to suit the needs of the individual user is paramount.

2.3.2 Ethical Challenges

The ethical challenges of BCI are closely tied to its usability challenges as the ethical challenges question the acceptability of EEG and BCI in terms of regulated individual and social impact of the technology and its industrial applications [107]. Burwell et al.

[99] suggests that EEG and BCI applications must ensure that user privacy and confidentiality are always maintained, especially given the personal nature of recorded physiological signals. In addition to obtaining users' consent for collecting their data, the data itself should be encrypted to ensure security from unintended users. Additionally, the EEG and BCI system should be secured enough so that no malicious third party can intervene and get access to confidential and highly sensitive information that would otherwise be available only to the sole concerned operator and the user. According to Fenton and Alpert [108], the need for regular, challenging training sessions such as for a Motor Imagery task may impose physical, emotional, and financial burdens on the user. According to Glannon [109], such an arduous task could require more cognitive planning and attention than an average user can achieve on a regular basis, which would lead to frustration and the abandonment of the technology.

2.3.3 Ergonomic Challenges

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to the engineering and design of products, processes, and systems in order to optimize human well-being and overall system performance [110]. The ergonomic issues such as aesthetic designs and user-friendly interaction methods are intertwined with usability and are crucial factors indicating a system's adoptability for human use [111]. According to Li et al. [112], the ergonomic limitations of EEG and BCI are another crucial concern for the end-users to adapt EEG and BCI in their daily lives. To increase their ease of use, EEG and BCI solutions must be non-invasive, comfortable to wear, portable and not bulky, allowing mobility in different areas, non-tiring for the user, compatible with multitasking to allow usual tasks to continue uninterrupted, and inexpensive in terms of training time, dedicated resources, and cost. However, for current state-of-the-art EEG and BCI devices, there is no one-size-fits-all approach to the abovementioned criteria as some passive BCI are currently more suited to the criteria of portability, non-fatigability, and multitasking [113] since unlike active BCI, passive BCI do not require the user to perform any cognitive tasks against any active or reactive paradigms [114], [115]. Moreover, while the training cost is fundamentally more important in active BCI, it is far less critical in passive and reactive BCI [116]–[118].

2.4 Impact of COVID-19 on EEG and BCI Research

Ever since the COVID-19 disease was declared a pandemic by the World Health Organization (WHO) in March 2020 [119], it has halted, delayed, and, in some cases, completely stopped almost all scientific research. Its impact on EEG and BCI research has been just as destructive. Since before the pandemic, the majority of EEG research was done while being confined in a laboratory. However, since the start of the pandemic, it has become extremely difficult for researchers and participants to meet each other in a confined space to conduct such studies. According to Bratan et al. [120], the COVID-19 pandemic has led to many complications such as restrictions on research, inability to perform data collection as planned, delayed or unfeasible publications, and adjustments in data collection methods.

Figure 2.6 shows the number of EEG publications in the last five years. A search was conducted using the keyword “EEG” in the ACM Digital Library [121], as well as the PubMed Library [122]. Since EEG itself is a multidisciplinary field, we decided to search in both a computer science related journal library, ACM, and a medicine and health-related journal library, PubMed. The keyword for both searches was “EEG”, and as can be seen in Figure 2.6, there is a remarkable difference in the number of EEG-related publications in a computer science related journal library and a medicine and health-related journal library. Although there are some similarities, such as: at the start of the pandemic, we can see a significant decrease in the number of EEG publications.

Additionally, even after two years of living in the pandemic, researchers are still trying to figure out the most efficient way to conduct in-person EEG research [2]. However, as can be noticed from Figure 2.6, the number of EEG publications is slowly coming back up to their pre-pandemic levels. This highlights the impact COVID-19 had on EEG research.

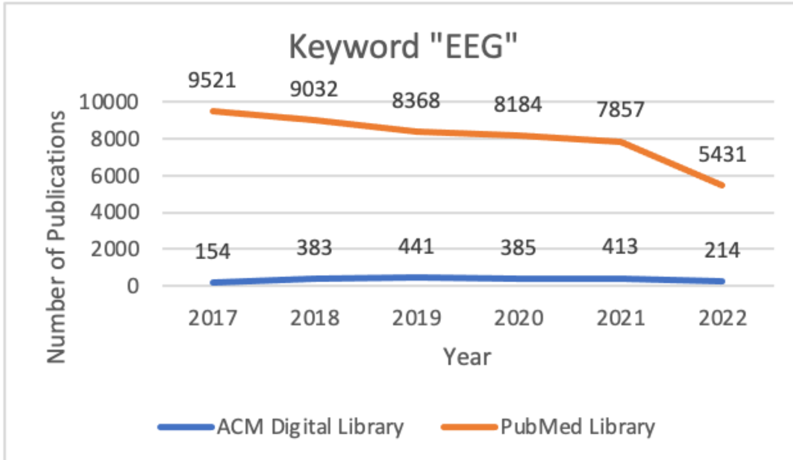


Figure 2.6: Number of 'EEG' publications in the last five years

Another substantial impact of the COVID-19 pandemic was that it pushed everyone towards a more digital work environment and took as many tasks "online" as possible. Even in the EEG field, the pandemic pushed researchers to take their research online and do online EEG since they were not able to do laboratory EEG studies. As illustrated by Figure 2.7, the number of "online EEG" publications increased by about 15% after the pandemic. We used Google Scholar [123] and PubMed to separately search for online EEG publications in the last five years with the search keyword "online EEG". Both searches performed AND operations and thus only showed publications related to online EEG and not just any of online or EEG publications.

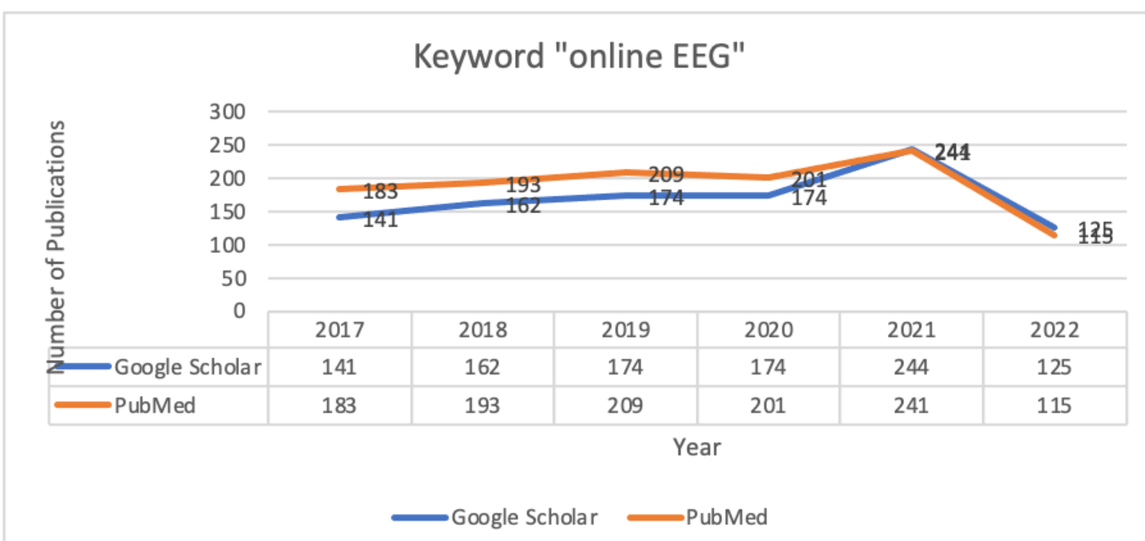


Figure 2.7: Number of 'online EEG' publications in the last 5 years

2.5 HCI and Neuroscience

As mentioned earlier, EEG and BCI research is a multidisciplinary field, with it being a combination of Neuroscience and HCI. HCI alone cannot make those complex BCI, and EEG systems work without the fundamental knowledge of the human brain, and Neuroscience alone would not be able to do anything without the knowledge of computer programming and how humans interact with the machine. The BCI field itself is under the more giant umbrella of the HCI field. Thus, a platform aiming for the democratization of EEG research should be developed via a multidisciplinary lens with a combination of expertise in both HCI and Neuroscience. Not only does HCI benefit from Neuroscience via BCI, wherein it presents a way to interact with machines using brain activity, but Neuroscience also serves as a window to the brain, which would help elevate HCI experiences based on cognitive and emotional reactions [124]. Thus, advances in the field pave the path for taking these systems out of the laboratory into real-world environments. For example, Riedl et al. [125] have outlined how Neuroscience could be beneficial to HCI in a conceptual manner, from behaviourally-oriented research to design science research, as well as a methodological manner; from brain imaging to neurophysiological techniques. By using neuroscience techniques, Riedl et al. [117] have also demonstrated the importance of measuring theoretical constructs in HCI, such as user satisfaction, usability, user experience, and accuracy.

Many studies have been conducted whereby both HCI and EEG research have been combined. For example, Aggarwal et al. [126] have successfully analyzed EEG data to evaluate User Experience by measuring participants' EEG data while interacting with a well-designed and poorly designed user interface. They claim that this tool could help measure any user interface. Frey et al. [127] also developed a framework for using EEG to evaluate User Experience. They validated their framework on a virtual environment by comparing a keyboard and a touch-based interface to show how it can be used to compare different interaction techniques or devices. Kumar et al. [128] have attempted to model human emotions using EEG. The researchers used power spectrum analysis of EEG signals associated with human emotions and then compared it with the participants' self-reported emotional state during the experiment. Frey et al. [129] also demonstrated the use of EEG as an evaluation method for HCI by identifying workload, attention, vigilance, fatigue, error recognition, emotions, engagement, flow, and immersion as being easily recognizable by EEG. Kumar et al. [130] also measured the cognitive load in HCI systems by identifying the EEG frequency band associated with Cognitive Load using the EEG power spectrum and verifying the framework via an experimental study. Quitadamo et al. [131] used EEG and EMG to review the usage of Support Vector Machine (SVM) in the determination of brain and muscle patterns for HCI. Lan et al. [132] developed a novel real-time subject-dependent algorithm with the most stable features that give better accuracy than other available algorithms. Appriou et al. [133] used modern machine learning algorithms, including Riemannian geometry-based methods and deep learning algorithms, to estimate the workload from EEG signals.

However, in all the abovementioned research attempting to combine HCI and EEG research, the studies and experiments remained confined to a laboratory, leading to the same limitations of non-generalizable sample size as mentioned in section 2.3.1. Moreover, researchers must constantly monitor the participants and physically be there for them at every part of the study to ensure they are performing the study correctly and that the recordings are being properly collected. Before our work, there is no single platform that lets researchers run EEG experiments from the participant’s home instead of the laboratories and collect EEG data online in an easy way.

2.6 User-Centered Design

The User-Centered Design (UCD) approach is an interactive system development approach that focuses on increasing the usability of system interfaces to align them more with a user's needs and expectations [134]. It achieves this by making the users the primary focus of the development process, and heavily involving the users in the design process [135]. The expectation is that the information obtained from the users during the design process will enhance the usability, usefulness, and accessibility of the system [136]. Norman and Draper [137] emphasized that systems are designed for the users, and therefore users’ needs must be at the forefront while designing interfaces. UCD aims to reflect the user’s perspective on usable system designs.

According to the International Organization for Standardization's (ISO) standard number 9241-210:2019, named Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems [138], UCD is a process which is executed as "planning, development, measurement and implementation". Figure 2.8 shows the design cycle of the UCD approach [139]. ISO 9241-210:2019 states that the UCD approach, which is an interdisciplinary activity unifying human factors and information of ergonomics in order to improve the effectiveness and efficiency of the system interface, requires a repetitive design process [140].

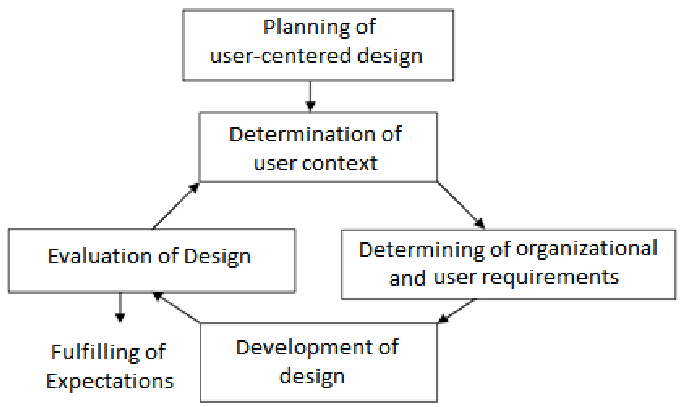


Figure 2.8: ISO 9241-210:2019 User-Centred Design Cycle [139]

After understanding the importance of the User-Centred Design in HCI and software development, we implemented the UCD approach and other factors (such as accessibility, the context of use, effectiveness, efficiency, ergonomics, satisfaction, usability and user experience) mentioned in the ISO 9241-210:2019 during our design process to ensure that our online EEG platform puts the users first and that the usability and user experience of our platform is in line with the needs and expectations of EEG beginners.

2.7 System Usability Scale

The System Usability Scale (SUS) is a technology agnostic tool that is most commonly used to measure the perceived usability of a system [141]. The SUS was originally created in 1986 by John Brooke [142] as a "quick and dirty" scale for administering usability tests on various systems. The SUS is technology independent and has since been tested on hardware, consumer software, websites, cellphones, IVRs and even the yellow pages. Various industries have extensively used it to test numerous applications and systems. The SUS is a 10-item questionnaire with five response options for each question ranging from "strongly disagree" to "strongly agree" [143]. The SUS will likely continue to be the most popular tool for measuring perceived usability for the foreseeable future.

The SUS has been used in testing the perceived usability of various kinds of systems and applications. For example, Klug [144] has reviewed the use of SUS in the usability testing of Library websites, and Katsanos et al. [145] have used the SUS to evaluate the usability of Learning Management Systems (LMSs) and even prepared a Greek version of it. Furthermore, Vlachogianni and Tselios [146] have reviewed the use of SUS in evaluating the perceived usability of educational technology, while Pradini et al. [147] have used the SUS in the evaluation of perceived usability of a SIPR (Spatial Information System) website, and Wahyuningrum et al. [148] performed usability evaluation of e-commerce websites using the SUS.

To date, there has not been any use of the SUS for the evaluation of any EEG or BCI system. However, as HCI researchers, we understand the importance of the SUS in evaluating the perceived usability of platforms developed using the UCD approach. Thus, we have used the SUS, Perceived Usefulness and Perceived Ease of Use [149], and the ARCS motivational appeal model [150] as the usability evaluation metrics for our platform.

2.8 Similar Platforms

Previous research has been conducted for at-home EEG studies. Biondi et al. [151] conducted an 'EEG@HOME' study to develop a new procedure that would help people with epilepsy self-monitor themselves at home. Muhammad et al. [152] proposed an EEG-based remote system for pathology detection. Askamp et al. [153] surveyed Dutch neurologists and patients to evaluate the feasibility of home EEG recordings being used in hospitals. Baum et al. [154] further assessed the feasibility of patient-controlled EEG home-monitoring in their 'HOMEONE' study. They concluded that it is feasible to use patient-controlled home-monitoring as a part of routine care for neurological outpatients. Even most mobile EEG uses cases and studies have been heavily focused around syndrome classification in confirmed epilepsy, or differentiation between epileptic and non-epileptic seizures. However, most of these studies have been specifically designed for specific use-cases and have not been generalized for other use-cases. Every researcher is doing their own thing and there is not a standardized platform allowing for study participants to view and select different studies they would want to participate in.

There are many platforms which serve as an online collection of EEG databases where one can get EEG datasets for free. OpenNEURO [155] is one such platform which has about 765 public datasets from 29,170 participants, which can be used for validating and sharing BIDS-compliant MRI, PET, MEG, EEG, and iEEG data. NEMAR [156] developed by Delrome et al. [157] is another open access data, tool, and computer resource for EEG, MEG, and iEEG data, where one can search, visualize, analyze, and download free datasets. The Canadian Open Neuroscience Platform (CONP) [158] provides and infrastructure for the collection, promotion and sharing of open science workflows and neuroscience data. However, all these platforms primarily serve just as a collection of EEG datasets and cannot run online studies. They do help visualize and analyze the datasets online, but if one wants to host and run their own online studies, it is not yet possible to do so using these platforms.

Currently, numerous web platforms can run behavioural studies online. These platforms allow the users to host and run online behavioural studies. The neuroscience researchers could develop their studies online on a computer, and once they are ready, they would then send the study participation link to their participants. The participants of such studies would be able to use the links provided by the researchers to participate in those studies using their computers. Many platforms are running online behavioural studies, such as Pavlovia [142], an organization for the wide community of researchers in the behavioural sciences to run, share, and explore experiments online. In spite of originally being created as a repository, it is now able to seamlessly integrate with behavioural experiments development tools such as PsychoPy [159], jsPsych [160], and lab.js [161].

Just Another Tool for Online Studies (JATOS) [162] is another free platform that allows users set up and run online studies on their own servers. Running online studies on users' servers gives them complete control over the access to result data. JATOS also seamlessly integrates with tools like jsPsych, lab.js, OSWeb/OpenSesame [163], and PsyToolkit [164] which let researchers write their own studies using programming languages like HTML [165], Javascript [166], and CSS [167]. JATOS also lets users run their studies on smartphones, tablets, and personal computers (laptops/desktops). JATOS is open-source, GUI-based, and lets users recruit participants via participant recruitment tools and crowdsourcing platforms such as Amazon Mehcanical Turk (MTurk) [168] and Prolific [169]. Gorilla [170] is a paid experiment builder which helps behavioural scientists create and host online experiments using a GUI-based, easy-to-use interface which does not require coding. Another platform Lioness-Lab [171], is a free web-based tool that enables researchers to conduct interactive experiments online. It speeds up the life cycle of an experiment and facilitates replication. It also provides a Graphical User Interface (GUI) for researchers to design their own experiments.

However, all the abovementioned platforms are only limited to running online behavioural studies, and none of them have the ability to run an EEG-based study, support BCI experiments or possess the capability to collect EEG data neither online nor in-person. Regarding running EEG studies remotely, there are currently only two options available: EEG-notebooks [172] and MYND [173].

2.8.1 EEG-notebooks

EEG-notebooks is a collection of classic EEG experiments which are implemented in Python 3 [174] and Jupyter notebooks [175]. Its experimental protocols and analysis are indeed quite generic, but they are primarily designed for low-budget consumer-grade EEG hardware instead of the costly research-grade ones. They aim to make cognitive neuroscience and neurotechnology more accessible, affordable, and scalable. It was initially created by the NeurotechX [176] developer community, with its foundations laid by Alexandre Barachant. Now, the lead developer on the project is John Griffiths. EEG notebooks has various features such as: streaming data from various wireless consumer-grade EEG devices, visual and auditory stimulus presentations concurrent with EEG recordings, a library of well-documented, ready-to-use experiments, signal processing, and statistical and machine learning data analysis functionalities. It is quite a one-stop solution.

However, despite all its various functionalities, it has some critical limitations, which leads to the technology not being ready for in-the-wild use by the general public. Their one-stop solution is only from a researcher's perspective, and that too is only for a limited number of researchers. It was never designed from an end-user's perspective, and thus it has no usability features. It is incredibly blended and boring to look at and highly complex to work with. The installation process for EEG-notebooks is so convoluted that it could take weeks to set up the environment even for a person who is an expert with strong technical skills and programming knowledge [177], [178]. Even after the initial setup, the running and conducting of a study process are still highly arduous. Finally, if one manages to make it run, it can only operate on personal or work computers (i.e., laptops and desktops). It is not cross-platform, and thus it does not run on any other types of devices. With such a laborious process, one cannot expect the study participants to go through it every time they want to participate in an EEG study. Thus, they will not be able to perform experiments independently.

Moreover, despite its technically being an online platform, the only way to use it in an actual study is if it is installed and set up on the researcher's machine. The participants are called to the laboratory to take part in the experiment. This defeats the entire purpose of at-home EEG studies, as regular people will not have the patience to go through all the trouble of setting up and running such gruelling EEG studies.

2.8.2 MYND

MYND is a smartphone application that regular people could use to take part in large-scale neuroscientific studies from their houses. Developed in 2019 by Hohmann et al. [173], the platform's main aim is to establish user-experience design as a paradigm in neuroscientific research to overcome the limits of current studies and to improve ecological validity. Unlike EEG-notebooks, it is indeed developed, keeping the user at the forefront of their design process. Thus, it has a simple user interface which enables users to self-administer multi-day studies by guiding them through experiment selection, hardware fitting, recording, and upload.

However, the main issue with MYND is that it is just a smartphone application, and the smartphone screen size is not ideal for research involving presenting visual stimuli to the users as such research generally uses stimuli that cover a much more significant portion of the participant's field of view. Such a larger field-of-view for the EEG experiments would have been possible if MYND was a cross-platform application instead of just being a smartphone application, as being cross-platform would have allowed it to run and used from larger screens. It would have made the EEG experiments themselves more scientifically accurate. Additionally, it is limited to end-users, and neither does it allow researchers to use the platform to build EEG experiments nor does it allow them to integrate their own experiments with the platform to run such large-scale neuroscientific studies. Moreover, more recently, Hohmann et al. [179] have only released just one other publication in 2020 wherein they used MYND to evaluate BCI control strategies in a realistic scenario on consumer-grade hardware. Since the last two years, the project has had zero updates, and the application's codebase is no longer active. The application itself cannot be found on the smartphone app stores or anywhere else on the internet for people to download and use it. The MYND smartphone application is likely dead and will not be used anytime soon.

2.8.3 EEGEdu

EEGEdu is a browser-based tutorial on EEG [180]. Developed by Dr. Kyle Mathewson from the University of Alberta, EEGEdu is an Interactive Brain Playground. It is designed as an interactive educational website to learn and teach about working with EEG data. It is a teaching tool that allows students to interact with their brain waves. EEGEdu is entirely web-based, allowing students to interact with EEG brain data without installing any additional software. Being web-based also allows EEGEdu to be cross-platform and it has been used on Android smartphones and laptops. Its curriculum consists of 10 step-by-step incremental lessons and tutorials for students to interact with EEG-based signals. EEGEdu has a simple but attractive user interface and can be used without a complex installation process. Its primary purpose is to serve as an educational tool. Thus, it is used to educate people (primarily students) about EEG and BCI and get them interested in general EEG and BCI research. However, this means that it cannot be used to run either a small-scale or a large-scale online EEG study. It has some small fun experiments as a part of its curriculum, but none can be used for new scientific research. Moreover, it does not currently provide any tools for researchers to build/integrate their own experiments with the platform. Despite being unable to run large-scale online EEG studies, EEGEdu is still one of the best ‘online EEG’ platforms and is an excellent tool for a beginner to get acquainted with EEG and BCI research.

Table 2.1 shows the comparisons between these three platforms and Sans Tracas providing an overview of how Sans Tracas fills the gaps in the current state of EEG and BCI research.

Table 2.1: Comparison of Features between EEG-notebooks, MYND, EEDEdu, and Sans Tracas

Criteria	**EEG-notebooks**	**MYND**	**EEGEdu**	**Sans Tracas**
Is the platform entirely online?	Yes (to an extent)	Yes	Yes	Yes
Can the platform run EEG experiments?	Yes	Yes	Yes (to an extent)	Yes
Does it have a simple and intuitive user interface?	No	Yes	Yes	Yes
Can the participants perform EEG experiments on their own using just this platform?	No	Yes	N/A	Yes
Can a layperson use the platform?	No	Yes	Yes	Yes
Is the installation and setup of the platform relatively easy?	No	Yes	Yes	Yes
Does the platform allow researchers to build/integrate their own EEG experiments with the platform to run EEG studies?	Yes	No	N/A	Yes
Can the researchers integrate their own EEG experiments with little to no technical knowledge and programming	No	No	N/A	Yes

experience?				
Does the platform connect with the EEG hardware without requiring any additional software/hardware?	No	Yes	Yes	Yes
Can the participants take part in an EEG study using the platform from their homes?	No	Yes	N/A	Yes
Is the platform a cross-platform tool?	No	No	Yes	Yes
Does the platform protect users' privacy?	No	Yes	Yes	Yes
Does the platform take necessary measures (such as encryption) to ensure user data security?	No	Yes	No	Yes
Can the platform be used to perform large-scale neuroscientific studies?	No	Yes	No	Yes
Does the platform act as an educational tool for EEG beginners?	No	No	Yes	Yes
Does the platform help invoke interest in users for EEG and BCI research?	No	No	Yes	Yes
Is the platform developed via a user-centred design approach?	No	Yes	N/A	Yes
Does the platform provide video tutorials for users to	No	No	No	Yes

guide them through the experimental process?				
Does the platform allow participants to view their own EEG data	Yes	No	Yes	Yes
Does the platform have measures to ensure that the EEG signal received from the EEG devices is of good quality?	No	Yes	No	Yes
Does the platform work with a consumer-grade low-cost EEG device?	Yes	Yes	Yes	Yes
Does the platform have both the researchers and study participants (end-users) as its target audience?	No	No	No	Yes
Does the platform allow researchers to integrate their own experiments without any external help?	No	N/A	N/A	Yes
Does the platform allow end-users to perform an EEG experiment independently?	No	Yes	N/A	Yes
Is the platform currently active?	Yes	No	Yes	Yes

Our research study addresses the gaps in EEG and BCI research outlined in this chapter with the design and evaluation of Sans Tracas: A cross-platform tool for online EEG experiments.

2.9 Summary of Research Background

In this chapter, we discussed EEG and BCI research at length, its origin, its recent applications and breakthroughs, the limitations of the current research approach and its trends in moving the research online. We also provided a detailed comparison of currently available tools for online EEG research with our developed platform.

In 1929, Hans Berger recorded the first EEG in humans [18]–[21] and the amount of EEG and BCI research has evolved. Secondly, we discussed the wide range of BCI applications. Although BCI is being heavily applied in the medical and health industry [60]–[65], BCI have also been used in industries such as neuro-ergonomics and smart environment [72], neuromarketing and advertisement [75], education and self-regulation [82], [83], games and entertainment [92], and security and authentication [84]. Afterwards, we discussed how apart from the obvious technical limitations, other major challenges currently surround EEG and BCI research, such as usability challenges [96], [97], ethical challenges [99], and ergonomic challenges [112]. These three challenges combined are the biggest hurdles to the adaptability of BCI by the general public. Thus, to encourage the acceptance and trust of EEG and BCI research amongst regular people, we must work on decreasing the barriers in these three crucial areas. Finally, Figure 2.6 shows how severely the COVID-19 pandemic has affected EEG research. Moreover, through the analysis of Figure 2.7, the time has come to take EEG research online, which would also help with the democratization of the field.

To solve these challenges, we combine HCI and neuroscience, as HCI design principles can help us improve on all three aspects. However, a further critical review of the related literature showed that most of the previous work in the area had been focused on using EEG as another evaluation metric for the perceived usability of some other system [126] instead of evaluating the perceived usability of the EEG system itself. Moreover, for all the research attempting to combine HCI and EEG research, the studies and experiments remained confined to a laboratory setting, leading to the same limitations of generalized sample size as mentioned in section 2.3.1. This inspired us to develop an online platform wherein users can run EEG experiments from the comfort of their homes.

However, before beginning the design process of our platform, we reviewed other similar platforms. The review showed that currently, many platforms could run online behavioural experiments [162], [170], [171], [181]. However, none of them can capture EEG data along with it. EEG-notebooks [172] allows researchers to build and run their own EEG experiments. However, it cannot be used for large-scale EEG studies because of its highly complex user interface and poor user experience. This motivated us to adopt a UCD approach and keep the users at the centre of our design process. MYND [173] is a smartphone application for running large-scale EEG studies. However, it is limited to smartphones and does not let researchers build or integrate their own EEG experiments. As such, we decided to define two target users: (1) a researcher, and (2) a study participant (end-user). We thus developed our application, keeping both target users at the centre of the design process. EEGEdu [180] is a cross-platform educational tool which provides EEG tutorials. However, it cannot run a large-scale EEG study. However, it inspired us to develop our platform to be cross-platform and cater to an EEG beginner's needs so that it is not limited to one device type or user type and is accessible to everyone, genuinely democratizing EEG and BCI research.

Finally, we concluded the chapter with a detailed comparison of the three abovementioned platforms that are capable of doing online-EEG with our platform "Sans Tracas". Table 2.1 shows this comparison and how Sans Tracas prevails while other platforms fail. It shows the gaps in current EEG and BCI research and provides an overview of how Sans Tracas fills those gaps.

CHAPTER 3 DESIGN AND DEVELOPMENT OF SANS TRACAS

This chapter discusses the user-centered iterative design and development process of Sans Tracas [182]. It also outlines the platform design, design requirements, design solutions, development stages, experiment designs, and platform workflow in detail. Figure 3.1 presents an overview of the iterative design process.

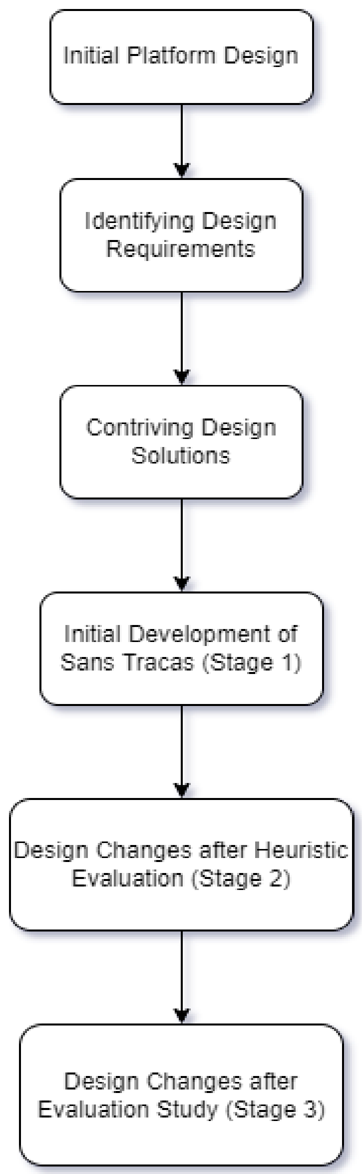


Figure 3.1: Overview of the Iterative Design Process

3.1 Sans Tracas Design

Sans Tracas is a cross-platform tool that enables users to run online EEG experiments and participate in large-scale EEG studies. It was evident from the background research that I needed to combine HCI and neuroscience principles to design and develop such a platform. Therefore, the platform is developed via a multidisciplinary lens. The objective was to create a platform that simplifies the process of conducting large-scale EEG studies both from the researcher (currently unevaluated) and end-user perspectives. As I have adopted a user-centered design approach [136], I identified two-ideal users: (1) an EEG beginner as the ideal end-user, and (2) an EEG expert but a novice in terms of computer programming as the ideal researcher. The platform was developed, keeping both users at the centre of the design process. The ideal users were determined based on the scenario that neuroscience researchers would be using Sans Tracas to conduct EEG studies and the study participants would be participating in those studies from their homes, instead of a laboratory. Thus, before starting the development process, I identified multiple design requirements based on what users would like to see in such a platform, some of which have been summarized in this section with their solutions. As mentioned earlier, the platform is designed for both the EEG researchers and the end-users (study participants). Thus, the design requirements were identified from both ends of the spectrum, and the solutions were developed keeping both perspectives in mind.

I employed an iterative user-centered design approach for the platform development. This involved regular meetings, brainstorming sessions, prototype design reviews, and feedback between the neuroscientists and HCI researchers. I conducted regular bi-weekly zoom meetings with behavioural studies and neuroscience experts from Baycrest, University of McMaster, and University of Toronto, and HCI researchers from Dalhousie University. The meetings ran for about an hour or two and had set agendas based on the specific design element we were working on during that cycle. In each meeting, the experts would review the design element protypes and I would later refine them based on their suggestions. Each meeting moved the design forward by either providing suggestions on improving a design element or by introducing a new design element altogether. After developing an initial prototype, I gathered informal feedback from the target audience in form of a pilot study. Specifically, end-users provided feedback on the end-user part of the platform.

In contrast, the researchers provided feedback on both the researchers' and end users' parts of the platform, considering that the researchers will be formally using the platform to conduct their EEG studies and thus should have a say in how they would like their participants to interact with the platform. Using this feedback, I refined the design and developed the initial version of Sans Tracas, which was later evaluated via the pilot study. From the feedback received from the pilot study, I developed the final version of Sans Tracas, which was later evaluated via a Usability study.

3.2 Sans Tracas Design Requirements

Based on brainstorming sessions and meetings with neuroscience experts, discussing what a potential platform for conducting online EEG studies should look like, I identified six design requirements for the platform, which were directly linked to the main aspects in which Sans Tracas would differ from the traditional laboratory system and its predecessor while advancing the field significantly. These design requirements were identified for the specific scenario of conducting online EEG studies. Thus, neuroscience experts were consulted to determine requirements pertaining to the scientific accuracy of EEG experiments and HCI researchers were consulted to determine requirement pertaining to the usability of the platform. DR3, DR5, and DR6 were suggested by the neuroscience experts based on their experience conducting regular in-lab EEG studies and their expectations of how they would want to conduct online EEG studies. DR1, DR2, and DR4 were suggested by HCI researchers based on their experience designing and developing various systems and interfaces and their expectations of how they would want such a platform to behave and interact with the user.

3.2.1 Design Requirement 1 (DR1): Accessibility

To make EEG studies accessible to everyone, the platform should work across different types of devices and different operating systems. The platform needs to connect to a low-cost consumer-grade wireless EEG device across those different types of devices (such as laptops, desktops, tablets, and smartphones). It should be able to collect and store EEG data transmitted from the EEG device. The platform should work uniformly across all major operating systems such as Windows, Ios, iPadOS, Android, macOS, and Linux. Ideally, a user should be able to access the platform from anywhere in the world with nothing but an internet-enabled device.

3.2.2 Design Requirement 2 (DR2): The Platform should be Interactive and Easy to Use

Once the platform can work uniformly across different devices, it must be interactive. The platform should be attractive and engaging enough to keep the user's attention throughout the study. The platform should also be simplistic while simultaneously being informative and intuitive. Moreover, the platform should be able to keep the ideal end-user's attention throughout the duration of the study, and it should also be interesting enough to retain the user and bring them back to perform more such online EEG experiments. Lastly, the platform should be easy to use for running EEG experiments from both an end-user and a researcher's perspective.

3.2.3 Design Requirement 3 (DR3): EEG Data Obtained from the Platform should be Useful and of Good Quality

Fitting the EEG device on the users' heads should be a relatively easy task and should be achievable by the users on their own. For users to participate in EEG studies from the comfort of their houses, they should be able to properly fit the low-cost consumer-grade wireless EEG device independently without relying entirely on the researcher or needing external help. Moreover, once the device is correctly fitted on a user's head, the platform must ensure that the integrity of the EEG data received from the low-cost consumer-grade wireless EEG device is of sufficient quality to be used for an EEG study. Additionally, the final EEG data obtained from the platform must be presented in a useable and readable format for the researchers to conduct their analyses.

3.2.4 Design Requirement 4 (DR4): Privacy and Security

The EEG and behavioural data recorded during the study must be transmitted over the internet to allow for feedback during the study, as well as for real-time data analysis.

Thus, security and privacy measures must be taken to ensure secure storage and transmission of the data. Additionally, the users' privacy should be maintained so that their EEG and behavioural data is not personally identifiable, and thus can never be traced back to them. As exemplified in section 2.3.2, privacy and security of user data are one of the most critical aspects of building a user's trust in the platform. Thus, this specific design requirement is paramount for increasing the adaptability of EEG and BCI research amongst regular people (the ideal end-user).

3.2.5 Design Requirement 5 (DR5): Pre-established Collection of Behavioural and EEG Experiments

For the initial version of Sans Tracas, the platform should have an initial collection of natively designed behavioural experiments for end-users or researchers to choose from to be able to test the platform. While the users perform said behavioural experiments, their EEG data from the low-cost consumer-grade wireless EEG device should be recorded in the background. Moreover, these natively-designed EEG experiments should be fun, engaging, effective, and designed according to neuroscience standards. In addition to natively-designed behavioural experiments, it is crucial that the platform is also able to integrate behavioural experiments designed by other researchers on other platforms (such as Pavlovia). This integration should be seamless, and the platform should also record EEG data in the background while running these integrated experiments.

3.2.6 Design Requirement 6 (DR6): Flexibility and Ease of Use for the Researchers

In order to allow other neuroscience researchers to integrate their own behavioural experiments with the platform for collecting EEG data, it is essential that the researchers perform this integration process independently. The integration process should be simple, intuitive, and easy to understand so that even researchers with no programming knowledge (ideal researcher) can integrate their experiments within the platform. The researcher should do the entire integration process without any external help. Moreover, the integration process should be engaging 35noughh to capture user attention and retain users so that they can come back to integrate more of their experiments with the platform.

Additionally, the integration process should be easy to use, involving minimum computer programming so that even a researcher with little to no computer programming knowledge (ideal researcher) will be able to integrate their experiments with the platform.

3.3 Sans Tracas Design Solutions

The initial version of Sans Tracas featured solutions for the six main design requirements identified above. These solutions were later improved upon based on the feedback from the pilot study.

3.3.1 Solution for Accessibility (DR1)

I decided to build a web application to make Sans Tracas cross-platform and easily accessible. Building the platform as a web app allows the platform to be accessed via any device that can run a web browser and has access to the internet. Hence, not only can the platform be accessed via a desktop, laptop, smartphone, or tablet-type device, but in reality, a device like an Android TV can also access it.

To collect EEG data from a low-cost consumer-grade wireless EEG headset, I chose the Muse EEG [3] because it is one of the most commonly used low-cost consumer-grade wireless EEG devices. The Muse EEG headset is extremely easy to set up as it is just a headband and requires less than two minutes to place it on the user's head. The latest Muse models, Muse S, and Muse S (Gen 2) are designed for wearing while sleeping to track users' sleep patterns making it highly comfortable to use. It has also been used in other previous studies and has been shown to record meaningful neural activity. For example, researchers such as Krigolson et al. [183] demonstrated the use of The Muse for collecting ERPs (Event Related Potential), and Hashemi et al. [184] illustrated the use of The Muse for collecting resting state EEG. To connect the Muse EEG device with the user's devices via web-Bluetooth, we used muse-js [185], a JavaScript library, to access Muse's EEG readings over a web-Bluetooth connection. The web-Bluetooth connection works on BLE (Bluetooth Low Energy), and it is the same technology The Muse operates on. Muse-js is compatible with all versions of Muse EEG headsets that came out since Muse 2016 (this includes Muse 1, Muse 2, Muse S, and Muse S (Gen 2)). Thus, Sans Tracas is a complete, cross-platform solution.

3.3.2 Solution for Making the Platform Interactive & Easy to Use (DR2)

I built the platform using the React JavaScript library [186], a helpful framework for building a clean, simplistic, and intuitive user interface. I also used Bootstrap [187], a free and open-source CSS framework directed at responsive, mobile-first front-end web development, to make the platform and its content visually appealing. I made the platform's content informative and user-friendly, informing the user about every single aspect of the study. I also created a video tutorial that gives the user a virtual tour of the platform and explains concepts about EEG, BCI research, and its potential advantages and disadvantages. The video serves as a bridge for building trust between the user and the platform. The video has been uploaded to YouTube [188] so that anyone can view it at any time. I created a signal quality check process to keep the users intrigued, informed, and engaged with the platform. In this process, the users are asked to sit quietly for 30 seconds and then their EEG signals from that period are displayed in a waveform. The users being able to see their live signal allows them to have more fun with the platform and use the platform more playfully to just check their brain data without worrying about anything else. Figure 3.2 demonstrates the result of the signal quality check process, which shows users their live EEG signal over the last 30 seconds from all four Muse channels (the AUX channel is also displayed if there is anything connected to the AUX port).

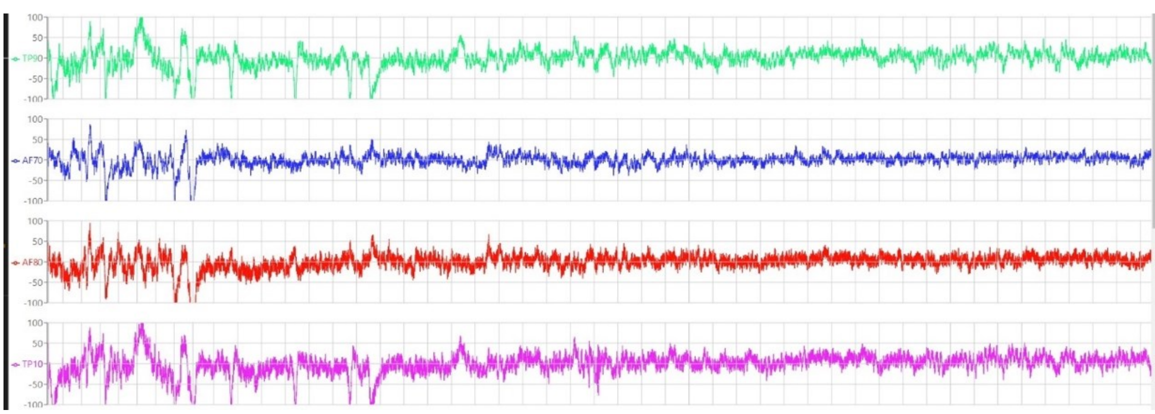


Figure 3.2: Signal Quality Check: The results screen shows the users how their signal quality is represented as a live signal. The Channel names with respect to their position on the head are mentioned above this figure (not shown here)

3.3.3 Solution for Ensuring the EEG Data Obtained from the Platform is Useful and of Good Quality (DR3)

I linked video tutorials from InteraXon's YouTube channel on how to properly fit Muse 2016, Muse 2, and Muse S devices to the platform. I accompanied these videos with my own explanation of how to achieve the desired fitting and why proper fitting is necessary to ensure that users are able to fit the Muse without assistance from the researcher or anyone else. Moreover, the placement of the Muse headset is very intuitive in and of itself, and it generally takes less than two minutes for even a beginner to properly put it on themselves.

I developed a Signal Quality Check process that runs before beginning the experiment to ensure that EEG data recorded from the Muse is of good quality and usable for analysis. Signal variability (zero-mean standard deviation) for each channel is shown to the user as a bar graph which is accompanied by explanations, and hovering over the bars reveals more information. Figure 3.3 shows the results screen of the Signal Quality Check process. It contains the bar graph and its accompanying explanation for users to understand how to interpret it and check their signal quality. If the value of Signal Variability (standard deviation) for each channel is below 45, the signal quality is considered to be adequate, while higher values are considered too noisy. In such a scenario, the platform advises the participants to adjust the Muse so that it fits to improve the connection and goes through the signal quality check again.

Additionally, to guarantee good data quality for remote EEG data collection, I adopted most of the experimental infrastructure recommendations, suggested by Demazure et al. [189] such as using a low-density, consumer-grade, wireless, dry EEG device (Muse), using API for EEG data acquisition along with open-source software for time-synchronization and stimuli presentation (muse-lsl [190] combined with the native experiment design). Moreover, as muse-js only gives access to the clustered raw EEG signals (they come in a cluster of 12 data points bundled together) coming from the Muse headset, I have applied additional processing to it to ensure that each timestamp is accompanied by its corresponding data value. The processing also helps ensure that the

Muse's maximum sampling rate of 256Hz is utilized (the raw sampling frequency received from muse-js is only about 21Hz). This processed signal is then presented to the user at the end of the study in a downloadable Comma Separated Value (CSV) file, wherein each data value corresponds to its respective channel and timestamp. Additional artifact removal methods such as multivariate EMD (Empirical Mode Decomposition) and others mentioned by Soler et al. [191] and Jiang et al. [192] can be used during offline data analysis to improve the EEG data quality even further.

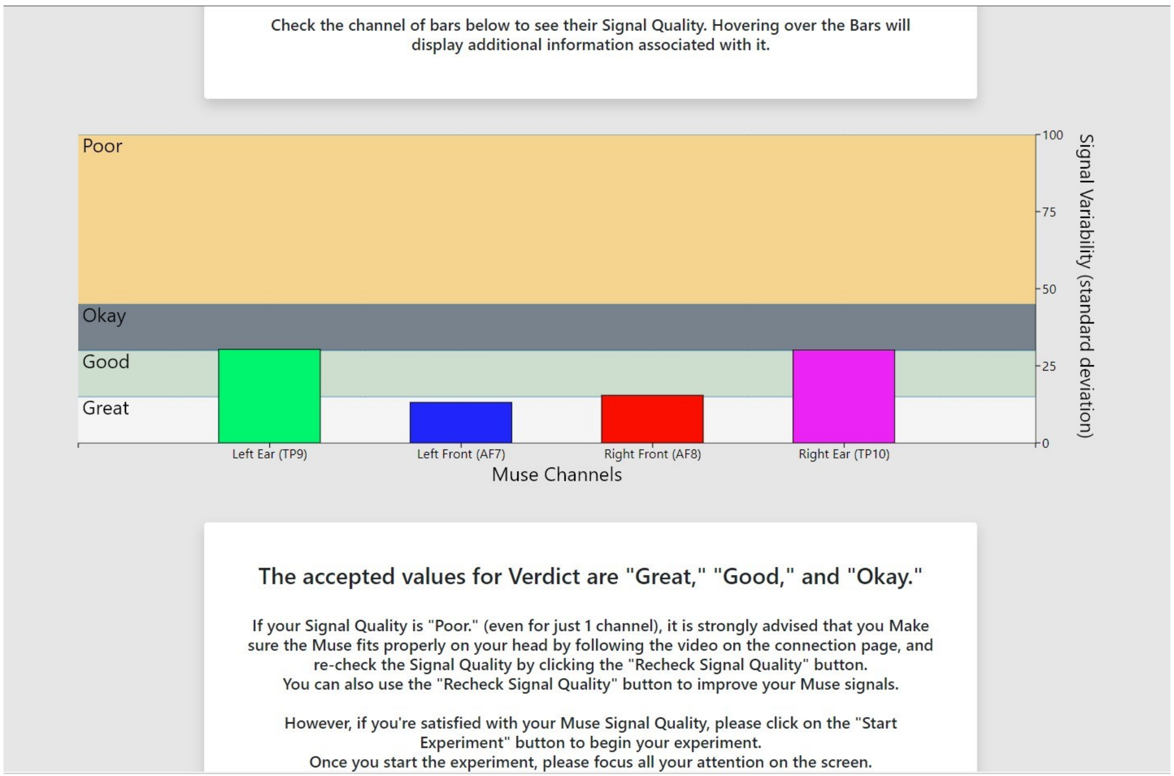


Figure 3.3: The results screen shows the users their signal variability as a bar graph. The bar graph itself is informative, but hovering over the bars displays additional information, and description below the graph provides more information

3.3.4 Solution for Privacy & Security (DR4)

To ensure the security of user data, I employed asymmetric encryption to all the data transferred over the internet. The public key is stored in the web browser cookies for encrypting the data before sending it to the server, whereas the private key is only known to the experimenter to decrypt the data. Additionally, the Microsoft Azure [193] server where the data is stored is secured with a two-factor authentication method to sign into the server to access the encrypted data. Such a sign-in method prevents attackers from accessing the data even if they know the SSL certificate for the server. However, the server's location is also not publicly available as it is only accessible through a dedicated FTP client.

Moreover, to ensure user privacy and trust, Sans Tracas never collects any personally identifiable data from users. The only information Sans Tracas collects from the user is a unique participant ID that is randomly generated during the study. This makes it impossible to identify which EEG data belonged to which participant. Even if one knows the identity of a participant, one cannot know what particular data file belonged to that participant. Not even the researchers who would be running their EEG studies through the Sans Tracas platform nor I or anyone else will be able to link the EEG data with a participant, thereby eliminating the possibility of the EEG and behavioural data being traced back to any specific individual. This will help the platform gain users' trust and increase the platform's acceptance by regular people.

3.3.5 Solution for Pre-established Collection of Behavioural and EEG Experiments (DR5)

I developed three natively designed behavioural/EEG experiments: (1) a Visual N170 experiment, (2) a Face XAB experiment, and (3) a resting state experiment with eyes opened and eyes closed paradigms. The design of these experiments will be explored in detail in the upcoming sections. In addition to these experiments, I integrated three experiments that were designed and stored in Pavlovia [181]. As Pavlovia experiments cannot run outside the boundaries of Pavlovia, I downloaded the codebase for it, added it to the Sans Tracas platform, and ran the experiment via GitHub Pages [194]. I designed an additional screen layer that enables the Pavlovia experiments to run in the front section of users' screens using the Sans Tracas platform.

In contrast, the platform itself runs on the back section of the screen and records EEG data from the Muse in the background. The platform also records EEG data from the Muse in the background while the natively designed experiments are running. However, the natively designed experiments do not employ a two-screen approach. Hence, while the running of the experiment and the collection of EEG data both happen on the same screen for natively designed experiments, for the integrated experiments, it happens on two different screens, with the experiments running on the front screen and the EEG data being recorded in the back screen. Figure 3.4 explains the basic components of Sans Tracas and how it works.

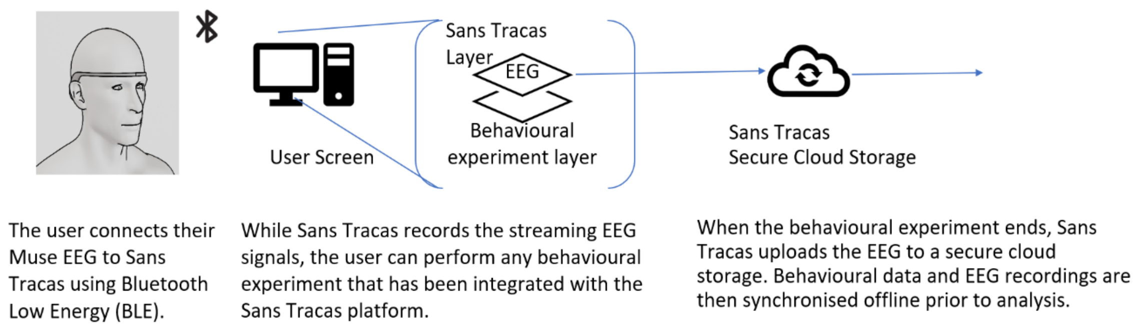


Figure 3.4: Sans Tracas components and functionalities

3.3.6 Solution for Achieving Flexibility and Ease of Use for the Researchers (DR6)

I developed a documentation section in the platform containing a detailed guide on how researchers can integrate their experiments with the platform. The entire integration process has been divided into four steps to make it easy to understand, with each step being simple and straightforward. The guide contains a picture corresponding to every step involved in the process for a better understanding of any specific step and easier identification of what to do and how to do it. The guide covers everything from installing Git [195] to running their experiments without Pavlovia, and integrating any experiments into the Sans Tracas platform to start running EEG studies and collecting a large amount of EEG data.

Researchers do not need to learn programming to be able to integrate their experiments into the Sans Tracas platform. Even the parts like making a GitHub account and then making changes to the platform's publicly available GitHub repository [196] do not require them to learn any coding or computer programming. Researchers have to copy and paste a few lines of code and change the experiment names and button labels to the names of their experiments, and the system is ready to be used. The researchers are specifically guided on what exact line of code they have to make the changes and what exactly that change would be. Thus, even someone with zero programming knowledge is able to integrate their experiments with the Sans Tracas platform. To make the process simpler, a video of the entire process is provided to ensure potential problems encountered by the researcher during the process are covered and that they can complete it independently.

3.4 Sans Tracas Stages of Development

Sans Tracas is a cross-platform tool that lets users (study participants) run EEG experiments online. Simultaneously, it also allows neuroscience researchers to integrate their own behavioural experiments with the platform to add EEG to their studies. Consequently, allowing them to run large-scale online EEG studies. The development process of the Sans Tracas platform was divided into three stages. In each stage, the platform was evaluated and refined by HCI researchers who are experts in the UCD approach and usability evaluation domain. As the platform is developed via a multidisciplinary lens, at each stage, it was also evaluated and refined by neuroscience researchers who are experts in the domain of EEG and behavioural experiments. The stages are as follows:

- Stage 1: Evaluation of the natively designed EEG experiments.
- Stage 2: Evaluation of the integration process and the integrated behavioural experiments.
- Stage 3: Evaluation of the user interface (UI) elements.

Table 3.1 shows the outcome of the stages, and the following sub-sections explain what we did at each stage.

Table 3.1: Sans Tracas platform development stages and outcomes

STAGES	OUTCOMES
Stage 1: Evaluation of the natively designed EEG experiments.	Improve the working and implementation of natively designed EEG experiments.
Stage 2: Evaluation of the integration process and the integrated behavioural experiments.	Improve the integration process and the working and implementation of the integrated behavioural experiments.
Stage 3: Evaluation of the user interface (UI) elements.	Refine and improve the UI elements of the platform.

3.4.1 Stage 1: Evaluation of the Natively Designed EEG experiments

In stage one, we evaluated the platform for the proper functioning of the natively designed EEG experiments. We designed three EEG experiments natively (1) Visual N170 experiment, (2) Face XAB experiment, and (3) Resting state experiment. The unique design of these experiments will be discussed in the next section. Four expert HCI researchers from the Persuasive Computing Lab evaluated the functioning of the experiments, how the device connects with the Muse headset and whether it is able to read EEG data. Two expert neuroscience researchers evaluated the EEG experiments' scientific design and the quality of the EEG data obtained from the Muse headset. The HCI researchers performed their evaluation individually, whereas the neuroscience researchers performed a collective evaluation. The evaluation process was done online by both groups. However, the HCI researchers took four weeks for their evaluation, whereas the neuroscience researchers adopted three months of continuous feedback-changes-evaluation methodology. In the first month, they evaluated the Visual N170 experiment, Face XAB experiment was evaluated in the second month, and Resting State experiment was evaluated in the third month. With at least two meetings in a month, the first meeting would be focused on evaluated the initial version of the experiment and the consequent meeting(s) would be focused on evaluating the changes from the last meeting. We elicited feedback from all the researchers and took note of the changes that required.

After that, we analyzed every piece of feedback and performed the necessary changes. The result of the evaluation helped us improve on various aspects such as the scientific design, accuracy of EEG experiments, the ease of connecting to the Muse headset, the frequency of readings obtained from the Muse headset, the way users interact with the platform, and the manner in which they perform the experiments.

3.4.2 Stage 2: Evaluation of the Integration Process and the Integrated Behavioural Experiments

We improved the platform from the feedback collected in stage one. The EEG experiments were made more scientifically accurate to the experiment task with proper presentation and recording (in milliseconds) of the visual stimuli. In stage two, the platform was evaluated for the integration process to integrate other researchers' behavioural experiments with the platform and how those integrated experiments would function on the platform along with the natively designed experiments. In this stage, six expert HCI researchers from the Persuasive Computing Lab evaluated the usability of the integration process and the integrated experiments. Three expert neuroscience researchers evaluated the scientific accuracy of the integrated experiments and how participants would interact with them. They also evaluated the integration process's usability both from EEG users' and non-EEG users' perspectives. Both researcher groups performed their evaluations individually and online and took four weeks to provide their feedback. They took one week for the evaluation of each integrated experiment and the last week to evaluate the integration process. The feedback from this stage helped us to improve the integration process and the way those integrated experiments are implemented with the platform. For example, we adopted a dual-screen design approach to run those integrated experiments on the platform. The front screen will run the visual elements from the behavioural experiment, and the back screen will collect EEG data from the Muse headset. This approach helped in keeping the behavioural and EEG parts separate but well-integrated.

3.4.3 Stage 3: Evaluation of the User Interface (UI) Elements

We improvised the platform based on the feedback collected in stage two. In stage three, the application was finally evaluated for feedback on the usability of user interface (UI) elements. The platform was presented to seven HCI researchers in the Persuasive Computing Lab and two expert neuroscience researchers. Each researcher evaluated the platform individually and online and took four weeks to provide the feedback. Everyone was asked to provide their feedback in this stage regarding the overall platform UI. This helped us refine the positions of some UI elements and colours to make the platform more appealing. For example, we received feedback about changing the background colour scheme during the experiment to be more subtle and match the overall aesthetic of the platform, changing the colour, size, position, and orientation of the buttons and changing the order and workflow of the connection and Signal Quality Check process and furthermore, improving the sound that indicates the end of the calibration phase. These were all considered for improving the UI.

The final platform [182] developed after this iterative design and development process was the Sans Tracas platform used in this study for evaluation.

3.5 Sans Tracas Experiment Design

As a solution to Design Requirement 5 (DR5) (see section 3.2.5), we established a collection of six EEG experiments for participants to try out during the study. Out of the six, three experiments were natively designed EEG experiments, and the other three were behavioural experiments designed on Pavlovia [181] that were integrated with the Sans Tracas platform. The following sub-sections will discuss the individual design of these experiments.

3.5.1 Visual N170 Experiment Design

This is a traditional Visual N170 experiment, wherein the N170 is a face-sensitive ERP (Event Related Potential) component characterized by a negative deflection in wave amplitude that occurs around 170ms after the presentation of a face [197]. In this experiment, the participants were asked to look at a series of faces and houses on the screen. They had to keep their eyes fixated on the dot. There was no other task. This experiment took approximately 3 minutes. The experiment was designed in such a way that once the signal quality check process was completed, the participants would click the "start experiment" button when they were ready. Upon clicking the "start experiment" button, the first stimulus they would see is a freeze screen which displays the purpose of the experiment, and the instructions participants were meant to follow. After they had read the instructions and were ready to start the experiment, they could begin. The experiment then presented participants with a series of visual stimuli which contained three different image types: (1) an image containing a house, (2) an image containing a face, and (3) an image containing a red dot. The first image displayed was the red dot, followed by a house or a face image randomly. The red dot image was shown for 300ms, and the house or face image was shown for 200ms. The total number of house and face images shown to the participants was the same, but their order was randomized. Once the experiment was completed, the participants had an option to view and download their EEG data, as well as the behavioural data for the N170 experiment.

3.5.2 Face XAB Experiment Design

The Face XAB experiment is loosely derived from the Still-face experiment [198]. However, unlike the still-face experiment, the Face XAB experiment is designed for adults. In this experiment, participants were shown a face for a few seconds and then asked to look at it and remember it. Afterwards, they had to choose the face which was previously displayed to them from two available options. They could use either the mouse, keyboard, or touch input to select their answer. They would have to repeat this process a few times. Figure 3.5 shows the image selection screen employed in the experiment. This experiment took approximately 5-10 minutes. Similar to the N170 experiment, this experiment also started with a freeze screen containing details about the experiment and instructions on how to perform the experiment. Furthermore, after the completion of the experiment, the participants would be able to view and download their EEG data, as well as the behavioural data for the Face XAB experiment. The behavioural data for this experiment would contain information such as whether they selected the correct face for each turn, the position of the face, the time it took for them to select the face, and the input method they used for their selection.

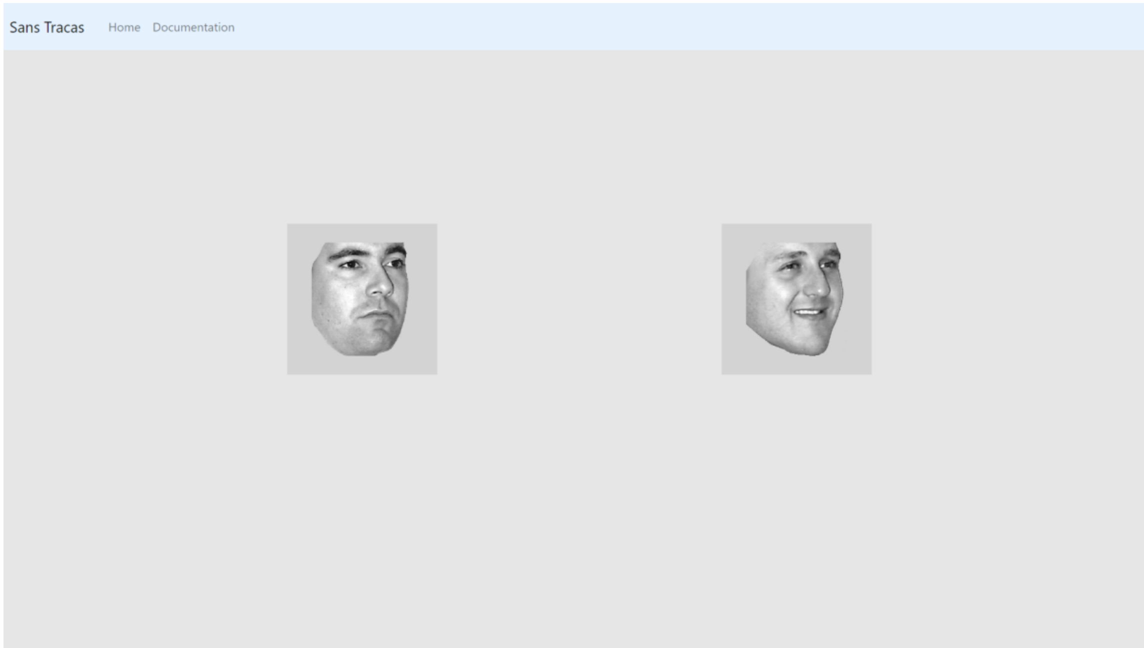


Figure 3.5: Face XAB – Image selection screen

3.5.3 Resting State Experiment Design

This is a traditional Resting-State EEG experiment. Resting-State EEG studies are generally used to evaluate intrinsic neural activity, which is not elicited through a task [199]. In this experiment, the participants were asked to relax for a few minutes. The duration of relaxation time is up to the participant. During the experiment, they would either choose to keep their eyes open or closed for the duration of the experiment. They would also be allowed to choose to meditate for that time period. After the experiment, they would be asked to answer a few questions regarding their sleepiness. There was no other task.

The experiment time for this experiment will depend on what a participant chooses it to be. This experiment, too, had a freeze screen at the beginning, which explains the difference between performing an eyes-open vs. an eyes-closed resting state experiment. It also contained instructions on how to perform both types of experiments which could be viewed by selecting what type of experiment they wanted to perform. At this screen, they would also select the experiment duration in minutes. If they selected the eyes-open experiment, they would see a red dot at the centre of the screen and would be asked to keep their focus on it for the duration of the experiment. A progress bar at the bottom of the screen displayed the progress of the experiment duration. Figure 3.6 shows what users see when they run the eyes-open resting state experiment.

However, suppose they selected the eyes-closed experiment. In that case, they would not have anything on the screen except for the progress bar showing the progress of the experiment duration and a text which instructs them to keep their eyes closed for the duration of the experiment. Once they completed the sleepiness survey attached to the experiment, they would be able to view and download their EEG data.

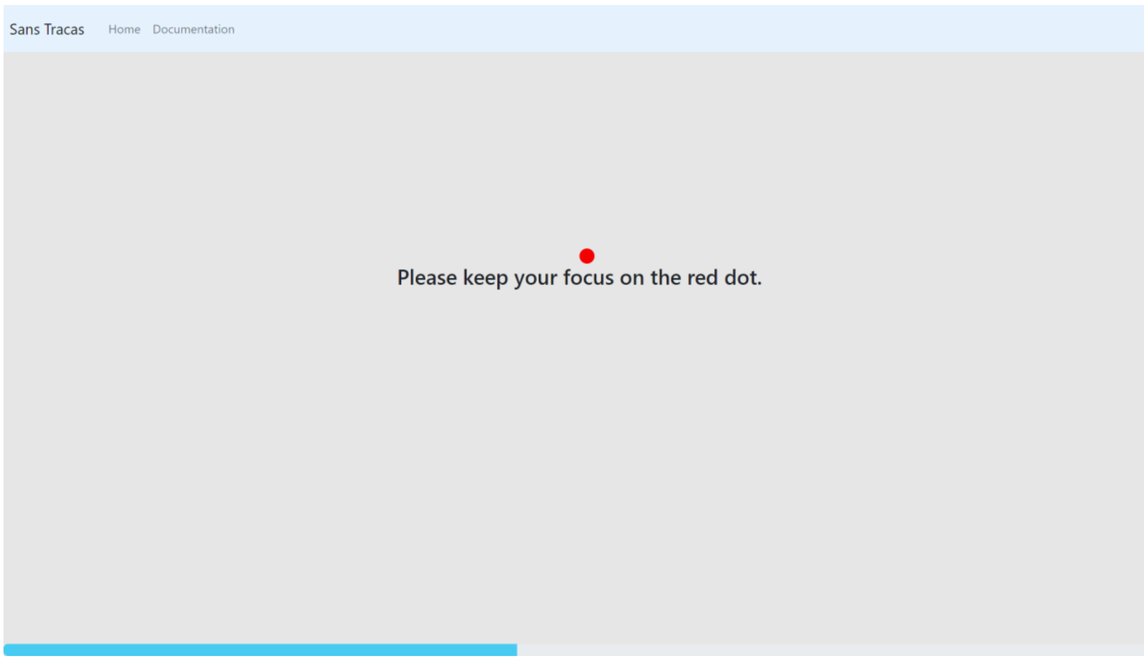


Figure 3.6: Resting State – Eyes-open experiment screen

As mentioned earlier, the three integrated experiments run on a dual-screen approach. When the integrated experiments are running, there is an end-bar provided at the top of the screen for participants to stop the experiment or completely abandon it. Furthermore, at the end of those experiments, the participants could view and download their EEG data. Their behavioural data for the experiment would automatically be downloaded to the participants' devices. However, since they were designed by other neuroscience researchers using PsychoPy [159] and Pavlovia, their design details will not be discussed here.

3.6 Sans Tracas Platform Workflow

A typical Sans Tracas platform workflow from both an end-user perspective and a researcher perspective are discussed in this section.

3.6.1 End-User Workflow

An ideal end-user will start their journey with Sans Tracas by watching the tutorial video so that the users have some idea about the platform's operations and functionalities. Their actual start will be by selecting an EEG experiment from the available list of many experiments. The user will be able to view a description about each experiment by clicking on the hamburger button and select the experiment by clicking on the play button. Figure 3.7 shows the Sans Tracas experiment selection screen. This experiment selection screen is located at the bottom of the Sans Tracas homepage. Once an experiment is selected, they will enter their participant ID, which will be given to them by the platform on the same page. The participant ID is randomly generated for each user. Afterwards, they will turn on the Bluetooth on their device and connect the Muse EEG headset with the platform. Once the Muse is connected, they will follow the placing instruction videos and properly place the Muse on their head. After properly fitting the Muse headset, the participants will begin the Signal Quality Check process. During the process, they will be asked to sit still for 30 seconds with a relaxed jaw and eyes closed. They will also try to meditate or keep their minds as calm as possible. The end of the calibration phase will be signified via a tranquillizing sound.

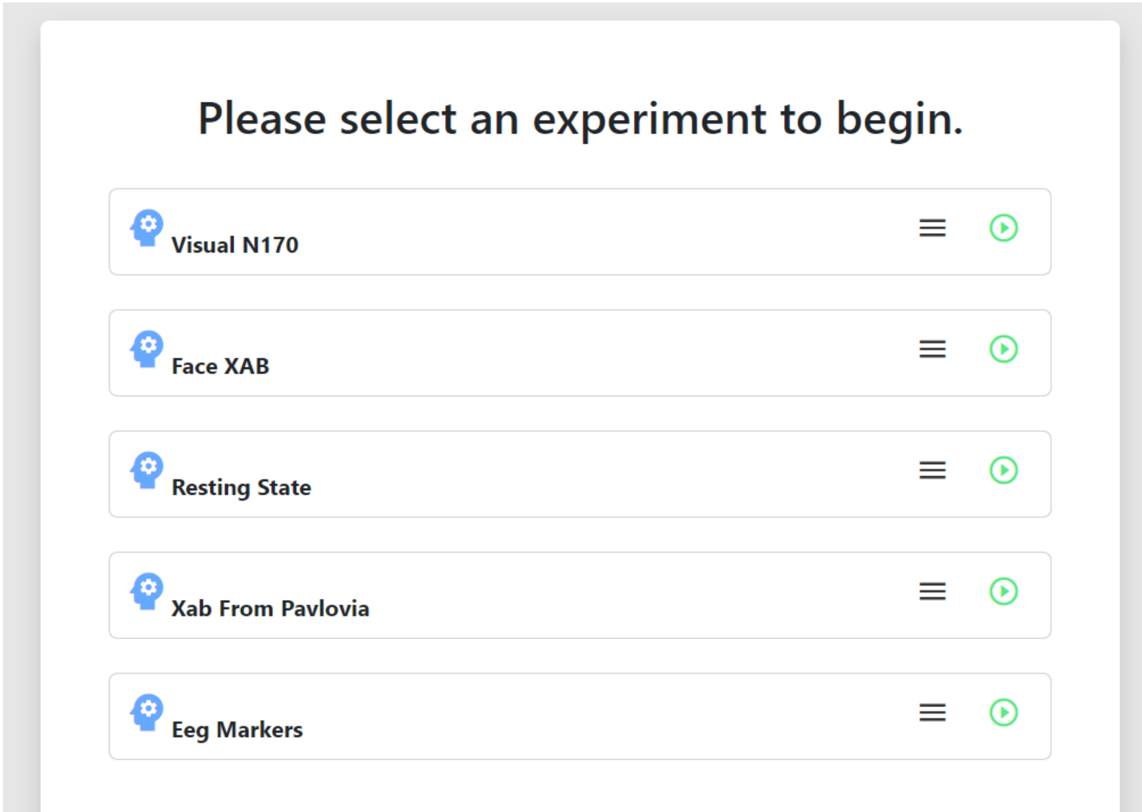


Figure 3.7: Sans Tracas experiment selection screen

Afterwards, they will be able to view their live EEG signal during those 30 seconds in the form of line graphs, with each graph representing different Muse channels. Scrolling a little further will show them their signal variability in the form of a bar graph, and the accompanying text will help them understand the bar graph to determine their signal quality. At this point, if they are satisfied with their signal quality, they can proceed further or go through the process again to improve their signal quality by adjusting and refitting the Muse. Before starting the experiment, they will see a freeze-screen explaining details about the experiment and providing instructions on how to perform the experiment. Once they are ready, they can start the experiment. After the experiment is completed, they can view and download their EEG data and end their study. Alternatively, they can choose to redo the experiment or perform any other experiment from the list. Figure 3.8 illustrates the typical Sans Tracas end-user workflow.

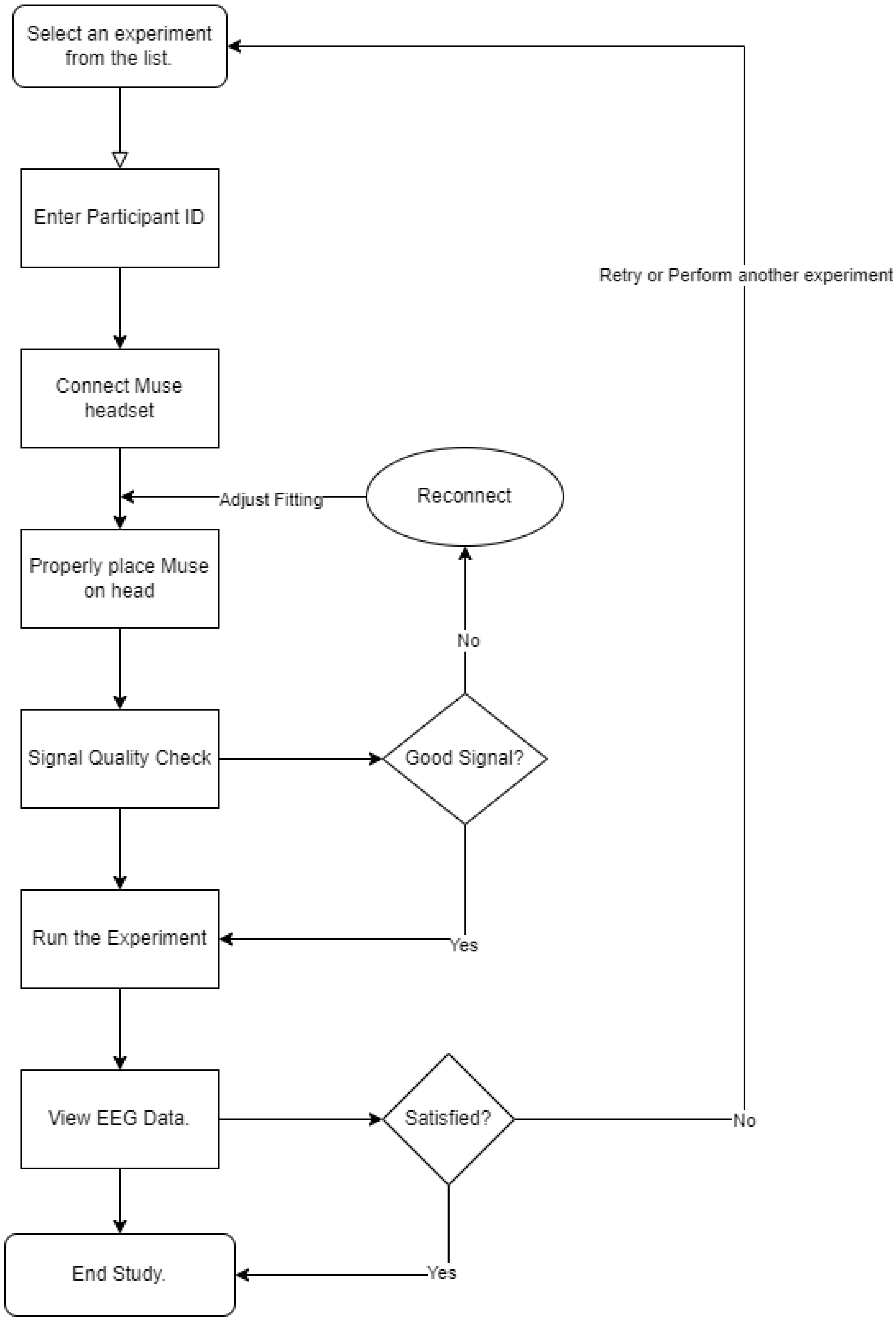


Figure 3.8: Sans Tracas End-User Workflow

3.6.2 Researcher Workflow

An ideal researcher will begin their four-step integration process by going through the documentation and thoroughly reading the researcher guidelines. Step one will require them to make sure that they have three prerequisites: (1) A Pavlovia Account with an already designed behavioural experiment, (2) A GitHub Account, and (3) Git installed on their personal computer. Step two will guide them through how they can download their experiments from Pavlovia and how to add the library files. Step three guides them through creating a new GitHub repository, uploading their experiment on it, and publishing their experiments by hosting them on GitHub Pages. Step four guides them through forking a GitHub repository to add their experiment files in the Sans Tracas codebase. It also teaches them how to edit the Sans Tracas main file to add their experiment display cards and buttons to play their experiments. Finally, they will be shown how to create a pull request to merge their changes with the original Sans Tracas code. I will review this pull request, and if I find all the changes to be satisfactory and not harmful to the platform, I will approve the pull request.

Once their pull request is approved, they will be able to see their experiment on the Sans Tracas platform immediately, and they can start using the platform to run their own large-scale EEG studies. However, suppose, for some reason, their pull request is not approved. In that case, they will be notified about this, and changes will be suggested to improve their experiment or something that would have gone wrong during the integration process. Once those changes have been implemented, they will have to create another pull request which will then be reviewed again. This approval process could be repeated a couple of times until it satisfies all the conditions of the newly added experiments not causing any harm or damage to the platform or its existing experiments. Figure 3.9 illustrates the typical Sans Tracas researcher workflow.

One important point of consideration here is that the researcher interface and the researcher workflow by extension were not evaluated during the study and thus its evaluation is not a part of this thesis.

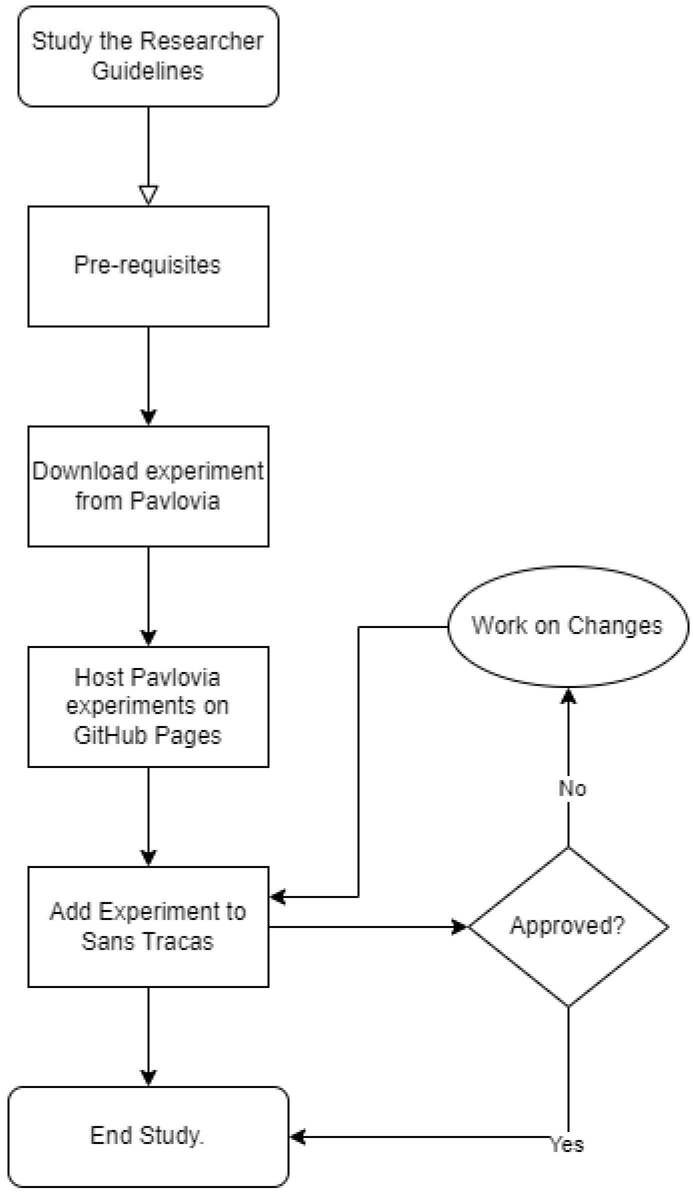


Figure 3.9: Sans Tracas Researcher Workflow

CHAPTER 4 EVALUATION PROCESS OF SANS TRACAS

After developing the platform Sans Tracas, I needed to investigate whether it is usable with respect to conducting an online EEG experiment for people with varying EEG and BCI knowledge. Therefore, I developed the following research questions to guide the evaluation process.

The overarching research question of the study is:

Is Sans Tracas usable and useful for conducting online EEG experiments?

To answer this research question and evaluate the usability of the platform Sans Tracas, I collected the data for individuals with regard to their experience with the platform. The goal was to evaluate the platform's usability, which includes factors such as the platform's intuitive design, ease of learning, the efficiency of use, memorability, error frequency and severity, and subjective satisfaction [200]. To effectively evaluate the platform's usability and answer the overarching research question, I further divided the overarching question into 16 sub-questions measuring parts of a platform's usability.

As effectiveness, efficiency, and satisfaction are the most crucial metrics for usability evaluation [201], I determined that in order to evaluate the usability of Sans Tracas, I need to evaluate how effective, efficient, and satisfactory it is with regard to running an online EEG experiment. Moreover, I used scales that are common in HCI such as the System Usability Scale (SUS) [141], Perceived Usefulness scale (PU) and Perceived Ease of Use scale (PEOU) [149] to determine the perceived usability of Sans Tracas. Hence, the following five research questions were developed:

RQ1: How effective is Sans Tracas with respect to using it to conduct an EEG experiment?

RQ2: How efficient is Sans Tracas with respect to enabling the user to independently conduct an EEG experiment and help them learn how the system works?

RQ3: How satisfied are the users after completing their task of conducting an EEG experiment using Sans Tracas and their overall experience with Sans Tracas?

RQ4: How useful is Sans Tracas for conducting an online EEG experiment?

RQ5: How easy is it to use Sans Tracas for conducting an EEG experiment?

One of the secondary purposes of the platform is to serve as an educational tool and to offer an initial interactive EEG experience to EEG beginners. The platform aims to make people more interested in EEG and BCI research. Thus, I collected data from participants regarding their interest and knowledge about EEG and BCI research before and after using the platform. I then compared their responses to investigate for a change in their attitude towards EEG and BCI research. Moreover, the ARCS motivation model is widely used to inform the design and evaluation of the motivational appeal for persuasive and behaviour change systems. Previous studies have employed ARCS to evaluate the motivational appeal of an interactive persuasive system [202], [203]. However, it has never been used to evaluate a BCI system. Therefore, I used the ARCS motivation model to determine the overall motivational appeal of Sans Tracas across the four dimensions of motivation; Attention, Relevance, Confidence, and Satisfaction; by answering the following two research questions.

RQ10: How effective is Sans Tracas in generating interest for EEG and BCI research in users?

RQ11: How effective is Sans Tracas with respect to motivational appeal?

Since Sans Tracas was developed via a multidisciplinary lens, it is prudent to evaluate the technical aspects of the platform too. A platform running online EEG experiments should meet some technical standards with respect to its handling of EEG data, such as recording, transmitting, and storing EEG data on a secured server. The platform must also be entirely cross-platform, and the EEG data recorded from it should be of good quality. Additionally, similar platforms such as eeg-notebooks require additional software such as BlueMuse [204], BGAPI [205], Bluefy [206], jupyter notebooks, anaconda, python, etc. to facilitate an LSL connection and to operate their platform in the first place. Sometimes, they even require a hardware BLE dongle such as the BLED112 USB dongle [207] to facilitate a connection with the EEG headset. Thus, it is important to determine whether Sans Tracas can function independently. Hence, the following five research questions were developed.

RQ12: Can Sans Tracas record and transmit accurate EEG data while running a natively designed or integrated EEG experiment?

RQ13: Is the EEG data obtained from Sans Tracas transferred and stored securely?

RQ14: Can Sans Tracas independently and effectively run an EEG experiment without needing the user to install any other software or hardware add-ons, dongles, or accessories?

RQ15: Is Sans Tracas genuinely cross-platform, and does it behave the same across devices?

RQ16: Is the EEG data obtained from Sans Tracas of good quality?

Table 4.1 summarizes the research question numbers and their corresponding investigations.

Table 4.1: Research questions for the evaluation of Sans Tracas

Research Questions	**Investigations**
RQ1	Effectiveness of Sans Tracas for conducting an EEG experiment
RQ2	Efficiency of Sans Tracas for conducting an EEG experiment

RQ3, RQ4, and RQ5	Perceived usability of Sans Tracas from an end-user perspective (using SUS, PU, and PEOU scales)
RQ10	Effectiveness of Sans Tracas for generating interest in EEG and BCI research
RQ11	Effectiveness of Sans Tracas with respect to motivation appeal (using ARCS model of motivation)
RQ12 and RQ13	Ability of Sans Tracas to record, transmit, and securely store EEG data while running an EEG experiment
RQ14	Ability of Sans Tracas to run an EEG experiment without any additional hardware or software
RQ15	Ability of Sans Tracas to be genuinely cross-platform
RQ16	The quality of EEG data obtained from Sans Tracas

4.1 Study Design Overview

To answer these research questions presented in Table 4.1, I conducted a study using an online survey method to evaluate Sans Tracas, followed by a semi-structured interview. The study design is as follows:

To understand the effects of Sans Tracas on participants, I followed a two-step study design approach, with the first step consisting of a pilot study and the second step consisting of the main study. After receiving the ethics approval from Dalhousie University's research ethics board, I sent out recruitment emails for the pilot study. Afterward, HCI researchers from the Persuasive Computing Lab at Dalhousie University and other Dalhousie University students were invited to a laboratory (Jan 2022). Each participant was provided with a Muse EEG device and was asked to conduct an EEG experiment using Sans Tracas and the Muse. After that, they were asked to fill out the post-study survey, which was followed by an unstructured interview regarding their experience with the platform. Unlike the pilot study, which was confined to the laboratory, the main study was entirely online, and all participants performed the study from the comfort of their houses.

For the main study (May 2022 – June 2022), I ran a pre-study and post-study design followed by a semi-structured interview. After receiving the ethics approval for the main study from Dalhousie University's research ethics board, I gathered participants from advertising the study on social media platforms and university email list. I had the participants fill out the pre-study survey. After that, they had to use Sans Tracas along with a Muse EEG device to perform an EEG experiment. I tracked the average time to perform an experiment to check the efficiency of Sans Tracas. The average time was calculated based on the time difference between the first and last recorded signal in the EEG data file. On average, the participants took 20 minutes to complete the experiment. After completing the experiment, they were asked to fill out the post-study survey. At the end of the post-study survey, the participant could consent to be contacted for a semi-structured interview to provide deeper insights regarding their experience with Sans Tracas (June 2022 – July 2022). Figure 4.1 shows the flow of the process for each study. The following sections present the details about the study design, data collection, study instruments, and participants' demographics.

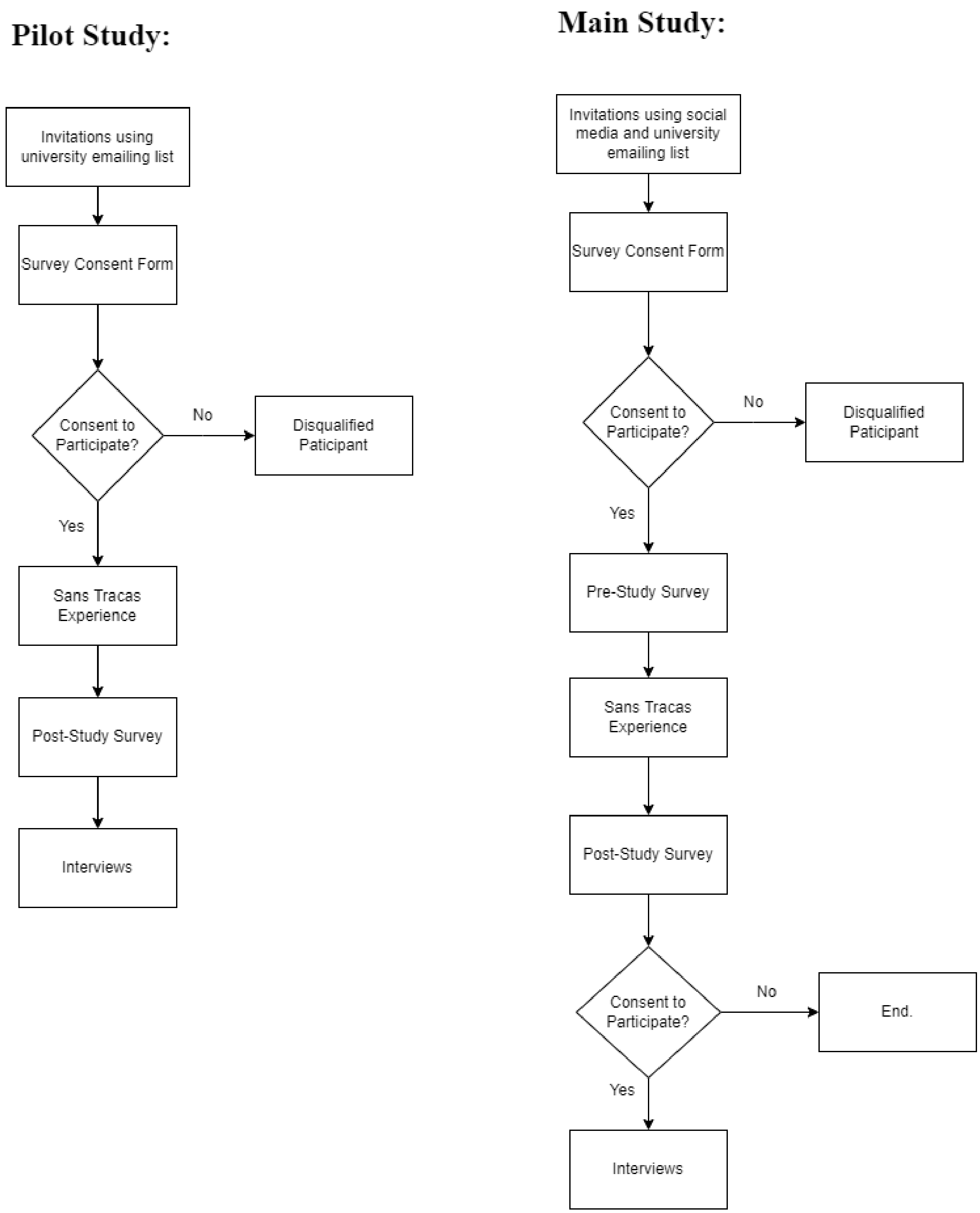


Figure 4.1: Flow of Processes in User Study

4.2 Study Design

To answer the research questions mentioned at the beginning of this chapter, I conducted a study that would collect data about baseline attitude, knowledge, and interest (pre-study) about EEG and BCI research, have participants use Sans Tracas to perform an EEG experiment, then collect their data about their attitude, knowledge, and interest about EEG and BCI research after performing an EEG experiment (post-study). However, this was not part of the goals for the pilot study. Thus, I only conducted a post-study survey for it. All surveys were designed and hosted on Opinio [208], and all the data collected was stored on Dalhousie University's online server. Figure 4.2 shows the methodology stages of the study.

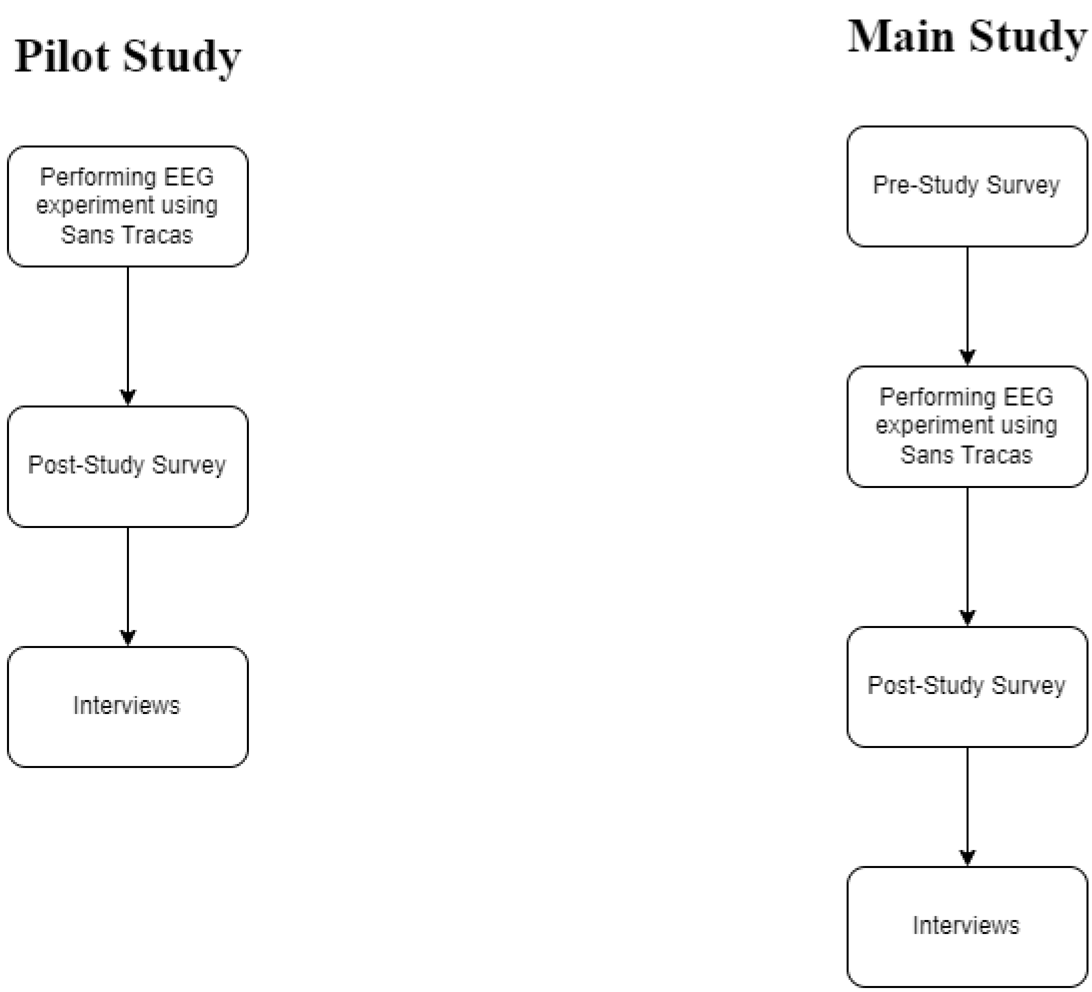


Figure 4.2: Study Methodology Stages

The pilot study was divided into two parts:

First, I invited HCI researchers from the Persuasive Computing Lab and other Dalhousie students to participate in the pilot study. Due to time constraints, they were invited to a laboratory and then handed the Muse EEG devices. After briefly explaining the need for a platform like this, the participants were left alone to perform the experiments independently to simulate at-home conditions as closely as possible. All participants (N = 7) were asked to perform at least one experiment, the visual N170, independently from start to finish. The participants were only provided with the Muse device, and they had to use their own laptops, desktops, or cellphones to access Sans Tracas. They were provided with the link to the platform and asked to perform everything on their own, from looking at the platform for the first time to filling out the surveys.

After completing at least one experiment, they moved on to stage two, where they were asked to fill out the post-study survey to evaluate the platform's usability and their experience. The survey contained questions for collecting both quantitative and qualitative feedback and questions from scales such as the SUS, PU, and PEOU to measure perceived usability. It also contained questions from the ARCS motivation appeal test to measure the platform's motivational appeal. The post-study survey link was provided to the participants at the bottom of the experiment completion page. Afterwards, they took part in an unscripted interview to reflect upon their experience using Sans Tracas.

Based on the pilot study and its results, I improved the design of the design of the platform and the experiments. I added the video tutorial to give the participants an overview of the platform and make them familiar with it. The video serves as a replacement for the physical presence of the researcher. I also upgraded the Visual N170 and resting state experiments and made them more scientifically accurate. In the pilot study, the Visual N170 would just display images of houses and faces and run for 20 iterations of each. But in the main study, it now presents a red dot in between each image and each image itself runs for only 200 milliseconds, while the red dot is present for 300 milliseconds. The entire experiment runs for 300 iterations which is about 3 minutes. I also added proper descriptions of each experiment before the start of the experiment.

Furthermore, I divided the main study into the following four stages:

In Stage 1, unlike the pilot study, where participants were asked to come to a laboratory, the main study was conducted entirely online, with participants taking part in the study from the comfort of their own houses. Participants were asked to use their own Muse EEG devices, and if they did not own one but still wanted to participate in the study, they could borrow one from me. The link to the consent form was shared with the recruitment notice, and once a participant provided consent, they were automatically redirected to every other part of the study. After agreeing to participate in the study and giving their consent online, the participants first encountered the pre-study survey. I designed the pre-study survey to capture data about participants' baseline attitude, knowledge, and interest about EEG and BCI research (Appendix B.). The pre-study survey also contained demographic questions regarding the participants' age, gender, level of education, and field of study.

In Stage 2, the participants were automatically redirected to the Sans Tracas homepage after submitting the pre-study survey. On the homepage, they were greeted with a welcome message and presented with a tutorial video which gave them a tutorial on the Sans Tracas platform and how to perform an EEG experiment using it. The video also explains the purpose of the study. After watching the video, they were asked to ensure that their internet-enabled device met the system requirements for Sans Tracas. Once everything was ready, they were asked to perform at least one of the available EEG experiments from the list using the corresponding button for each experiment. The Visual N170 experiment was the required one, and the participants had the choice to return to the homepage if they wanted to perform any other experiment. While the participants were performing the experiment, their EEG data from the Muse was being recorded by the platform and securely transmitted to the Sans Tracas server. The EEG data was later downloaded from the server for EEG data analysis. The Sans Tracas server is secured with two-factor authentication and can only be accessed via an ftp client.

For Stage 3, I conducted the post-study survey after participants completed performing an EEG experiment. The link to the post-study survey (Appendix C.) was at the bottom of the experiment completion 'endscreen' wherein participants were instructed to either use the link to fill out the post-study survey or go to the homepage to try out other experiments. In the post-study survey, I included questions to receive qualitative and quantitative feedback regarding participants' overall experience using Sans Tracas. I also included questions from the pre-study survey so I can compare any changes in their attitude, knowledge, and interest in EEG and BCI research after using Sans Tracas. Apart from that, I included questions to measure various aspects of the platform, such as the number of trials required by a participant to connect the Muse headset. Moreover, I included questions from the ARCS motivational appeal model and various usability scales such as SUS, PU and PEOU to measure the perceived usability of Sans Tracas. Only the participants who completed the post-study survey (N = 55) were considered for data analysis, and the incomplete submissions were discarded.

Finally for Stage 4, I conducted one-on-one semi-structured interviews via Microsoft Teams to collect qualitative data. The online interview invites were only sent to the participants who consented to participate by providing their email at the end of the post-study survey as this interview was optional for the participants. I conducted a total of 11 semi-structured interviews, and each interview lasted about 20 minutes (Appendix D.). I audio-transcribed all 11 interviews with the participants' permission. This semi-structured interview helped me to collect rich qualitative feedback from the participants about their experience with the platform, its impact on their interest and knowledge about EEG and BCI research, what they like/dislike about the platform, their thoughts on the technical and usability features used in the platform, and any suggestions for improvements to the platform. Each participant was compensated with a $15.00 CAD Amazon gift card if they completed the post-study survey, and an additional $15.00 CAD Amazon gift card if they participated in the semi-structured interview. The results of the evaluation study are discussed in the next chapter.

4.3 Data Collection

I used snowball sampling [193] to recruit participants for the main study. The recruitment notice was shared using university email lists and social media sites like Twitter, Instagram, LinkedIn and Facebook. I also shared the recruitment notice with the NeurotechX [176] community via their slack channel.

There were two sections in the pre-study survey. The first section contained demographic questions such as participants' age, gender, level of education, and field of study. In the second section, I asked participants about their EEG and BCI background, their familiarity with EEG experiments, the number of EEG studies they have previously participated in, and their knowledge and interest in EEG and BCI research.

The post-study survey was presented in five sections. The first section contained general questions regarding the participants' experience using the platform, such as their likes and dislikes, suggestions, and questions about their knowledge and expertise regarding computer programming, Muse, EEG and BCI research. Section two contained specific questions regarding their experience with Sans Tracas, such as the number of trials they had to perform, whether they were able to view and download their EEG data, whether they needed any help performing the experiment, and their preference for the type of device to run Sans Tracas. Section three included questions measuring attention, relevance, confidence, and satisfaction consisting of 12 items measured on a 5-point Likert scale (ranging from "1 = Strongly Disagree" to "5 = Strongly Agree"). The validated scales and questions for measuring ARCS constructs were adapted from Keller et al. [150]. In the fourth section, I included questions to measure the system usability using the System Usability Scale adapted from Kusic et al. [209]. The scale contains ten items measured on a 5-point Likert scale (ranging from "1 = Strongly Disagree" to "5 = Strongly Agree"). Sections five and six included questions to measure the perceived usefulness and the perceived ease of use of the platform using scales adapted from Bertagnoli et al. [149]. Both scales include six items each that were measured on a 7-point Likert scale (ranging from "1 = Extremely Likely" to "7 = Extremely Unlikely"). The final section included a question asking the participants to provide their email addresses to compensate them for their participation in the study. It also included a question for participants to enter their email addresses if they wished to participate in the optional semi-structured interview.

4.4 Study Materials and Instruments

Below is the list of instruments used in this study:

- Pre-study online survey form for collecting data about users' demographics and their baseline attitude, knowledge, and interest in EEG and BCI research.
- Sans Tracas platform for conducting an online EEG experiment.
- Post-study online survey form for collecting quantitative data regarding their experience with the platform.
- Semi-structured interview for collecting qualitative data regarding their experience with the platform.
- Microsoft Azure server [193] for storing EEG data.
- Dal Opinio Server for hosting the pre and post study surveys.
- SPSS and MS Excel for data analysis.
- MATLAB and EEGLAB for EEG data analysis.
- Affinity Diagram and MS Word for thematic analysis.

4.5 Participants' Demographics

Seven participants were recruited for the pilot study by sending the recruitment notice through the university email list. All seven participants interacted with the platform and completed the post-study survey. The mean age of the participants was 27.43 years, with an error rate of 3.74 years. Out of the seven participants, two (28%) were female, and five (72%) were male. All participants had completed at least a bachelor's degree.

For the main study, 63 participants were recruited from advertising and sending emails to potential participants. Of these 63 participants, 55 used the platform and filled out the post-study survey. After excluding the 8 participants who dropped out of the study, I included 55 responses in my final analysis.

For the included participants, I had 46 male participants (79%) and 12 female participants (21%).

The mean age of all the participants was 25.4 years old (*SD* = 5.14 years), with the minimum age being 19 years and the maximum age being 57 years. Figure 4.4 shows the

Histogram of the participants' age. As can be seen in Figure 4.3, the largest age group in my sample was '23-27' which had 34 participants (62%), followed by '19-23' with 12 participants (22%). The smallest age group I had was '27-31' with 6 participants (10%), followed by '31-35' with 2 participants (4%) and '55-59' with 1 participant each (2%).

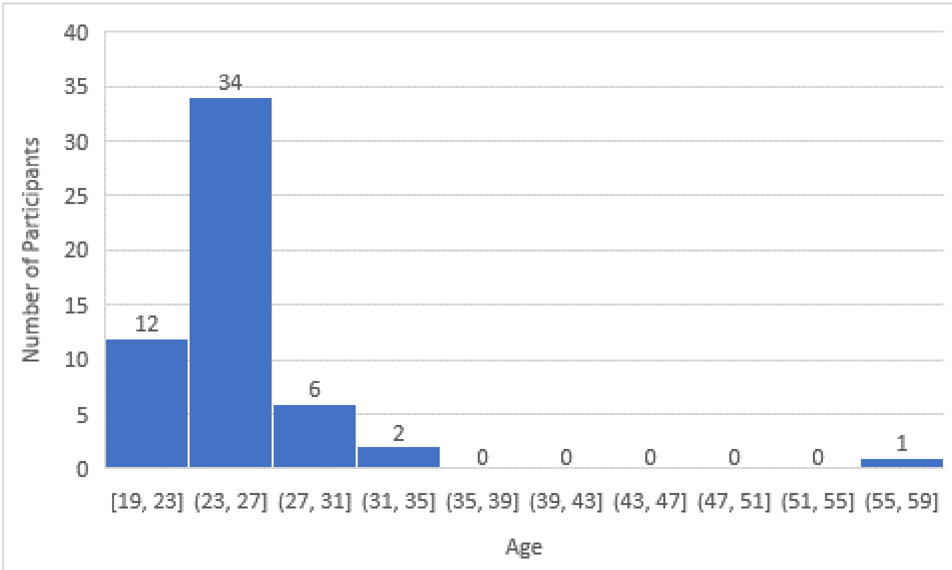


Figure 4.3: Study Demographics by Age

With respect to their education level, master's degree was most represented with 50%, followed by bachelor's degree with 38%, college diploma and high school or equivalent with 5% each, and doctoral degree had the lowest with 2% as shown in Figure 4.4.

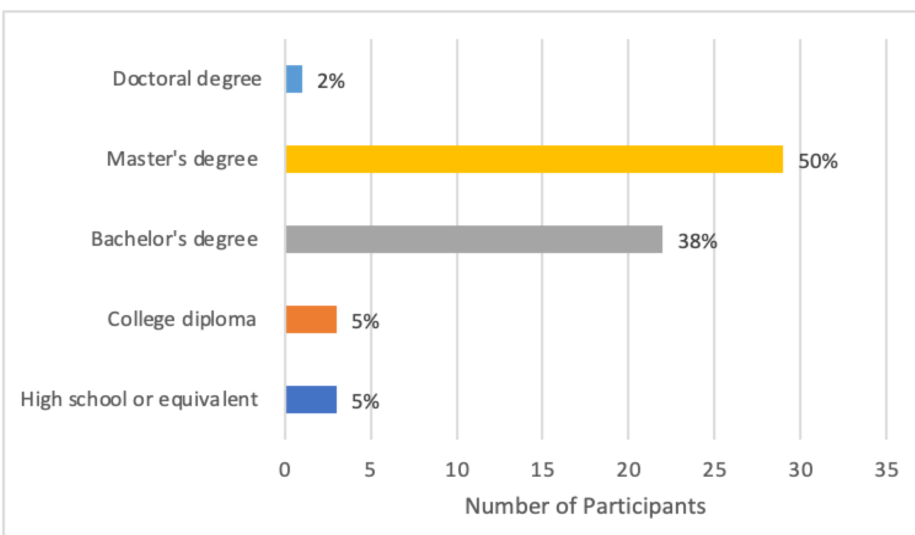


Figure 4.4: Study Demographics by Level of Education

With respect to participants' field of study, mathematical, information and computing sciences was most represented with 74%, suggesting that most participants were technically inclined; followed by engineering and environmental sciences with 9%; HCI with 5%; economics and commerce and others with 3% each; and medical and health sciences, physical, chemical and earth sciences, and neuroscience had the lowest with 2% each as shown in Figure 4.5.

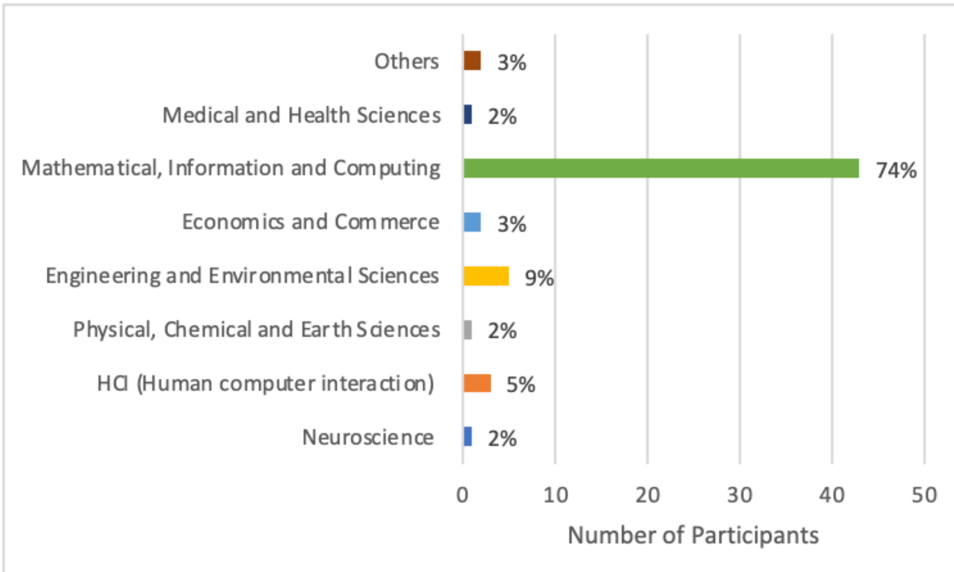


Figure 4.5: Demographics by Field of Study

With respect to their participation in EEG studies before Sans Tracas, 90% of the participants had never participated in an EEG study, 8% of the participants had participated in 1 to 3 EEG studies, and only 2% of the participants had participated in more than 5 EEG studies before Sans Tracas.

Table 4.2: Summary of Participants' Demographics

Total number of participants = 55	
Gender	Male (79%), Female (21%)
Age	23-27 years (62%), 19-23 (22%), 27-31 (10%), 31-35 (4%) 55-59 (2%)
Education	master's degree (50%), bachelor's degree (38%), college diploma (5%), high school or equivalent (5%), doctoral

	degree (2%)
Field of Study	mathematical, information and computing (74%), engineering and environmental sciences (9%), HCI (5%), economics and commerce (3%), others (3%), medical and health sciences (2%), physical, chemical and earth sciences (2%), neuroscience (2%)
Previous EEG study experience	0 (90%), 1-3 (8%), 5+ (2%)

4.6 Data Analysis

To analyze the quantitative data and answer my research questions, I used well-known analytical methods via IBM's SPSS. To answer RQ1, I calculated the number of participants (out of the total N = 55) that were able to conduct at least one EEG experiment using Sans Tracas and the Muse. I measured the task completion rate of the participants with their given task of having to conduct an EEG experiment using Sans Tracas. To answer RQ2, I calculated the number of times each participant had to retry before successfully connecting to the Muse. I measured the average number of trials for each participant, their error rate, and the overall average time it took them to complete an EEG experiment. To answer RQ6, I calculated the number of participants who successfully integrated their own experiments with the platform. I measured the task completion rate of the participants with their given task of integrating their own experiments with Sans Tracas using the documentation guide.

To answer RQ3 and RQ7, I performed descriptive analysis and ran a one-sample t-test on the SUS to evaluate the platform's usability. I also calculated the average SUS score of all participants to understand the platform's usability compared to other SUS studies. To answer RQ4 and RQ8, I performed descriptive analysis and ran a one-sample t-test on the PU scale to evaluate the platform's perceived usefulness. Similarly, to answer RQ5 and RQ9, I performed descriptive analysis and ran a one-sample t-test on the PEOU scale to evaluate the platform's perceived ease of use. To answer RQ10 and RQ11, I performed descriptive analysis and ran a one-sample t-test on ARCS constructs to measure the platform's overall motivational appeal across four dimensions of motivation (attention, relevance, confidence, and satisfaction).

To answer RQ12 and RQ13, I calculated the number of EEG files stored on the Sans Tracas server. I also cross-referenced each file's participant ID with the participant ID entered in the post-study survey to calculate the error rate and to check the number of participants whose data was not transmitted or stored on the Sans Tracas server. To answer RQ14, I calculated the number of participants that required external help to complete an EEG experiment. I also calculated the number of participants that needed to use any additional software or hardware to help them complete an EEG experiment. To answer RQ15, I calculated the number of participants that used the platform on a laptop or desktop compared to those that used it on smartphones and tablets. I also calculated the participant demographics based on the operating system they used to access the platform. Additionally, I collected and analyzed qualitative data regarding the platform's behaviour across different types of devices

Finally, to answer RQ16, I performed EEG data analysis on the participants' EEG data stored in the Sans Tracas server. I used MATLAB and EEGLAB for my EEG data analysis. The EEG data analysis was only performed on the EEG data obtained from the Visual N170 experiment. We selected the Visual N170 experiment for EEG data analysis as the Visual N170 experiment is believed to be a standard amongst the behavioural neuroscience community. It is believed that if a platform can run the Visual N170 experiment correctly, then it would be able to run other experiments correctly too. I checked the EEG data quality by splitting the data into epochs and looked for ERPs related to the face and house stimuli.

Moreover, to analyze the qualitative data, I first transcribed all the interviews. Afterwards, I extracted comments on different features of the platform and participants' views regarding EEG and BCI research. After that, I performed an inductive thematic analysis [210] on the overall survey comments and the interview transcriptions. While performing thematic analysis, I reviewed each comment by reading and rereading them and then generating the initial codes by clustering similar comments together to form a theme in an iterative manner.

CHAPTER 5 RESULTS

In this chapter, I present the results from both quantitative and qualitative evaluations of Sans Tracas. Specifically, in the subsections, I present the results from the quantitative data analysis of the pilot study data and the quantitative and qualitative data analysis of the main study data. I also present the results from the EEG data analysis of the participants' EEG data obtained during the main study.

5.1 Results of the Pilot Study

After conducting the pilot study with seven participants who were HCI researchers from the Persuasive Computing Lab and other Dalhousie University students, I prepared the survey data for analysis. All participants were able to complete at least one EEG experiment (Visual N170) from start to finish, on their own, without any external help. All participants could complete the experiment without needing additional software or hardware. The platform was accessed on six different Windows devices, one Mac device, and one Android device. The participants accessing the platform via more than one device did not observe a significant difference in its functionalities across device types. In the descriptive questions about their experience with the platform, four participants mentioned that they felt tthe platform was "intuitive and exciting", whereas three participants described the platform as "straightforward and easy to use".

The average SUS score of the platform was 81.07 (SD = 17.96), which is above (in the top 10%) the average of 68 obtained from 500 SUS studies [211]. Figure 5.1 shows average scores for the Perceived Usefulness and Perceived Ease of Use scales, both of which were conducted on a 7-point Likert scale. All calculated average scores for Perceived Usefulness and Perceived Ease of Use were above the neutral value of four (4). For the ARCS motivational appeal model, the results indicate that all average scores for the individual constructs of the model were above a neutral rating of three (3) on a 5-point Likert scale, as shown in Figure 5.2. Table 5.1 shows the one-sample t-test results for all the scales used in the survey, with the p-values indicating that all four scales have ratings that differ significantly from a neutral score ($p < 0.05$).

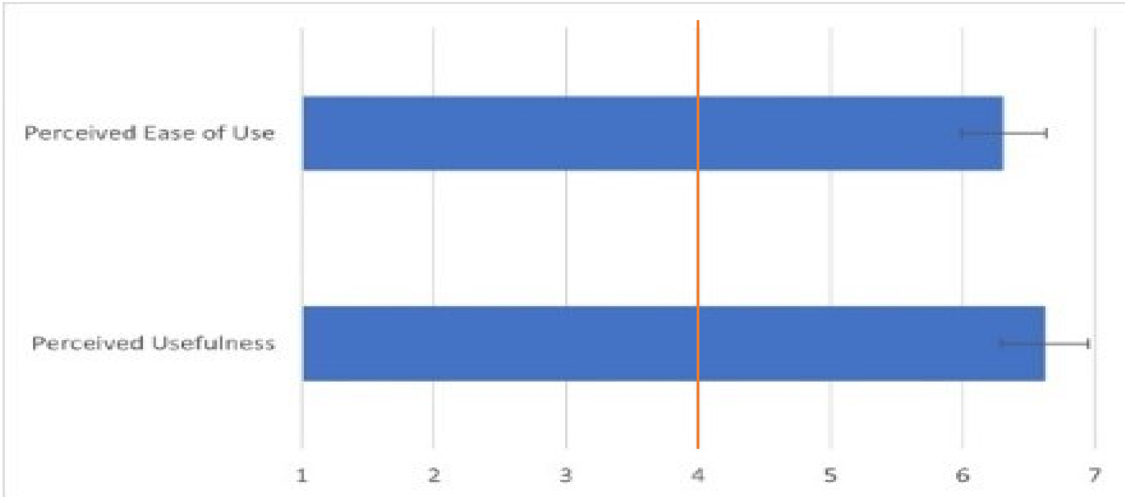


Figure 5.1: Bar charts showing the average scores for Perceived Usefulness and Perceived Ease of use on a 7-point Likert scale, with the neutral line of 4

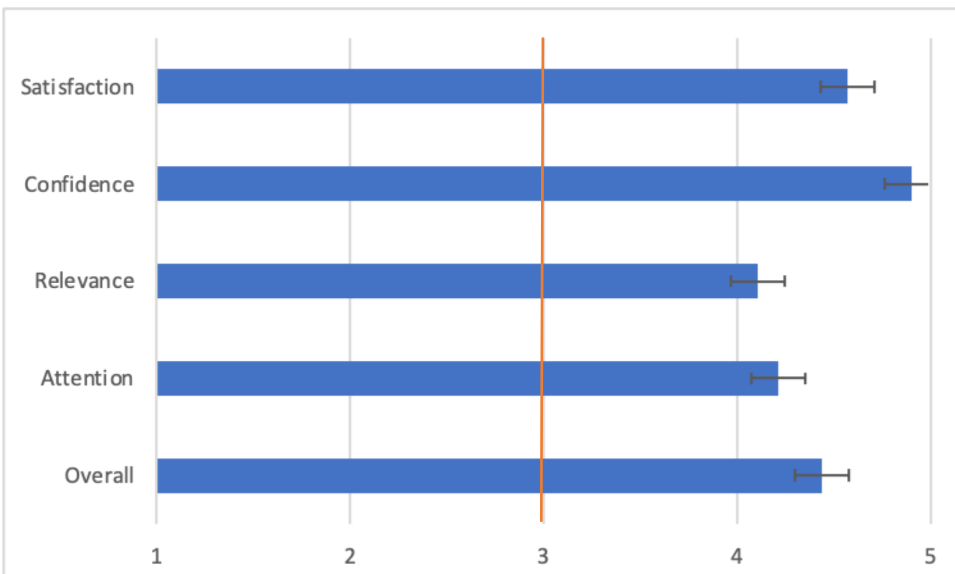


Figure 5.2: Bar charts showing the average scores of the overall motivational appeal and its constructs on a 5-point Likert scale, with the neutral line of 3

Table 5.1: Mean, standard deviation (SD), and one-sample t-test results for the four scales used in the pilot study survey

N = 7	**Descriptive Statistics**		**One-Sample t-test**		
Measures	**M**	**SD**	**t**	**df**	**p**
System Usability Scale (SUS) (Scored out of 100)	81.07	17.96	4.577	6	0.004

Perceived Usefulness (Scored on a 7-point Likert scale)	6.62	0.39	17.614	6	<0.001
Perceived Ease of Use (Scored on a 7-point Likert scale)	6.31	0.63	9.636	6	<0.001
ARCS' Motivation Scale (Scored on a 5-point Likert scale)	4.44	0.50	7.597	6	<0.001

5.2 Main Study Results: Overall Attitude, Knowledge, and Interest for EEG and BCI Research

Going forward, all the results discussed in this chapter, are obtained from the main study.

In the pre-study survey, participants were asked different questions regarding their attitude, knowledge, and interest in general EEG and BCI research. This section presents the results of those questions to understand the participants' overall attitude, knowledge, and interest in EEG and BCI research.

When asked during the pre-study survey how comfortable they were using a device that measured their brain activity, 21 (36%) participants mentioned being neutral about it, 14 (24%) participants felt comfortable with it, compared to 15 (26%) participants felt very comfortable. In contrast, 3 (5%) participants were uncomfortable with it, compared to 5 (9%) participants that were very uncomfortable.

When asked how familiar they were with electroencephalography (EEG), 16 (28%) participants mentioned being neutral about it, 8 (14%) participants were familiar with it, compared to 5 (8%) participants who were very familiar with EEG. Whereas 14 (24%) participants were unfamiliar with it, compared to 15 (26%) participants that were very unfamiliar with EEG.

When asked how comfortable they were with the idea of using a web application that uses brain activity, 19 (33%) participants mentioned being neutral about it, and 17 (29%) participants felt comfortable with it, compared to 13 (22%) participants who felt very comfortable. In comparison, 5 (9%) participants were uncomfortable with it, compared to 4 (7%) participants that were very uncomfortable.

When asked how interested they were in learning more about EEG or Brain-computer-interface research, 13 (22%) participants mentioned being neutral about it, and 22 (38%) participants were interested in it, compared to 23 (40%) participants who were very interested in it. Thus, it can be said that all participants were at least somewhat interested in learning more about EEG or BCI research.

When asked how familiar they were with BCI concepts, 19 (33%) participants mentioned being neutral about it, 9 (15%) participants were familiar with it, compared to 4 (7%) participants who were very familiar with BCI concepts. Whereas 12 (21%) participants were unfamiliar with it, compared to 14 (24%) participants that were very unfamiliar with BCI concepts.

When asked how trusting they were of general BCI research, 19 (32%) participants mentioned being neutral about it, 21 (36%) participants were trusting, compared to 12 (21%) participants who were very trusting of general BCI research. Whereas 5 (9%) participants had little trust, compared to 1 (2%) participant who had no trust at all in general BCI research.

When asked how accepting they were of general BCI research, 19 (33%) participants mentioned being neutral about it, 24 (41%) participants were accepting of it, compared to 15 (26%) participants who were very accepting of it. Thus, it can be said that all participants were at least somewhat accepting of general BCI research.

When asked how experienced they were with EEG studies, 19 (33%) participants mentioned being neutral about it, and 5 (9%) participants were experienced with it, compared to 2 (3%) participants who were very experienced with EEG studies. Whereas 18 (31%) participants were unexperienced with it, compared to 14 (24%) participants that were very unexperienced with EEG studies.

To summarize, most of the participants were neutral to very comfortable about using a device that measures their brain activity, neutral to very unfamiliar with EEG, neutral to very comfortable using a web application that uses brain activity, very interested to neutral in learning more about EEG and BCI research, neutral to very unfamiliar with BCI concepts, neutral to trusting in general BCI research, neutral to accepting of general BCI research, and neutral to very unexperienced with EEG studies. This shows that most of the participants are novice to EEG. Since the target audience for the Sans Tracas platform are EEG beginners, the majority of the study participants being novice to EEG is a good thing as this will help get some valuable feedback and evaluate the platform from the perspective of a completely new user.

5.3 Effectiveness and Efficiency of Sans Tracas for Conducting an EEG Experiment

To answer ***RQ1***: *"How effective is Sans Tracas with respect to using it to conduct an EEG experiment?",* I calculated the number of participants that were able to conduct at least one EEG experiment using Sans Tracas and the Muse. All 55 participants were able to conduct at least one EEG experiment using Sans Tracas and the Muse. Thus, the task completion rate of the participants with their given task of having to conduct an EEG experiment using Sans Tracas was 100%.

To answer ***RQ2***: *"How efficient is Sans Tracas with respect to enabling the user to independently conduct an EEG experiment and help them learn how the system works?",* I calculated the number of times each participant had to retry before successfully connecting to the Muse. Figure 5.3 shows the number of trials each participant took to connect the Muse with Sans Tracas. The average number of trials to connect the Muse with Sans Tracas was 2.55 (SD = 3.42). The average time taken by the participants to complete the entire study was 17 minutes, with a standard deviation of 4 minutes. In comparison, the EEG device setup time in-lab studies can be anywhere from 5 minutes to 2 hours based on the number of trials, number and the type of electrodes [212], [213]. The average setup time is about 20 minutes [214].

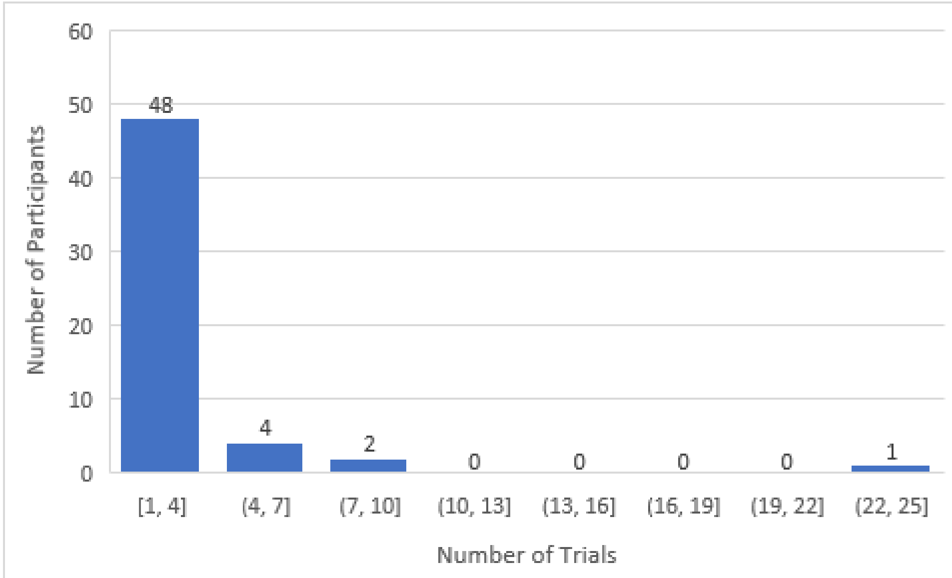


Figure 5.3: Number of Trials to connect the Muse with Sans Tracas

5.4 Sans Tracas Overall capabilities and Functionalities

The following subsections will present the results of the different capabilities and functionalities of Sans Tracas, such as recording and storing EEG data, being independent and genuinely cross-platform tested during the main study.

5.4.1 Sans Tracas' Capability to Record, Transmit, and Store EEG Data

To answer ***RQ12***: *"Can Sans Tracas record and transmit accurate EEG data while running a natively designed or integrated EEG experiment?"* and ***RQ13***: *"Is the EEG data obtained from Sans Tracas transferred and stored securely?",* I calculated the number of EEG files stored on the Sans Tracas server. At the end of the study, there were 63 EEG files stored on the secure Sans Tracas server as many participants chose to perform multiple experiments. Thus, I cross-referenced each file's participant ID with the participant ID entered in the post-study survey, which showed that all 55 participants had performed the Visual N170 experiment, resulting in an error rate of 0. Thus, all participants' data was transmitted and stored on the Sans Tracas server.

Additionally, 8 participants chose to perform other experiments too (6 participants performed the Face XAB experiment and 2 participants performed the resting state experiment) after completing the Visual N170 experiment. However, as the results of those experiments were not included in the scope of the study, those files were not considered for EEG data analysis. However, this shows that Sans Tracas could capture participants' interest and made them perform additional experiments on their own.

Moreover, in the post-study survey, I asked the participants if they were able to download their EEG data at the end of the experiment. 49 (89%) participants said that they were able to download their EEG data at the end of the experiment, whereas only 6 (11%) participants were not able to download their EEG data.

Out of the 6 participants who did not download their EEG data, I further asked if they saw the option to download their EEG data but chose not to. Four participants (67%) said they saw the download EEG data button but chose not to use it. Whereas 2 participants (33%) did not see the download EEG data button.

Furthermore, to validate the choice of EEG headset, I asked the participants whether they had any issues with the Muse. 50 (91%) participants did not face any issues with the Muse EEG headset. In contrast, only 5 participants (9%) faced some issues with the Muse. Those issues included 'not fitting properly due to participant head size', 'initial connection issues', and 'sensor issues with the temporal sensors (behind-ear)'.

5.4.2 Sans Tracas' Capability to Run EEG Experiments Without any Additional Hardware or Software

To answer ***RQ14****: "Can Sans Tracas independently and effectively run an EEG experiment without needing the user to install any other software or hardware add-ons, dongles, or accessories?",* I asked the participants in the post-study survey, if they required any external guidance or help while participating in the EEG experiment. I calculated the number of participants that required external help to complete an EEG experiment. Fifty-three participants (96%) mentioned that they did not require any external help and were able to do everything on their own. Only 2 (4%) participants said they required external help. Out of the 2 participants, one participant took help from their roommate for adequately fitting the Muse headset on their head, and the other participant contacted me via email for help, as they faced initial connection issues with the Muse.

I also calculated the number of participants that needed to use any additional software or hardware to help them complete an EEG experiment. None of the 55 participants needed to use any additional software or hardware to help them complete an EEG experiment, and all of them were able to do it independently. Thus, resulting in a completion rate of 100%.

5.4.3 Sans Tracas' Capability to be Genuinely Cross-Platform

To answer ***RQ15****: "Is Sans Tracas genuinely cross-platform, and does it behave the same across devices?",* I asked the participants to select the type of device they had used to access the platform. I calculated the number of participants that used the platform on a laptop or desktop compared to those that used it on smartphones and tablets. 45 (82%) participants used their personal or a work computer to access Sans Tracas compared to 9 (16%) participants who used their smartphones and only 1 (2%) participant who used their tablet. Even though they were using different platforms, all participants were able to successfully complete the experiments using Sans Tracas.

I also calculated the participant demographics based on the operating system they used to access the platform. I asked the participants to indicate the operating system they used to access the platform. 37 (67%) participants used the Windows operating system, compared to 8 (15%) participants who used MacOS. Whereas when it comes to smartphones or tablets, 8 (15%) participants used Android, compared to only 2 (3%) participants that used iOS or iPadOS. Despite the different types of devices and operating systems used by participants to access Sans Tracas, no participant faced any issue because of the operating system or device type. Thus, implying that an operating system or device type has no significant impact on the performance of Sans Tracas.

On the contrary, when asked what type of device they would prefer to access Sans Tracas in the future, 39 (71%) participants responded that they would prefer to use a desktop or a laptop, compared to 14 (25%) participants who would prefer to use a smartphone, and only 2 (4%) participants would prefer to use a tablet to access Sans Tracas in the future.

Additionally, when participants were asked to rank the different device types based on their preference, for accessing Sans Tracas in the future, 37 participants had a personal or a work computer as the most preferred device type. Compared to 11 participants who had the smartphone as their most preferred device type and 6 participants who had the tablet as their most preferred device type. The ranking for each device type, along with their least, most, and neutral preference count, is shown in Figure 5.4.

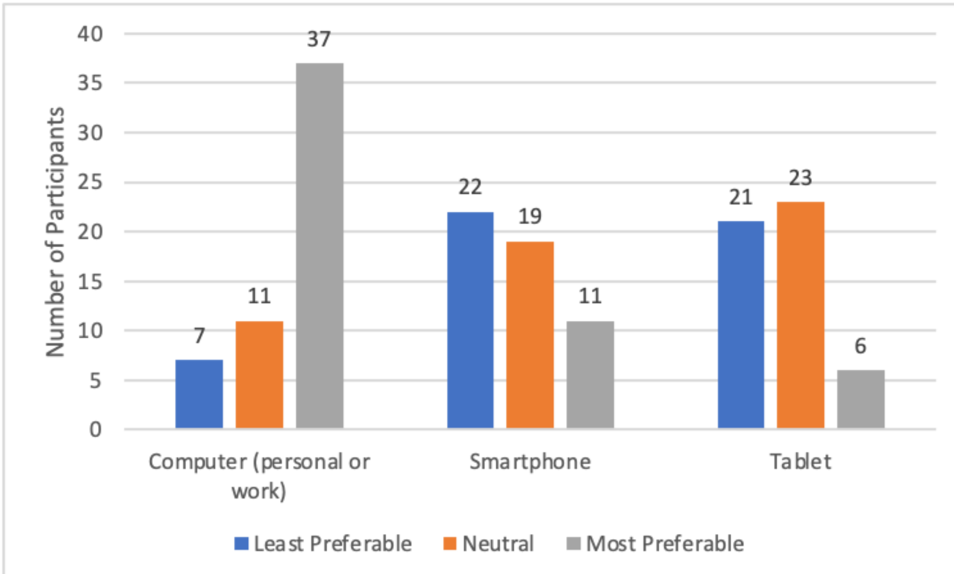


Figure 5.4: Device Type based on Participants' Preference for accessing Sans Tracas

5.5 Overall Technical Level of Expertise

In the post-study survey, I asked participants different questions regarding their technical knowledge and level of expertise regarding different factors such as computer programming, EEG, and the Muse headset. This section presents the results of those questions to understand the participants' overall technical level of expertise.

When asked to indicate their level of expertise with regards to computer programming and technical knowledge, 7 (12%) participants self-identified as a beginner. Compared to 35 (64%) participants who self-identified as an intermediate and 13 (24%) participants who self-identified as an expert.

However, when asked to indicate their level of expertise with regard to using the Muse EEG headset, the majority of the participants, 50 (91%), self-identified as a beginner. Only 3 (5%) participants self-identified as intermediate, and only 2 (4%) participants self-identified as experts. Thus, even though most participants were either intermediate or an expert in programming and technical knowledge, most of them were absolute beginners when it came to using the Muse EEG headset.

Participants were also asked to rank their technical programming knowledge on a scale of 1 to 10, with 1 being the lowest and 10 being the highest. Figure 5.5 shows how each participant ranked themselves based on their technical knowledge. The average rating was 6.89 (SD = 2.24). It can also be seen that 3 participants rated their technical knowledge 10 (highest), and 3 participants rated their technical knowledge 1 (lowest). However, the median rating was 8.

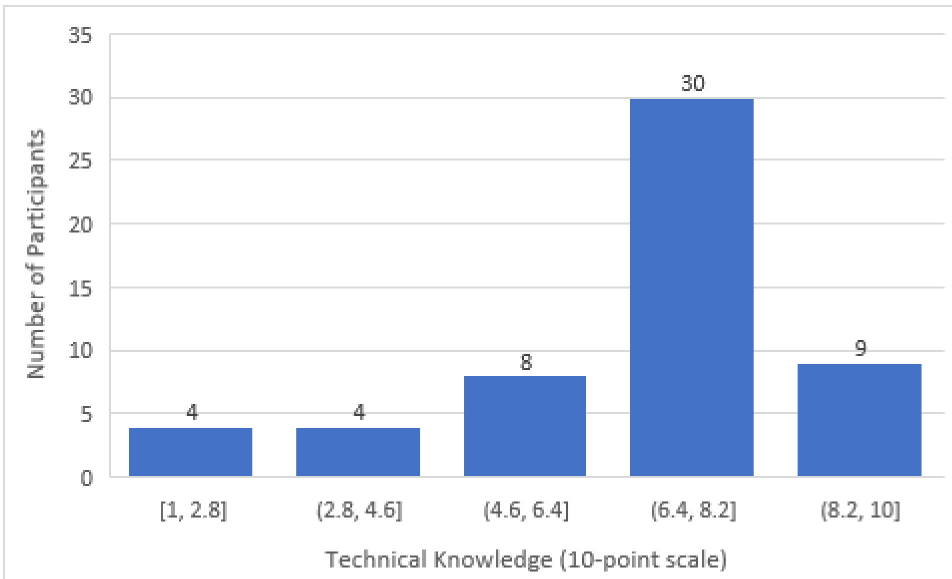


Figure 5.5: Technical Programming Knowledge of Participants on a scale from 1 (lowest) to 10 (highest)

5.6 Sans Tracas Overall Motivational Appeal

To answer ***RQ10***: *"How effective is Sans Tracas in generating interest for EEG and BCI research in users?"* and ***RQ11***: *"How effective is Sans Tracas with respect to motivational appeal?"*, a one-sample t-test was conducted on the ARCS constructs to measure the platform's overall motivational appeal across four dimensions of motivation (attention, relevance, confidence, and satisfaction). The ARCS constructs were rated on a 5-point Likert scale; thus, I compared the data with a neutral rating of 3. In general, the results of the One-Sample t-test show that Sans Tracas is effective with respect to the motivational appeal; the overall motivational rating is significant, $t(54) = 13.11$, $p < 0.001$. In addition, the results show that all four constructs of the ARCS motivational model are significant ($p < 0.001$), see Table 5.2 and Figure 5.6.

Table 5.2: One-sample t-test values for Motivational Appeal (ARCS)

N = 55	**Descriptive Statistics**			**One-sample t-test**		
Motivational Dimensions	**Mean**	**SD**	**MD**	**t**	***df***	***p***
Attention	4.30	0.74	1.30	13.09	54	<0.001
Relevance	3.97	0.90	0.97	7.98	54	<0.001
Confidence	4.35	0.76	1.35	13.23	54	<0.001
Satisfactions	4.39	0.74	1.39	14.02	54	<0.001
Overall	4.23	0.69	1.23	13.11	54	<0.001

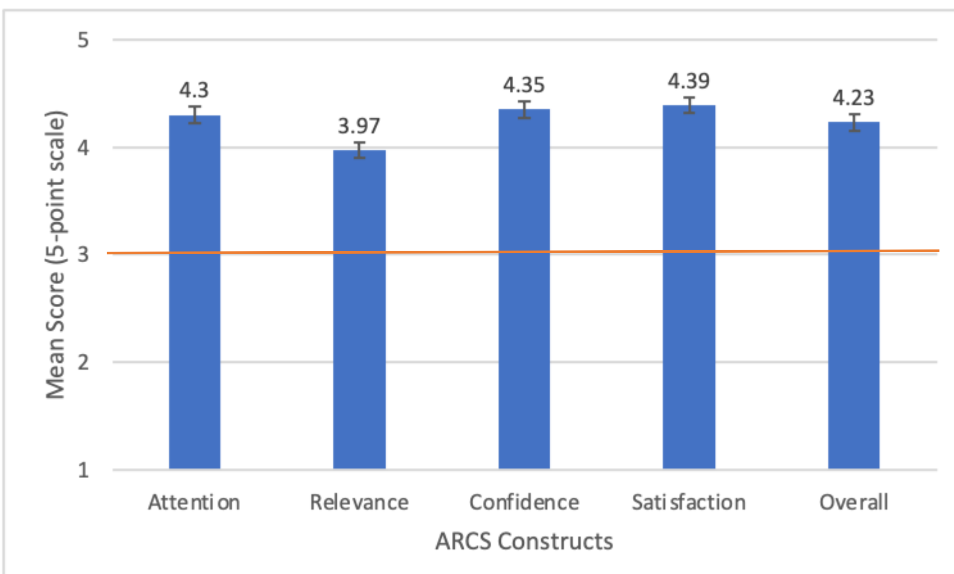


Figure 5.6: Mean Values of ARCS with a neutral line of 3

5.7 Sans Tracas Overall Perceived Usability

This section will present the results of the overall perceived usability of Sans Tracas derived from the System Usability Scale, Perceived Usefulness Scale, and Perceived Ease of Use Scale.

5.7.1 System Usability Scale Results

To answer ***RQ3***: *"How satisfied are the users after completing their task of conducting an EEG experiment using Sans Tracas and their overall experience with Sans Tracas?",* In the post-study survey, the System Usability Scale (SUS) was included in the post-study survey to evaluate the perceived usability of Sans Tracas. It was measured on a 5-point Likert scale. The final SUS score of Sans Tracas was 81.82, thus, placing Sans Tracas in the top 10% of the systems to ever conduct a SUS evaluation. The average SUS score obtained from 500 SUS studies [211], [215] is 68. Thus, for conducting the One-Sample t-test on the SUS, I used the test value of 68. The overall SUS score, as shown in Table 5.3, is significant, $t(54) = 5.24$, $p < 0.001$. Overall, Sans Tracas' SUS score can be deemed as "acceptable' according to Bangor et el. [216].

5.7.2 Perceived Usefulness Scale Results

To answer ***RQ4***: *How useful is Sans Tracas for conducting an online EEG experiment?* In the post-study survey, the Perceived Usefulness (PU) Scale was included to evaluate the perceived usefulness of Sans Tracas. It was measured on a 7-point Likert scale; thus, I compared the data using a One-sample t-test with a neutral rating of 4. In general, the results of the One-sample t-test show that Sans Tracas is perceived to be useful for conducting an online EEG experiment. The overall PU rating is significant, $t(54) = 12.15$, $p<0.001$. The average PU rating is shown in Table 5.3 and Figure 5.24.

5.7.3 Perceived Ease of Use Scale Results

To answer ***RQ5***: *How easy is it to use Sans Tracas for conducting an EEG experiment?* In the post-study survey, the Perceived Ease of Use (PEOU) Scale was included to evaluate the perceived ease of use of Sans Tracas. It was measured on a 7-point Likert scale; thus, I compared the data using a One-sample t-test with a neutral rating of 4. In general, the results of the One-sample t-test show that Sans Tracas is perceived to be easy to use for conducting an online EEG experiment. The overall PEOU rating is significant, t(54) = 12.57, p<0.001. The average PEOU rating is shown in Table 5.3 and Figure 5.7.

Table 5.3: One-sample t-test values for SUS, PU, and PEOU Scales

N = 55	**Descriptive Statistics**			**One-sample t-test**		
Measures	**Mean**	**SD**	**MD**	**t**	**df**	**p**
System Usability Scale	81.82	19.56	13.82	5.24	54	<0.001
Perceived Usefulness	6.05	1.24	2.05	12.15	54	<0.001
Perceived Ease of Use	6.08	1.23	2.08	12.57	54	<0.001

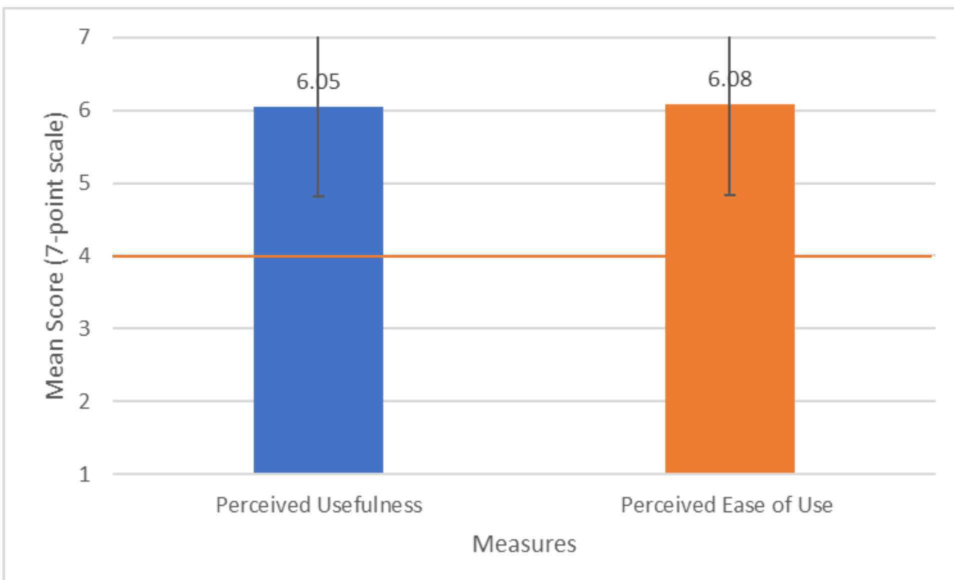


Figure 5.7: Mean Values of PU and PEOU scales with a neutral line of 4

5.8 Qualitative Analysis

After the post-study survey, I conducted one-on-one semi-structured interviews (Appendix D) to gain further insight on participants' experience with the Sans Tracas. A total of 11 interviews were conducted wherein 10 participants participated in the end-user-focused study, and 1 participant participated in both the end-user-focused study and the researcher-focused study. The interviews were optional and were audio recorded with the participants' consent. The purpose of the interview was to collect qualitative data about the participants' opinions, perceptions, and reviews about Sans Tracas, and their overall experience with the platform. The participants were asked different questions to get more insights regarding their experience, knowledge, reactions, thoughts, criticisms, and feedback for improvement and suggestions. I transcribed the interview data and analyzed them according to the questions asked to the participants.

I then conducted an inductive thematic analysis of the interview transcriptions. Braun and Clarke's [210] six-phase framework was followed for the thematic analysis. The interviews were openly coded as there were no predefined codes. Thus, the codes were expanded, developed, and modified as new themes emerged. The codes were developed after reading and re-reading the interview transcripts. An affinity diagram as shown in Figure 5.8, was used to organize the codes, cluster similar comments together, and generate themes. Initially, few themes overlapped each other and were thus combined into a larger theme. In the end, ten main themes emerged from the thematic analysis, as shown in Table 5.4, with a few other sub-themes.

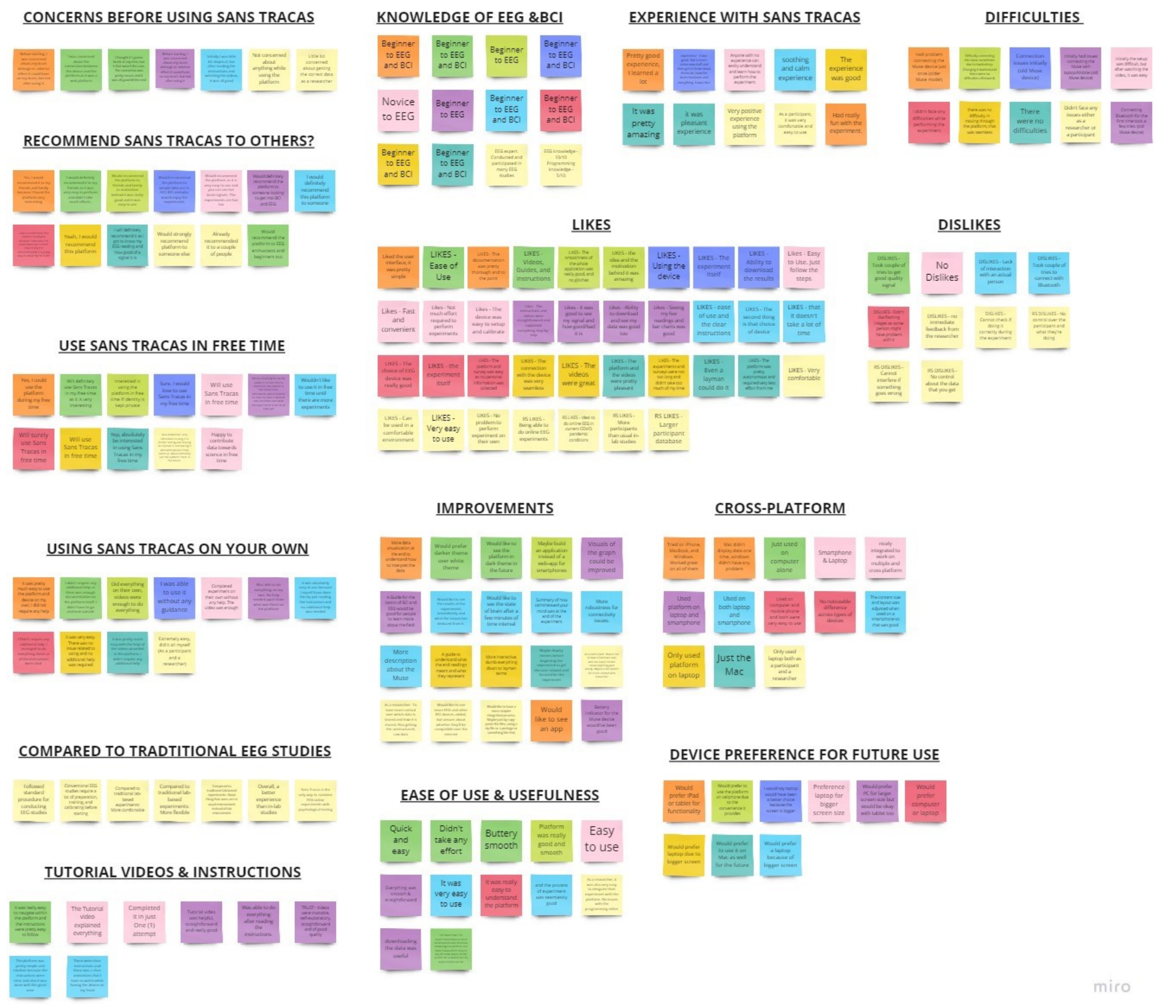


Figure 5.8: Affinity Diagram for Thematic Analysis of the Interview Data

Table 5.4: Main Themes obtained from the Affinity Diagram

<u>**Themes for Qualitative Analysis**</u>
Knowledge of EEG and BCI
Concerns Before using Sans Tracas
Overall Experience with Sans Tracas
Likes and Dislikes
Cross-Platform
Ease of Use and Usefulness
Improvements
Recommend Sans Tracas to Others

Using Sans Tracas on your Own
Compared to Traditional EEG Studies

5.8.1 Knowledge of EEG and BCI

When asked about their knowledge and experience with respect to EEG and BCI and participating in EEG studies, 10 out of 11 participants mentioned that they were novice EEG users. Participating in an EEG study was a first for all 10 participants, and for a few participants, this was the first time they had heard about EEG. However, the 11th participant was an EEG expert and had been conducting and participating in EEG studies for decades. They evaluated the platform from both an end-user and a researcher perspective as they participated in end-user-focused and researcher-focused studies. Almost all participants being EEG beginners was a good thing as they were the target audience of the end-user side of Sans Tracas. They were the ideal users, and their feedback on Sans Tracas is paramount in making more people interested in EEG and BCI research by tailoring Sans Tracas to an EEG beginner's needs. Additionally, having the platform evaluated by an EEG expert from an end-user perspective was extremely helpful in determining how the researchers would want Sans Tracas to behave with their study participants and what improvements are needed to improve the platform. Table 5.5 shows some of the sample comments from the participants.

Table 5.5: Sample comments for the theme Knowledge of EEG and BCI

Sample Comments
*"I think this was my **first experience,** I haven't participated in any EEG experiment before, so **I'm pretty new to this as a user**."* – P2 *"I haven't participated in any EEG experiments before, and this was **my first time** and it was **really exciting** to learn about some new stuffs."* – P4 *"I've never participated in an EEG experiment before. This was my **first experiment**. **Very easy** and I really liked it."* – P7 *"I'm doing EEG studies myself and I have participated as a participant as well in **many EEG studies**."* – P11

5.8.2 Concerns Before using Sans Tracas

The thematic analysis was performed on participants' comments regarding any concerns before starting the study to understand the concerns participants would have before using a device that would record their brain activity. Three sub-themes emerged based on pariticpants’ concerns:

(1) Brain Damage - Two participants mentioned that they were concerned about the Bluetooth connection over a web platform, and others were concerned about brain damage and the side effects. However, their concerns were pacified after watching the tutorial videos and reading the instructions. This shows that Sans Tracas can change people’s opinion about EEG and BCI research and make them more trustworthy of it. This is in-line with the results of the ARCS motivational scale.

(2) Connection Between the Device and the Platform - One participant was also concerned whether the connection between the device and the platform would hold up and whether it would last during the entirety of the experiment. However, since Sans Tracas is robust, it did not face any connection breaks and was secure.

(3) Getting Correct Data – As a researcher, the participant was concerned about getting the correct data. However, they were not concerned about anything as a participant. Another participant was also skeptical before beginning the study, but after reading the instructions and watching the video, they were confident about the platform.

Table 5.6 shows some of the sample comments from the participants illustrating the concerns they had before using Sans Tracas.

Table 5.6: Sample comments for the theme Concerns Before using Sans Tracas

Sample Comments
Brain Damage *“Before starting, I was concerned about any* ***brain damage or adverse effect*** *it could have on my brain, but* ***not after using*** *it.”* – P1

Connection Between the Device and the Platform

"I was concerned about the ***connection between the device and the platform*** *as it was a web platform..."* – P3

"...I thought it's gonna break at any time, but it that wasn't the case. The ***connection was pretty secure*** *and it was all good till the end."* – P3

Getting Correct Data

"Initially I was ***little bit skeptical****, but after reading the instructions and watching the videos, it was all good."* – P5

"...Little bit concerned about ***getting the correct data as a researcher****."* – P11

*"****Not concerned*** *about anything while using the platform..."* – P11

5.8.3 Overall Experience with Sans Tracas

Regarding their overall experience with Sans Tracas, three sub-themes emerged:

(1) Learning – Three participants mentioned learning new things about the brain and its functions.

(2) Positives – Almost all participants had largely positive experience with the platform. Furthermore, their reasons for it can be further classified into the following two categories:

   a. Comfortable, Fun, and Pleasant - Six participants mentioned it was a tremendously positive, unique, and fun experience.

   b. Soothing and Calm – Three participants also mentioned that it was soothing and calm. The first three themes align with the SUS results showing the platform's high usability.

(3) Difficulties – Very few participants faced any difficulties with the Sans Tracas platform. The difficulties can be further classified into following two categories:

a. Connection Issues - Four participants faced some issues with the Muse connections, which could be because they used the older models of the Muse EEG headset.

b. None – However, most (six) participants mentioned they did not face any difficulties while using the platform.

Table 5.7 shows some of the sample comments from the participants related to their overall experience of how the system was generally positive, easy and comfortable.

Table 5.7: Sample comments for the theme Overall Experience with Sans Tracas

Sample Comments
<u>Learning</u> *"**Pretty good** experience, I **learned a lot**."* – P1 *"…It was **good**. Got to **learn some new stuff** and then got to **know about the brain**, how the brain functions and everything. **It was nice**."* – P3 *"Anyone with **no experience** can **easily understand** and **learn** how to perform the experiment."* – P4 **<u>Positives:</u>** - **<u>Comfortable, Fun, and Pleasant</u>** *"Had **really fun** with the experiment."* – P6 *"The experience was **good**."* – P7 *"It was pretty amazing… it was pleasant experience"* – P9 *"Very **positive experience** using the platform..."* – P11 *"…As a participant, it was very **comfortable and easy to use**."* – P11 - **<u>Soothing and Calm</u>** *"**soothing** and **calm** experience"* – P2 *"It felt very **soothing** and I had a sense of **calmness** while doing experiment"* – P2 **<u>Difficulties:</u>**

- **<u>Connection Issues</u>**

  *"**Connection issues** initially with old Muse device."* – P3

  *"Initially the **setup** was difficult, but **after watching the video**, it was **easy**."* – P4

  *"**Connecting Bluetooth** for the **first time** took a few tries."* – P8

- **<u>None</u>**

  *"There was **no difficulty** in moving through the platform, that was **seamless**."* – P2

  *"**Didn't face any issues** either as a **researcher** or a **participant**."* – P11

  *"I **didn't face any difficulties** while performing the experiment."* – P4

5.8.4 Likes and Dislikes

Regarding participants' likes and dislikes, two sub-themes emerged:

(1) Likes – The reasons for participants liking Sans Tracas and its features can be classified into the following six categories:

a. Seeing Live Readings – Four participants mentioned that they liked how interactive the platform was as they enjoyed seeing their live brain signals.

b. Videos, Guides, and Instructions – Six participants said they liked the videos, guides, and instructions as they were simple, easy, clear, and straightforward.

c. Easy Setup and Use – Nine participants also liked the platform's ease of use as they mentioned the platform being easy to set up, easy to use, and easy to understand, even for a layman.

d. Downloading EEG Data – Four participants liked the ability to download their EEG data as it gave them a sense of ownership over their data.

e. Being Comfortable and Requiring Minimal Efforts – Six participants liked the comfortability of performing experiments in their homes and the fact that the experiments themselves required minimal effort from them.

f. Doing Online EEG with Larger Participant Database – As a researcher, the participant mentioned that they liked doing EEG studies online as it allows for a more extensive participant database.

(2) Dislikes – The reasons for participants disliking Sans Tracas and its features can be classified into the following three categories:

a. Connection Issues – Two participants disliked the connection issues and mentioned that it took them a couple of tries for the initial setup.

b. No Interaction with Researchers for Immediate Feedback – As a researcher, a participant mentioned that they did not like the lack of control over participants as they could not check if the experiments were being performed correctly and thus could not interfere. As an end-user, a participant did not like the lack of control with an actual person.

c. Flashing Images – A participant mentioned that they did not like the flashing images in the experiment as it could be a problem for some people. Another participant mentioned that they had no dislikes.

Table 5.8 shows some of the sample comments from the participants about the various aspects of the system they liked and disliked.

Table 5.8: Sample comments for the theme Likes and Dislikes

Sample Comments
<u>**Likes:**</u> - <u>**Seeing Live Readings:**</u> *"**Seeing my live readings and bar charts** was good."* – P1 *"It was good to **see my signal** and **how good/bad it is**."* – P3 "*Liked the **user interface**, it was pretty **simple***." – P4 - <u>**Videos, Guides, and Instructions:**</u> *"The connection with the device was **very seamless**…. The **videos were great**… the platform and survey was **easy** as **no personal information was collected**."* –

P10

"…The ***documentation*** *was* ***pretty thorough*** *and* ***to the point****."* – P4

"***Ease of use*** *and the* ***clear instructions***" – P5

"*The* ***instructions and videos*** *were* ***straightforward*** *and* ***explained everything step-by-step***" – P3

- **Easy Setup and Use:**

  *"**Easy to Use**. Just follow the steps…* ***Fast and convenient****… … The device was* ***easy to setup and calibrate****."* – P4

  "The ***smoothness of the whole application*** *was really good, and* ***no glitches****… the* ***idea and the motivation*** *behind it was* ***amazing****."* – P1

  "*The platform and the videos were* ***pretty pleasant****…* ***Even a layman could do it"*** – P7

  "The ***ease of use and the clear instructions****…. The second thing is that* ***choice of device****… that it doesn't take a lot of time."* – P9

  *"**Very easy to use**… **No proble**m to perform experiment on their own"* – P11

- **Downloading EEG Data:**

  "Ability to ***download the results****."* – P1

  "*Ability to* ***download*** *and* ***see my data*** *was* ***good*** *too*" – P3

- **Being Comfortable and Requiring Minimal Efforts:**

  *"**Not much effort required** to perform experiments."* – P4

  "*The platform was* ***pretty autonomous*** *and required* ***very less effort*** *from me****" – P7***

  "***Very comfortable****... Can be used in a comfortable environment…"*- P11

- **Doing Online EEG with Larger Participant Database:**

  *"…**Being able to do online EEG experiments**…. **Ideal to do online EEG** in current COVID pandemic conditions… **More participants** than usual in-lab studies… **Larger participant database**"* – P11

<u>Dislikes:</u>

- **<u>Connection Issues</u>**

  *"Took **couple of tries** to get **good quality signal**."* – P6

  "*Took **couple of tries** to **connect with Bluetooth***" – P9

- **<u>No Interaction with Researchers for Immediate Feedback</u>**

  *"Lack of interaction with an **actual person**."* – P9

  *"…**No immediate feedback from the researcher**… **Cannot check** if doing it correctly during the experiment."* – P11

  *"…**No control over the participant** and what they're doing… **Cannot interfere** if something goes wrong… **No control about the data** that you get."* – P11

- **<u>Flashing Images</u>**

  *"Didn't like **flashing images** as some person might have problem with it."* – P10

  *"**No Dislikes**."* – P7

5.8.5 Cross-Platform

To determine if Sans Tracas is genuinely cross-platform, I asked the participants if they had used Sans Tracas on more than one device type and what their experience was like. Based on the thematic analysis of their comments, three sub-themes appeared:

(1) Multiple Device Type – Six participants used the platform on multiple device types. However, the participants who used it on more than one device did not see any noticeable difference in the functionalities of Sans Tracas and mentioned that it is well integrated for different device types. This is in line with the quantitative analysis results showing that Sans Tracas is genuinely cross-platform.

(2) Single Device Type – Five participants only used one device type.

(3) Preference for Future Use of Sans Tracas - Additionally, when asked about their preferred choice of a device type for using Sans Tracas in the future, seven

participants mentioned that they would use a laptop or desktop due to the larger screen size. Although, one participant did seem to prefer tablets and one participant even chose smartphones for their convenience.

Table 5.9 shows some of the sample comments from the participants.

Table 5.9: Sample comments for the theme Cross-Platform

Sample Comments
<u>**Multiple Device Type**</u> *"Tried on* ***iPhone, MacBook, and Windows****. Worked* ***great on all of them****… Mac* ***didn't display data one time****, windows* ***didn't have any problem****."* – P2 *"****Smartphone & Laptop****…* ***nicely integrated*** *to work on multiple and* ***cross platform****."* – P4 *"Used on* ***computer and mobile phone*** *and* ***both were very easy to use****…* ***No noticeable difference*** *across types of devices"* – P7 *"Used on* ***both laptop and smartphone****… The* ***content size and layout was adjusted*** *when used on a smartphone so that was good."* – P8 <u>**Single Device Type**</u> *"Just the* ***Mac****."* – P9 *"Only used* ***laptop*** *both as a participant and a researcher."* – P11 <u>**Preference for Future Use of Sans Tracas**</u> *"Would prefer* ***iPad*** *or* ***tablet*** *for* ***functionality****."* – P2 *"Preference* ***laptop*** *for* ***bigger screen size****."* – P4 *"Would prefer to use the platform on* ***cellphone*** *due to the* ***convenience*** *it provides."* – P5 *"Would prefer* ***PC*** *for* ***larger screen size*** *but would be okay with* ***tablet*** *too."* – P6

5.8.6 Ease of Use and Usefulness

To further investigate Sans Tracas' overall Perceived Ease of Use and Perceived Usefulness, thematic analysis was performed on participants' comments and based on it, the following four sub-themes emerged:

(1) Sans Tracas is Easy to Use - Nine participants mentioned that Sans Tracas is extremely easy to use.

(2) Sans Tracas is Easy to Understand – Four participants mentioned that the platform was easy to understand as it did not require any technical knowledge from them.

(3) Smooth and Straightforward – Seven participants mentioned that Sans Tracas is exceptionally smooth in its operation. All the instructions were clear, straightforward, and very easy to understand. The navigation among the different aspects of the platform was smooth

(4) Usefulness – The reasons for participants finding Sans Tracas and its features useful can be classified into the following two categories:

   a. Videos and Tutorials – Eight participants mentioned that the videos and instructions were very helpful in understanding the workings of the platform and learning about EEG and BCI.

   b. Downloading EEG Data – Four participants also mentioned that downloading the EEG data was useful as they could see their own data, which helped them trust the site more.

The findings from these themes align with the results of the PEOU and PU scales which had high scores for both. Table 5.10 shows some of the sample comments from the participants.

Table 5.10: Sample comments for the theme Ease of Use and Usefulness

Sample Comments
<u>**Sans Tracas is Easy to Use**</u> ***"Quick and easy"*** – P1

"It was ***very easy to use****."* – P9

"As a ***researcher****, it was also* ***very easy to integrate their experiment*** *with the platform.* ***No issues*** *with the* ***programming*** *either."* – P11

"It was ***really easy to navigate*** *within the."* – P1

Sans Tracas is Easy to Understand

*"****Didn't take any effort****"* – P1

"…I've heard that EEG experiments takes ***a lot of technicalities and technical knowledge to perform****, but Sans Tracas* ***didn't require any of it*** *and would be the* ***perfect for a newbie to EEG experiments*** *like me."* – P1

"It was ***really easy to understand*** *the platform."* – P10

"The platform was ***pretty simple and intuitive*** *because the* ***instructions were clear*** *and also it was done with the* ***great ease****…There were* ***clear instructions*** *and there was a* ***clear animations*** *that I have to watch while having the device on my head."* – P9

Smooth and Straightforward

*"****Buttery smooth****"* – P1

"Platform was really ***good and smooth****."* – P2

"Everything was ***smooth & straightforward****"* – P5

"And the process of ***experiment*** *was* ***seamlessly good****."* – P9

Usefulness:

- **Videos and Tutorials**

  "And the ***instructions were pretty easy to follow****."* – P1

  "The Tutorial video ***explained everything****…Completed it in just* ***One (1) attempt****."* – P4

  Tutorial video was ***helpful****,* ***straightforward*** *and* ***really good****…Was able to do everything* ***after reading the instructions****…. Videos were* ***trustable****,* ***self-explanatory****,* ***straightforward*** *and of* ***good quality****."* – P5

- **Downloading EEG Data**

*"**Downloading the data was useful**"* – P5

*"I found the **downloading EEG data part very useful as I could see what actually was collected from me** during the experiment."* – P7

5.8.7 Improvements

Regarding what improvements the participants would like to see in the future versions of Sans Tracas, the following four sub-themes emerged:

(1) More Visualization and Interpretation of Data – Three participants wanted more visualization with improved graphics, interactive charts, and more interpretation of what the downloaded data meant and how to understand it.

(2) Learning More About Brain State, EEG, BCI, and Muse – Six participants were also eager to learn more about their brain state during the experiment, general EEG and BCI, and the working and status of the Muse headset during the experiment.

(3) Add Other BCI devices and Feedback Loop with Researchers – From the researcher's perspective, most improvements were regarding adding more EEG devices, simplifying the integration process, and having more control over participants' screens and data during the study.

(4) Arbitrary – This sub-theme includes other random improvement ideas mentioned by five participants, such as building a smartphone application, darker themes, more robustness, and a more straightforward integration process.

This feedback was essential in understanding the users' needs beyond the scope of Sans Tracas' current functionalities. It also provided various ideas for improving Sans Tracas while keeping the users at the centre of its design process. Table 5.11 shows some of the sample comments from the participants.

Table 5.11: Sample comments for the theme Improvements

Sample Comments
More Visualization and Interpretation of Data *"**More data visualization** at the end to understand **how to interpret the data**."* – P1 *"Would like to see the **results** of the experiments **immediately** and what the researcher deduced from it."* – P5 *"**A guide** to **understand** what the end **readings** meant and what they **represent**...**More interactive**, dumb everything down to **layman terms**."* – P7 *"**Visuals of the graph** could be **improved**"* – P8 **Learning More About Brain State, EEG, BCI, and Muse** *"A **Guide** for the **basics of BCI and EEG** would be good for people to learn more about the field... **Battery indicator** for the Muse device would've been good."* – P4 *"Would like to see the **state of brain after a few minutes** of time interval...Summary of how calm/relaxed your mind was at the end of the experiment.... **More description** about the Muse."* – P5 **Add Other BCI devices and Feedback Loop with Researchers** *"As a participant, would like to have a **feedback loop with the experimenter** incase anything goes wrong. Maybe a **bot system** for **direct contact** with **researcher**... As a researcher, to have **more control** over **which data is stored** and **how it is stored**. Also getting the **unstructured, raw data**..."* – P11 *"... Would like to see **more EEG and other BCI devices** added, but unsure about whether they'll be **compatible over the internet**"* – P11 **Arbitrary** *"Would prefer **darker theme** over white theme... Would like to see the platform in **dark theme** in the future."* – P2 *"Maybe **build an application** instead of a web-app **for smartphones**."* – P3 *"**More robustness** for connectivity issues."* – P5 *"Would like to have a m**ore simpler integration process**. Maybe just by **copy-paste the***

***files**, using a **zip file** or a **package** or something like that…"* – P11 *"Maybe **display memes before beginning** the experiment **to get the user relaxed** and **focused** for the experiment"* – P6

5.8.8 Recommend Sans Tracas to Others

To understand if participants will come back to Sans Tracas out of their own volition and spread the word about the platform, I conducted a thematic analysis of their comments, from which the following two sub-themes emerged:

(1) Recommend – The reasons for participants recommending Sans Tracas could be classified into the following two categories:

a. Easy to Use – All participants mentioned that they would recommend Sans Tracas to their friends, family, and other people they know. Five participants mentioned that they would recommend it because Sans Tracas is straightforward to use, fun, and extremely easy.

b. Interesting and Great for Beginners – In contrast, six other participants mentioned that they would recommend Sans Tracas because it is fascinating and a great learning tool for EEG beginners. This shows that participants had a largely positive experience with Sans Tracas and consider it a great tool to get started with EEG and would like other people to have such a fun experience too.

(2) Future Use in Free Time – Nine participants also mentioned that they would be willing to use Sans Tracas again without any compensation and to contribute their data towards science in their free time.

Although, one participant said that they would not use Sans Tracas in their free time until more experiments were added, and another participant mentioned that they would only use it in their free time if their privacy were maintained and identity was kept private, just like in the evaluation study. This shows participants would like to use it again to learn more about EEG and BCI and contribute their data towards science by participating in more EEG studies. Table 5.12 shows some of the sample comments from the participants.

Table 5.12: Sample comments for the theme Recommend Sans Tracas to Others

Sample Comments
Recommend: - **Because it is Easy to Use** *“I would **definitely recommend** it to my **friends** as it was very **easy to perform** and didn't take much efforts.”* – P2 *“Would **recommend** the platform to **friends and family** as **motivation** behind it was **really good** and it was **easy to use**.”* – P3 *“Would **recommend** the platform as it is very **easy to use** and you can see live **brain signals**. The experiments are **fun** too.”* – P5 *“I would **recommend** this platform to **anyone** because it was **easier to understand** and it didn't require any pre instructions and it is a **new way of analyzing the brain**.”* – P10 - **Interesting and Great for Beginners** *“Yes, **I would recommend** it to my **friends and family** because I found the platform **very interesting**”* – P1 *“Would **recommend** the platform to **people who are in HCI, BCI** and who would **enjoy the experiments**”* – P4 *“Would **definitely recommend** the platform to someone **looking to get into BCI and EEG**.”* – P6 *" Would **recommend** the platform to **EEG enthusiasts and beginners** too.”* – P7 *“Would **strongly recommend** platform to someone else… **Already recommended** it to a **couple of people**.”* – P11 **Future Use in Free Time** *“**Yes**, I could use the platform during my free time.”* – P1 *“Will **definitely use** Sans Tracas in my free time as it is **very interesting**.”* – P2

*"**Interested** in using the platform in free time **if identity is kept private**"* – P3 *"Would be **willing to use** the platform in free time to **contribute the data** for a few initial times. Afterwards, would depend on **how my data is handled and processed** and what the experiment is, but as of now, yes."* – P6 *"As a **researcher**, **very interested** in using it in **further testing** and **helping to improve it**. **Comparing it with alternatives if they come up**. Would **definitely use** the platform more in the future."* – P11

5.8.9 Using Sans Tracas on your Own

To further investigate if Sans Tracas is genuinely independent, I performed a thematic analysis of participants' comments regarding using Sans Tracas independently. None of the participants required any external help, nor did they need to use any additional software or hardware to complete the experiments. The reasons for this were categorized into two sub-themes:

(1) Videos, Tutorials, Guides, and Documentation were Enough – Seven participants mentioned that they did not require any additional help because of the clear instructions of the guides and documentation. Additionally, they mentioned that the videos and tutorials were enough for them to understand everything.

(2) Easy to Use – Four participants mentioned that they did not require any additional help because Sans Tracas was easy to use, nothing was confusing or complicated, and thus, they were able to do everything on their own.

This shows that it was effortless to use Sans Tracas for conducting an online EEG experiment, even for someone who is new to EEG and BCI. Table 5.13 shows some of the sample comments from the participants.

Table 5.13: Sample comments for the theme Using Sans Tracas on your Own

Sample Comments
<u>Videos, Tutorials, Guides, and Documentation were Enough</u>
*"I **didn't require any additional help** as there was **enough documentation** on the*

platform itself. I didn't have to go and look outside." – P3 *"**Did everything on my own**, **videos were enough** to do everything."* – P4 *"Completed experiment **on my own without any help**. The **video was enough**."* – P6 **<u>Easy to Use</u>** *"It was pretty much **easy to us**e the platform and device **on my own**, I **did not require any help**."* – P1 *"it was **absolutely easy to use** because **I myself** have done this by just **reading the instruction** and **no additional help** was needed"* – P8 *"**Extremely easy**, did it all **myself**, as a **participant** and a **researcher**."* – P11

5.8.10 Compared to Traditional EEG Studies

To investigate how Sans Tracas differs from traditional in-lab EEG studies and how good or bad it is compared to them, I asked the participants with good to expert EEG knowledge to compare Sans Tracas with traditional EEG studies. I had only 1 participant with expert EEG knowledge, as the rest of them were EEG novices. This participant had been conducting and participating in EEG studies for decades. Their answer indicates that Sans Tracas is the only online platform running EEG studies. Additionally, for many reasons, such as being more comfortable, more affordable, easier to implement, and having a larger participant count. Table 5.14 shows some of the sample comments from the participants.

Table 5.14: Sample comments for the theme Compared to Traditional EEG Studies

Sample Comments
*"… I **Followed standard procedure** for conducting EEG studies…"* – P11 *"… **Conventional EEG studies** require a lot of **preparation, training, and calibrating before starting**..."* – P11 *"… **Sans Tracas is the only way to combine EEG online experiments with psychological testing**..."* – P11 *"… Compared to traditional lab-based experiments, it is **more comfortable**...* m***ore***

***flexible**… and it is a **good thing** that users are in **usual environment** instead of lab environment."* – P11

*"…Overall, a **better experience than in-lab studies**."* – P11

5.9 EEG Data Analysis

To answer ***RQ16:*** *"Is the EEG data obtained from Sans Tracas of good quality?",* EEG data analysis was conducted on the participants' EEG data collected during the study. The EEG data stored in the form of CSV files on the Sans Tracas served was downloaded on the lead researcher's local computer for analysis purposes. The server was only accessible via an FTP client, and it required two-factor authentication to access it. The downloaded CSV files were then converted to .set files as EEG data analysis is usually performed on .set files. Tools like MATLAB and EEGLAB were used for the EEG data analysis. After being converted to .set files, preprocessing techniques were used to filter out empty and NaN data. Then channel exclusion was performed wherein channels with 'channelVariability' more than 50 were excluded (i.e., the channels that were still noisy were removed). Afterwards, epoching was performed wherein face and house epochs were extracted. The epoch window was defined as 200 milliseconds before and 500 milliseconds after the stimuli presentation. The artifact thresholds for the epochs were set at + / - 80uV (i.e., trials with amplitude less than -80uV and greater than 80uV were rejected). The noisier epochs were then excluded based on this threshold. All approved epochs were then averaged to obtain the face and house ERPs as shown in Figure 5.9 and Figure 5.10. Afterwards, ERPs for all participants were averaged to get the group averaged ERPs as shown in Figure 5.11. As can be clearly seen in Figure 5.11, a negative potential is observed around the 250 milliseconds mark. This confirmed the Visual N170 experiment, and it shows that the EEG data obtained from Sans Tracas is of good quality, as we were able to identify the N170 potential from the EEG data obtained during the study. Table 5.15 further supports this claim by presenting the reported stats obtained during the EEG data analysis process. Finally, Figure 5.12 displays the entire EEG data analysis process.

As per the 10-20 EEG electrode placement system, in the following figures, AF7 and AF8 represent the Muse channel electrodes that are placed on the frontal lobe (near the forehead). And TP9 and TP10 represent the Muse channel electrodes that are placed on the temporal lobe (near the ears).

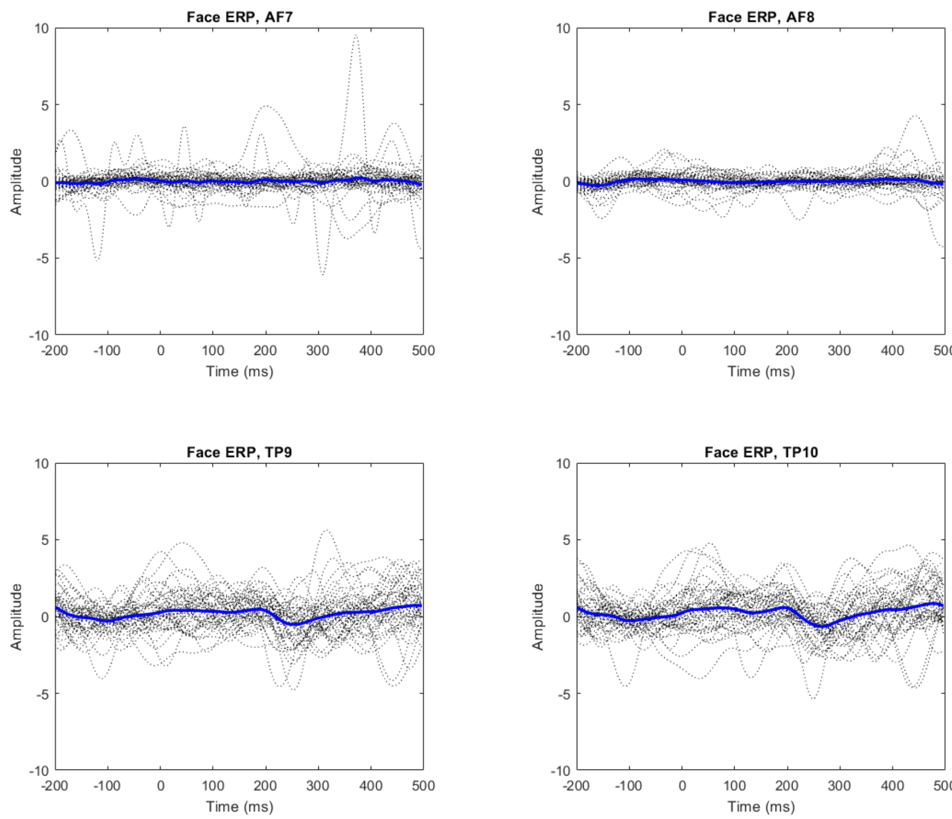


Figure 5.9: The Averaged Face ERPs for all Participants

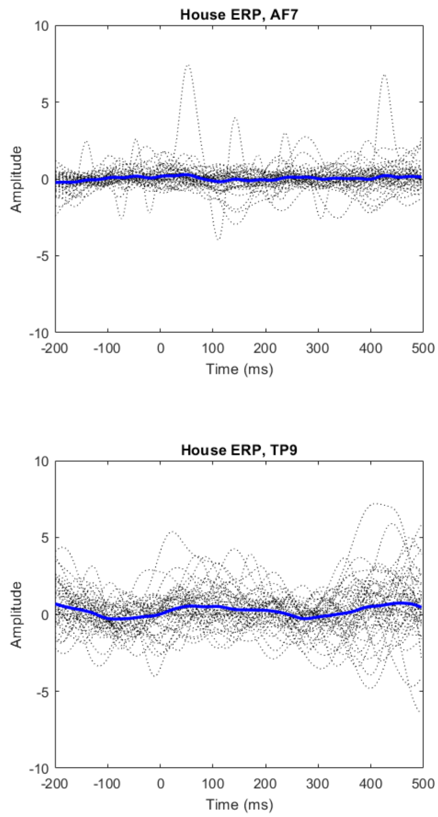


Figure 5.10: The Averaged House ERPs for all Participants

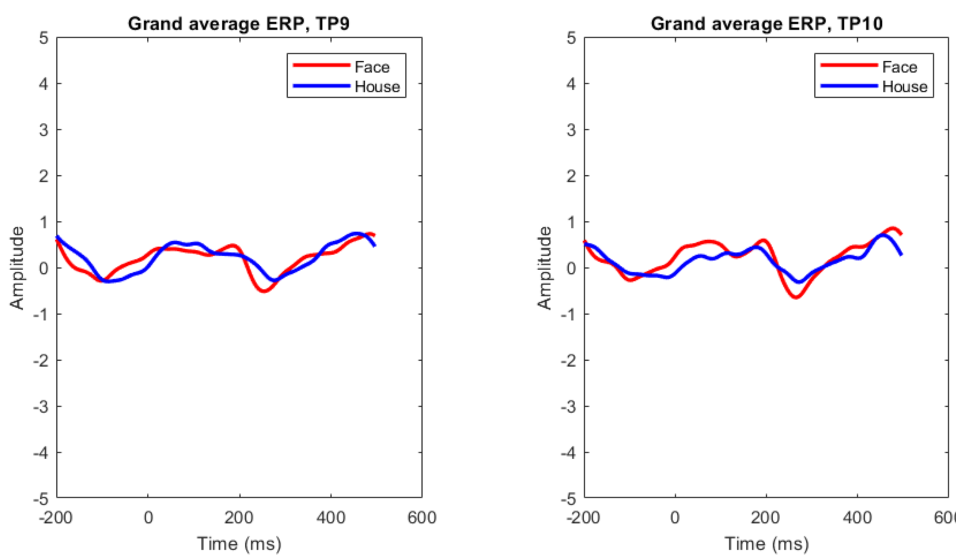


Figure 5.11: The Grand Averaged Face and House ERPs for all Participants

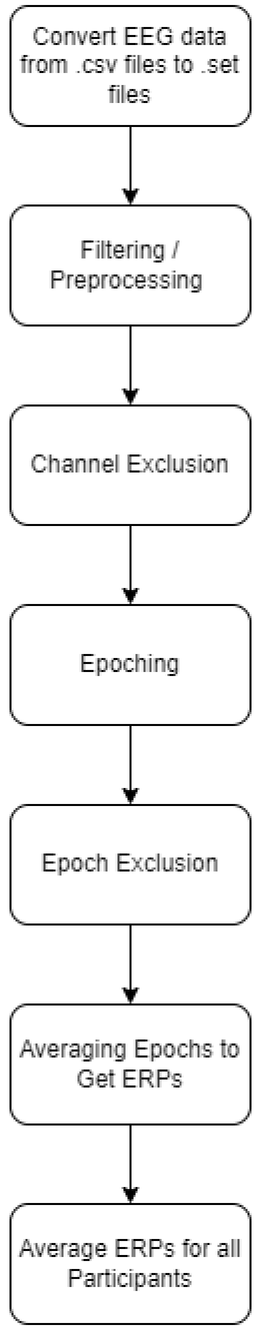


Figure 5.12: The EEG Data Analysis Process

Table 5.15: Reported Stats from the EEG Data Analysis

Total Number of Files	50
Files with NaN data	4
Files with no Epochs for Face ERP	3
Files with no Epochs for House ERP	3
Average number of Epochs for Face ERP per participant (with the maximum number of epochs being 150)	128
Average number of Epochs for House ERP per participant (with the maximum number of epochs being 150)	127
Files with all 4 channels excluded	3
Files with 3 channels excluded	1
Files with 2 channels excluded	2
Files with only 1 channel excluded	2
Total number of excluded channels (out of 50 x 4 = 200 channels)	21

CHAPTER 6 DISCUSSION

This chapter summarizes the research findings and offers a discussion of the implications based on the results.

Research on BCI and EEG began in the 1970s. Since then, it has helped advance the BCI field while applying BCI in various fields ranging from medial, education, and games to smart environments, neuromarketing, and security. However, in recent times, EEG and BCI research has picked up the pace, with about 50,000 EEG-related research papers published in the last five years with an average of about 8,400 research papers published each year. Additionally, with EEG and BCI research being a multidisciplinary field, many studies have been conducted combing EEG and HCI research. Unfortunately, most of these studies have remained confined to the laboratory. Thus, despite showing positive results, they are susceptible to poor generalization of their sample size, resulting in low statistical power. To solve this critical issue, democratizing the field of EEG and BCI research, and modernize how EEG studies are conducted, I developed a cross-platform tool for running large-scale neuroscientific (EEG) studies called Sans Tracas.

Using Sans Tracas to conduct online EEG studies has the potential to achieve an enormous sample size, which could increase the diversity of participants, reduce marginalization, and reduce the associated cost of conducting research in one specific fixed location. This is evident by the evaluation study presented in this thesis, which was conducted entirely online. The participants participated in the study from the comfort of their homes, on their own time. During the study, all 55 participants completed at least one EEG experiment using Sans Tracas. With the study being entirely online, the participants saved a great deal of time and cost due to not having to travel somewhere. The researcher also saved a lot of time and cost as more than one participant was able to perform the experiments simultaneously. The choice of using an in-expensive consumer-grade EEG device also helped reduce the cost, with some participants already owning a Muse EEG headset. The study's results were not affected by marginalization and are not localized either, as people from all over Canada and even some parts of Europe participated in the study. Sans Tracas also serves as a web-based EEG data collection tool, as all the EEG data collected during the study is stored in secure cloud servers with multi-factor authorization.

Moreover, the results of the EEG data analysis on the EEG data collected during the study revealed the EEG data obtained from Sans Tracas is viable and of good quality. Furthermore, the report stats from the EEG data analysis show that only 4 out of the 50 EEG files had NaN data and only 3 files had all its channels rejected. These are good results considering that the participants self-monitored the placement of the Muse EEG headset on their heads and that they performed all experiments entirely on their own, without any external help, guidance or supervision. The EEG data can also be used for further research.

However, one important aspect to consider here is that this thesis does not present the results of the researcher study. This is because I was only able to recruit just one participant for the researcher study and thus, the results based on their individual evaluation would have been subjective and not applicable to answer the research questions identified during the study design phase. Additionally, as a part of DR5, I mention that the platform should be able to seamlessly integrate experiments from other researchers. However, that part of the platform was not evaluated during the study as I only had 1 participant for the researcher study which was not significant enough to present as a result. Thus, research questions RQ6, RQ7, RQ8, and RQ9 remain unanswered, and the platform has limited evaluation from researchers. I hope to rectify this by simplifying the integration process and recruiting more participants for the researcher study.

Another consideration here is that the study evaluates the usability of Sans Tracas, which is a tool in the process of conducting large scale EEG studies. To truly evaluate Sans Tracas' efficiency and effectiveness, we need to evaluate Sans Tracas as a tool in the context of conducting online EEG studies for a set objective (such as: finding out at-home resting state paradigms in older population using Sans Tracas). Thus, in future work, I plan to conduct such as study from start to end, where a new experiment is designed, integrated with the platform, recruits and runs studies for participants, supports participants during the study, collects data, analyzes it, and visualizes the results.

Additionally, the evaluation study was not comparative. Thus, from the study results itself, it is not possible to determine how effective, efficient, usable, useful, and easy to use Sans Tracas is compared to other similar platforms or even traditional laboratory studies. By conducting a comparative evaluation study with other platforms and traditional laboratory studies, we can also determine what aspects Sans Tracas is critically lacking, what it does better than other platforms, what it does poorly, and how far along it is from being used as a viable alternative for traditional laboratory studies.

Furthermore, the evaluation of Sans Tracas' ability to be cross-platform is primarily focused on different device types and different operating systems. However, it is important to acknowledge that there was not a uniform distribution of device type and operating system amongst participants. The results indicate that personal computers (laptops or desktops) were the most used device type and windows was the most used operating system. The most preferred choices for device type and operating system were also similar. A more uniform distribution of operating systems and device type amongst the participants could have an impact on the results and could change participants' opinion about the platform.

6.1 Design Implications of Sans Tracas

To effectively combine HCI and neuroscience, I implemented a user-centric design approach while developing Sans Tracas. This enables the platform to cater to EEG beginner's needs and helps create more interest in general EEG and BCI research. I bifurcated the target users into researchers (neuroscientists) and end-users (study participants). The researcher-focused part of the platform aimed to have the researchers collect EEG data along with their self-designed behavioural experiments. Thus, I developed a detailed step-by-step guide for researchers to integrate their self-designed experiments with the platform while requiring little to no programming knowledge.

On the contrary, the end-user-focused part of the platform aimed to make the platform as simplistic, intuitive, and engaging as possible so that the end-users can perform EEG experiments entirely on their own by following the guidelines on the screen. I accomplished it by making the platform cater to EEG beginners' needs while also keeping them intrigued and engaged with the platform. I added features such as the signal quality check, showing them their live data, and giving them an option to download their EEG data recorded during the experiment.

Based on the thematic analysis of the study and interview data, it is clear that these design features have helped capture and maintain user attention. The user-centric design has been instrumental in providing an overall great experience to the users. The ability to see their live signal has been a great feature to attract and engage users. For example, one participant said that *"The platform is a **good way to note how brain signals are captured** and very well instructed on each page."* (P12). Another participant said that *"I really liked the 'check my signal' feature, where the **user can be confident** that the device is working."* (P2).

Moreover, the results suggest that since most of the participants were EEG beginners, they learned a lot about EEG and were interested to know more about it after using Sans Tracas. Participants liked the idea very much and the motivation behind the platform, and they felt that it was user-friendly and overall had a largely positive experience with it. For example, one participant said that *"The platform is **user-friendly** and **easy to understand**."* (P40), while a different participant thought that *"The impression of the platform was very good as it was **a great user interface** and **get to know something new about the EEG**. Especially **the idea was amazing**, and the well-designed application was structured so that the user would easily understand the flow."* (P41). One more participant felt that *"This platform **deserves applause** and i really felt great to use it."* (P49).

Based on the insights from the study, Table 6.1 proposes seven design guidelines for the future development of similar platforms or any technology aimed at democratizing EEG and BCI research.

Table 6.1: Design Guidelines for future work aimed at democratizing EEG and BCI research

Guideline 1: Design with a Multidisciplinary Lens *Find a good middle ground between the multiple disciplines*. Being a multidisciplinary field is at the heart of EEG and BCI. Thus, it was inevitable for Sans Tracas to be designed with a multidisciplinary lens and combine HCI and Neuroscience concepts to develop a platform for conducting online EEG studies. Nevertheless, it is not easy to combine two separate disciplines. Thus, it is necessary to find a common middle ground first. This can be achieved by various measures such as making a glossary of technical jargon, having regular brainstorming sessions, and explaining the concepts native to your disciplines to the people of other disciplines. You must take the best elements from both disciplines and combine them to create a unique experience for the users. e.g., Sans Tracas achieved this by involving HCI and Neuroscience experts at every stage of the design process to ensure that the EEG experiments were true to the Neuroscience concepts while simultaneously ensuring that they were presented beautifully using HCI concepts. This resulted in a unique experience for every user regardless of their technical programming knowledge or EEG and BCI knowledge.
Guideline 2: Open Access *Design open-access features for both developers and users*. Developing technologies with open access for all is the only way to democratize EEG research truly. This would allow anyone with the right set of skills to develop better technologies inspired by existing ones. Thus, the codebase of your new technology should be publicly available. e.g., Sans Tracas' code is available on a public GitHub repository with an open licence for anyone to use. Moreover, open access should also extend to the users, as it would make them feel more involved with the technology and greatly helps increase users' trust in it. e.g., Sans Tracas achieves this by allowing users to download the EEG data collected during the experiment. Not only does this allow knowledgeable users to play with their raw EEG data, but even for novice users, it lets them see the exact data that the platform collects. As evidenced by the results of the study, this feature was helpful to the users in building trust with the platform as it gave them a sense of authority over their data.
Guideline 3: Multi-faceted Use Case

Consider the use cases for end-users and research experts in your design approach. Democratizing EEG research would only be possible if it is democratized from the perspective of an end-user as well as a researcher. We need more end-users or study participants with different backgrounds to be part of EEG research to reduce the marginalization of minorities. At the same time, we also need more experts from various fields to get involved with EEG research to democratize the field and take it forward meaningfully. e.g., Sans Tracas achieves this by allowing the end-users or study participants to participate in online EEG studies. At the same time, Sans Tracas also allows behavioural neuroscientists to augment their behavioural research with an EEG component by allowing them to integrate their own experiments with the Sans Tracas platform.
Guideline 4: User-Centric Design *Keep target users at the centre of the design approach*. Keeping the target users at the centre of the design approach and designing from their perspective has allowed Sans Tracas to be massively popular among its users. If it was not designed to cater to an EEG beginner's needs, the users would not have liked using the platform and would have rejected it considering most of our target audience is new to EEG studies. After identifying target users, involving them during various design stages is crucial to ensure the process is on track and the desired outcome is achieved. e.g., by collecting user input on different design stages.
Guideline 5: Simplicity and Ease-of-Use *Make the design, content, and tasks as simple, intuitive, and easy to use as possible*. Even when designing for technically expert users, it is essential to keep the process simple and easy to follow. It is the responsibility of the developer to produce content that is easy to understand, not only for a technically expert user but also for a layman, and to make the entire platform unified and simplistic. The goal should be to help the users and not to confuse them. It is paramount for the progress of EEG research to make users feel at ease while interacting with EEG technologies. The study results confirm that Sans Tracas was seamlessly easy-to-use and had straightforward instructions for everyone.
Guideline 6: Style and Substance *Style without substance is just an empty shell, and substance without style is unappealing*.

No matter how good EEG signals the platform can capture and how much processing it offers, if it is not visually appealing, there will hardly be any users. Similarly, no matter how good the platform looks and feels, the entire platform becomes useless if the EEG data captured from it is not viable. Thus, it is vital to balance the actual use case and its visual aesthetics. e.g., the Signal Quality Check feature of Sans Tracas. That feature is significant for ensuring that the EEG data collected by Sans Tracas is of good quality. However, since it also allows users to see their live brain signal, it further engages them with the platform and provides a visual representation of their signal quality. The results of the thematic analysis further support this.

Guideline 7: Privacy and Security

Privacy and Security are paramount in gaining users' trust in new technology. In order to democratize EEG research and have everyone be a part of it, developers need to ensure that their platforms give the utmost importance to users' privacy and security. Only then will the users begin trusting EEG and BCI research. e.g., Sans Tracas does not collect any personally identifiable data. It does not collect any data from the user except for the EEG data. Additionally, to ensure the security of EEG data, Sans Tracas uses encryption to transfer data over the internet, and the server where the data is stored has two-factor authentication.

One important limitation to consider here is that the literature review of this thesis was focused on EEG experiments and studies. There is still a lot more that can be learned by studying the broader area of conducting remote and online experiments and studies. Thus, the design guidelines provided here are also narrowly focused on creating such similar platforms for online studies, specifically for EEG experiments. The findings and recommendations provided from adjacent areas (such as online cognitive psychology experiments) could provide useful lessons and design guidelines for Sans Tracas and any future work in specific area of conducting online EEG studies.

6.2 Motivational Appeal of Sans Tracas

The results from the ARCS motivational appeal test indicate that Sans Tracas was able to motivate users to perform online EEG experiments. Sans Tracas was also successful in generating more interest in EEG and BCI research from the users. From the results of the individual constructs as evaluated by the ARCS motivational appeal model, it is apparent that Sans Tracas successfully increased user confidence (M = 4.35, SD = 0.76) and satisfaction (M = 4.39, SD = 0.74) with respect to conducting EEG studies. Confidence and satisfaction are pillars for building trust with the adaptation of any new technology. These results are an essential step towards achieving the goal of enabling users to adapt the platform for participating in EEG studies from their homes.

Moreover, based on the results of the thematic analysis, we found evidence to further support this claims as almost all participants mentioned that they would use Sans Tracas again in their free time without expecting any sort of compensation. This shows the participants' satisfaction with the platform, as they are willing to return just to try out other experiments and learn more about EEG. The participants also mentioned that they would recommend the platform to friends, family, and other people they know. This shows the participants' confidence in the platform as they believe that other people will have similar positive experiences with the platform as they have had. For example, one participant mentioned that *"I will **definitely use Sans Tracas** in my free time as **it is very interesting**."* (P2). While another participant said that *"I would **surely recommend the platform** to friends and family as **motivation behind it was really good** and it was **easy to use**."* (P3).

6.3 Perceived Ease of Use and Usefulness of Sans Tracas

To democratize EEG and BCI research and have as many people invested in it as possible, the first task that needs to be completed is to reduce the barrier to entry to the minimum. Thus, any software, tool, technology, or community, aimed at democratizing a specific field should have as small of a barrier to entry as possible. This includes making it easily accessible and easy to use and keeping the cost to as little as possible. With respect to Sans Tracas, its barrier of entry is extremely low. Not only is it free to use, but the evaluation study results could also suggest that Sans Tracas is cross-platform and thus can be used from any internet browser-enabled device. It is also not region specific and thus can be used from anywhere in the world as it is openly available on the internet [182].

Moreover, the results from the perceived ease of use scale (M = 6.08, SD = 1.23) showed that Sans Tracas is perceived to be easy to use. It is important to consider here that most of the participants were novices in terms of EEG knowledge. Thus, the platform being easy to use for them is critical because if it had required them to make a significant effort just to use the platform, they would not be interested in using it in the first place. In such a scenario, despite having the most functionalities, the platform would not have been used and would have failed to democratize EEG and BCI research. The results from the thematic analysis further support this claim as almost all participants mentioned that the platform is easy to use, and it was even one of the things that they liked when one participant said: *"It was* ***very easy to use****...and the process of experiment was* ***seamlessly good****."* (P9).

Furthermore, the results from the perceived usefulness scale (M = 6.05, SD = 1.24) showed that Sans Tracas is perceived to be useful in terms of conducing online EEG experiments. Participants and researchers alike found the features like signal quality check and downloading EEG data useful. Compared to traditional in-the-lab studies, the researcher found Sans Tracas to be more comfortable, more flexible, and a generally better setting as users are in their usual environments, thus, it seemed like an overall better experience to them. For example, one participant mentioned that *"Everything was* ***smooth and straightforward****...downloading the data was* ***useful****."* (P5). While another participant said that *"Sans Tracas is the* ***only way*** *to combine EEG online experiments with psychological testing."* (P11).

Some important aspects to consider here are: (1) the video presentation and particular phrases regarding the platform's novelty and ease of use could have potentially impacted the participants' perception of the platform. (2) The majority of the participants were technically knowledgeable, and this could have an impact on how the findings were interpreted. It is possible that with a less technically savvy participant population, the perceived ease of use scales could have shown lesser scores. (3) Most of the participants were novice to EEG and EEG studies. Thus, it is hard to know what they were assessing. Some of their responses may have been about participating in an EEG experiment more generally, rather than aspects of Sans Tracas specifically as they did not have any basis of comparison. (4) There was some variability which was not considered during the study such as: whether participants owned an EEG device or borrowed it for the purpose of the study, time of the day when they participated in the study, the environmental contexts (noisy, quiet, disturbing, stressful, etc.), participants' devices' screen characteristics, etc. All these factors could have an impact on participants' perception of the platform and the results and findings of the study in general. Thus, they need to be further studied and evaluated in future studies.

6.4 Perceived Usability of Sans Tracas

Perceived Usability is one of the most important metrics to determine whether a new piece of technology will be adopted by the users [200]. To evaluate the perceived usability of Sans Tracas, I used one of the most popular methods; the system usability scale (SUS). The final SUS score was 81.82 (SD = 19.56). Figure 6.1 shows four main ways to interpret raw SUS scores; grades, percentile, acceptability, and net promoter score (NPS) categories.

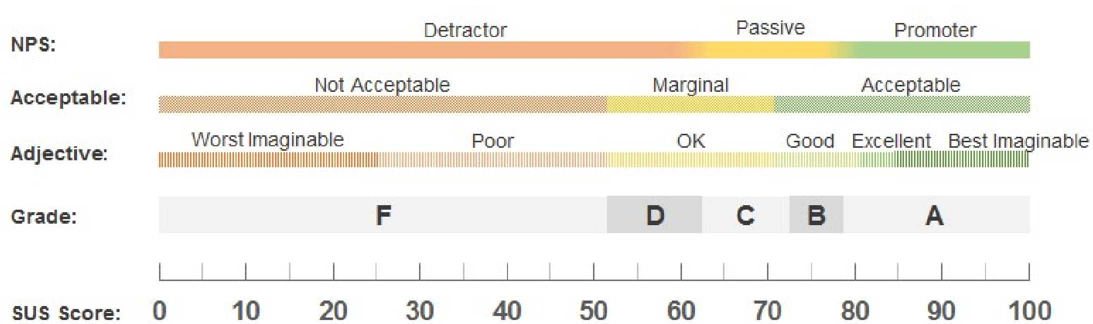


Figure 6.1: Grades, adjectives, acceptability, and NPS categories associated with raw SUS scores

Raw SUS scores can be converted to percentiles ranks. The average score obtained from over 500 studies is 68 [211], [215], which is placed at the 50th percentile mark, as shown in Figure 6.2. Sans Tracas' SUS score of 81.82 gets it an A grade, as represented by the red lines in Figure 6.2, and it also shows that Sans Tracas has a better SUS score than roughly 92% of the scores in the database. This also earns Sans Tracas an adjective of "Excellent," as interpreted from Table 6.2.

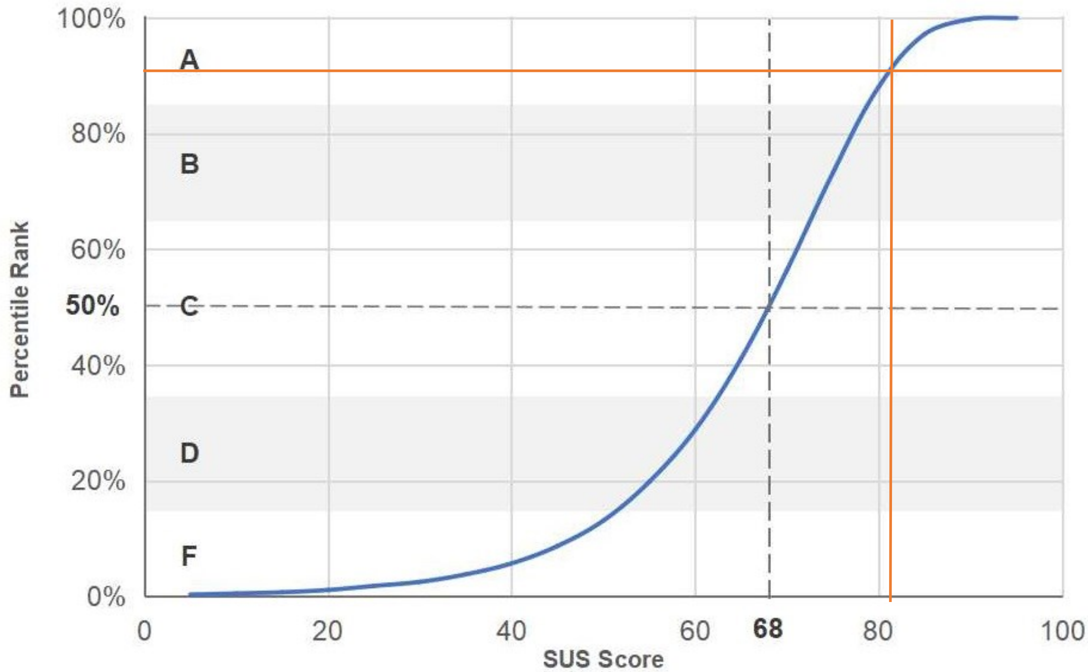


Figure 6.2: Sans Tracas' SUS score on a curve with percentile ranks and grades [217]

Regarding the acceptability of the raw SUS score as assigned by Bangor et al. [199], Sans Tracas' score would be considered "acceptable."

With respect to the Net Promotor Score (NPS), which designates three classes of recommenders based on their responses to the 11-point (0 to 10) likelihood to recommend question. Promoters score 9 and 10; passives 7 and 8; and detractors score 6 and below. While promoters (as the name suggests) are most likely to recommend the product, website, or app to a friend, detractors are more likely to discourage rather than recommend [218]. MeasuringU [219] (a mixed method research and software firm) computed the average SUS and NPS score from 4,664 respondents. Figure 6.3 shows this relationship (R-Sq = 42%). A SUS score needs to be reasonably close to 81 to achieve a Promoter classification. Thus, the Sans Tracas score of 81.82 will be considered as a promoter. This further supports our claim from the motivational appeal scale and its subsequent thematic analysis that all participants are extremely likely to recommend Sans Tracas to friends, family, and other people.

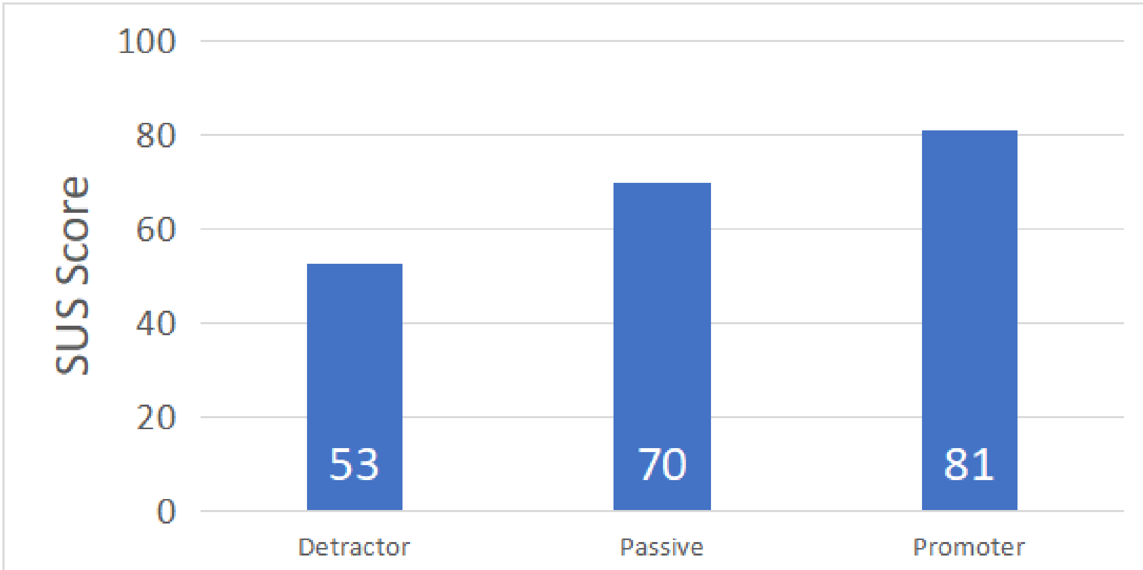


Figure 6.3: Average SUS scores associated with different NPS classes (4664 respondents) [217]

Table 6.2: Percentiles, Grades, Adjectives, and NPS categories to describe raw SUS scores [220]

Grade	SUS Score	Percentile range	Adjective	Acceptable	NPS
A+	84.1-100	96-100	Best Imaginable	Acceptable	Promoter
A	80.8-84.0	90-95	Excellent	Acceptable	Promoter
A-	78.9-80.7	85-89		Acceptable	Promoter
B+	77.2-78.8	80-84		Acceptable	Passive
B	74.1 – 77.1	70 – 79		Acceptable	Passive
B-	72.6 – 74.0	65 – 69		Acceptable	Passive
C+	71.1 – 72.5	60 – 64	Good	Acceptable	Passive
C	65.0 – 71.0	41 – 59		Marginal	Passive
C-	62.7 – 64.9	35 – 40		Marginal	Passive
D	51.7 – 62.6	15 – 34	OK	Marginal	Detractor

One important limitation of the SUS to consider here is that it measures perceived usability and not the actual usability. Thus, these are the subjective score and not the objective scores for the usability of the platform. The SUS scores are biased with what the participants need to do with the application. In the case of Sans Tracas, since the application was very simple, there were a few choice points, making it difficult for participants to make many mistakes or get lost in the process. Thus, it makes sense that the SUS score for the platform were much higher than average. Additionally, when comparing the SUS score with other SUS studies, it is important to note that most SUS studies are often performed for commercial applications and there is limited evaluation in research context. Thus, the tasks participants had to perform in other studies could differ widely from the tasks there were performed by the participants of this study.

CHAPTER 7 CONCLUSION

This chapter summarizes the thesis and highlights the limitations, contributions, and potential directions for future work.

7.1 Study Summary

This research focused on designing a cross-platform tool that enables users to run EEG experiments online. To democratize EEG and BCI research, the platform was developed via a multidisciplinary lens by combing HCI and neuroscience. Thus, the platform was developed using an iterative user-centric design approach [136], with two-fold target users in researchers (neuroscientists) and end-users (study participants). Following this, the platform was presented to subject matter experts for initial feedback, and then a pilot study was conducted with seven participants to evaluate the platform. According to its results, the platform’s design was refined, and the EEG experiments were updated to be more scientifically accurate. The final version of the platform was called Sans Tracas, and the main evaluation study was conducted on this version of Sans Tracas. Fifty-five participants participated in the study, with one participant participating in both the end-user-focused and the researcher-focused study.

The study's main goal was to determine whether Sans Tracas is usable for conducting online EEG experiments. Further, the study also investigated the motivational appeal of Sans Tracas in generating more interest in EEG and BCI research. Finally, the study determined the perceived usability, perceived ease of use, and perceived usefulness of Sans Tracas and the overall experience of using Sans Tracas. The findings are summarized in Table 7.1.

Table 7.1: Summary of the Findings from the Sans Tracas Evaluation Study

Tested Variables	**Outcome**
The ability of the platform to enable users to conduct online EEG experiments	Highly capable of secure collection and storage of accurate EEG data. Genuinely cross-platform, free to use, and accessible from anywhere in the world.

Motivational Appeal	Highly effective overall as well as across four dimensions (attention, relevance, confidence, and satisfaction).
Perceived Ease of Use	Perceived to be easy to use by end-users and researchers alike.
Perceived Usefulness	Perceived to be useful for conducting online EEG studies.
Perceived Usability	Perceived to be usable with an Excellent SUS score.
Quality of EEG Data	EEG Data obtained from Sans Tracas was of good quality and is viable for EEG research.
Overall Experience	Extensively Positive experience for end-users and researchers alike.

The study results indicate that Sans Tracas has the potential to be a good cross-platform tool for conducting online EEG experiments and is capable of being used for conducting large-scale "in-the-wild" neuroscientific studies.

7.2 Limitations

The primary limitation of this research is self-reporting. Since surveys are widely used in various research domains and are widespread methods in HCI [221]–[223], online surveys were used in this research too. Additionally, since, by nature, the entire survey was supposed to be online and performed by participants entirely on their own without any external help, it creates a possibility of bias. Although the participants were instructed in the consent form to answer the questions sincerely and to make their answers a representation of their individual state of mind, it is a common belief that human perception is not always perfect, and bias would most likely be present [224]–[227]. Participants performing the EEG experiments entirely on their own could lead to a scenario where the researchers have little control over any variables that could go wrong during the study, and they would not be able to interfere to help them. I hope to address this hurdle during the next development phase of Sans Tracas by providing more control measures to the researchers for when users are running their experiments, and a live hotline link for immediate feedback during the experiment for the end-users.

Another limitation of the research is the integration process of Sans Tracas. In its current form, the integration process is a little time-consuming, which could lead researchers not to use the platform. The next version of Sans Tracas would make the integration process as simple as just pressing a button. This could be achieved by packaging Sans Tracas' EEG data collection and signal quality validations into an API. We could then partner up with platforms that run online behavioural studies such as Pavlovia, JATOS, etc. and provide them the API for a seamless 'push-of-a-button' integration between user's behavioural experiments and adding the EEG component to it. Additionally, the library of EEG experiments available in Sans Tracas is currently limited. To solve this, the next version of Sans Tracas would have more natively designed and integrated experiments as more people use the platform.

Another important limitation here is that in its current state, the type of EEG experiments and studies that can be conducted using Sans Tracas is limited. This limitation is closely tied the type of EEG data we can collect through the Muse EEG headset. Thus, only experiments related to ERPs, SSVEPs, sleep analysis, brain waves (specifically alpha waves), and motor imagery can be conducted. However, if one wants to conduct deeper analysis with denser EEG channels and readings it is not possible. To solve this issue, I plan on increasing the device compatibility of Sans Tracas with more EEG headsets (such as: Emotiv, OpenBCI, and Neurosky). This would help make Sans Tracas truly cross-platform. Additionally, another important limitation to reflect upon is that since the design goals and objectives of the platform focused on providing a simple interface for the end-users and making the entire process as simple as possible for them; this likely lead to simplification in ways that limit the nature of the study that can be conducted using Sans Tracas. Many comments from P11's feedback was suggestive of the features that would be required in a real-world system. Thus, in next steps I will conduct further analysis with more EEG researchers in order to redesign and add features to the platform. And any such redesign or addition of features will then be re-evaluated with the study participants which will be consisting of both EEG beginners and experts.

As mentioned in the discussion chapter, the evaluation of effectiveness and efficiency of Sans Tracas is limited here as only one aspect is considered for both. Thus, it needs to be further evaluated in the context of using Sans Tracas as a tool for conducing EEG studies with set goals and for specific purposes. In such future studies, this issue could be solved by generating, maintaining, and analyzing software log files for studying specific aspects of the platform such as time taken, number of restarts, time to read guidelines, watch videos, and understand the workings of the platform, etc. for various sections of the platform.

Additionally, even though it is initially claimed that Sans Tracas will reduce time and cost associated with conducting EEG research, it is important to consider here is that this is still a hypothesis at this point. To truly evaluate whether the hypothesis is proven correct in the real world, there needs to be a simultaneous comparative study wherein the same experimental study is conducted online as well as in the laboratory with the exact same study parameters. Additionally, time logs will need to be maintained for every individual task associated with the study and then compared to truly determine exactly how cost and time efficient is Sans Tracas compared to traditional laboratory studies.

7.3 Future Work

For the future, the plan is to run a more comprehensive study with a much bigger sample size for a much longer duration of 6+ months. There would be a minimum of three points of data collection to monitor participants' knowledge and interest in EEG and BCI over a period and to see if Sans Tracas is able to change it. Another plan is to run a longitudinal study for an older population to determine how to expand the inclusivity criteria of EEG participants and thus increase the participant database. A third plan is to run a two-fold study comparing participants' and researchers' experiences while taking part or conducting a traditional in-lab EEG study against an online EEG study using Sans Tracas. This will help us understand how to improve Sans Tracas so that it becomes considerably advantageous to conduct an online EEG study over an in-lab study. Thus, encouraging more and more researchers to venture into EEG research, further democratizing the field.

Additionally, apart from further simplifying the integration process, increasing the experiment database, and increasing researcher control during the experiment, there are other features which could improve Sans Tracas, such as creating a dedicated smartphone application, user accounts, increasing compatibility with more online behavioural experiments platform, and increasing compatibility with more consumer and research grade EEG devices.

Ideally, in a hopeful future, Sans Tracas would also be used to identify the early onset of neurological diseases such as epilepsy from the user's home instead of going to the hospital.

7.4 Conclusion

This research is an important and fruitful contribution to EEG and BCI research, a sub-field under the more giant umbrella of HCI research. The platform Sans Tracas was developed via a multidisciplinary lens, and it combines HCI and neuroscience research to deliver a tool for running large-scale online EEG studies. The platform adopted an iterative user-centric design approach. It was thus designed to keep the usability, usefulness, and ease of use for the two target user groups (researchers and end-users) at the centre of Its design methodology. The platform achieved excellent scores on the System Usability Scale (SUS), Perceived Usefulness, and Perceived Ease of Use Scales, indicating that the platform is perceived to be usable, easy to use, and useful. The overall and the individual constructs score of the ARCS motivational appeal model indicates that the platform was able to increase user confidence and satisfaction with EEG studies, thereby displaying good signs of the platform being widely accepted for running online EEG studies.

This research serves as a demonstration and a proof of concept that conducting online EEG studies is possible. I hope this inspires other neuroscientists to use Sans Tracas for conducting online EEG studies, thereby increasing active participation in EEG and BCI research, leading to the democratization of the field.

7.5 Publications

Given below is the list of published conference papers from this thesis. Sans Tracas is freely available on the internet [182].

1. **Ronit Desai**, Rita Orji, Eugenie Roudaia, and Allison B. Sekuler. 2022. Sans Tracas: A Cross-platform Tool for Online EEG Experiments.. In Companion of the 2022 ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS '22 Companion), June 21–24, 2022, Sophia Antipolis, France. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3531706.3536461

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APPENDIX A. Permission To Use

In presenting this thesis in partial fulfilment of the requirements for master's in computer science degree from the Dalhousie University, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the Dalhousie University in any scholarly use which may be made of any material in my thesis.

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6050 University Ave,
Dalhousie University,
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APPENDIX B. Pre-Study Survey Questions

Section1: Demographics (age, gender, education, field of study)

Section2:

Questions related to your prior knowledge about EEG.

5. **How comfortable are you using a device that measures your brain activity?**

   - Very uncomfortable
   - Uncomfortable
   - Neutral
   - Comfortable
   - Very comfortable

6. **How familiar are you with electroencephalography (EEG)?**

   - Very unfamiliar
   - Unfamiliar
   - Neutral
   - Familiar
   - Very familiar

7. **How comfortable are you with the idea of using a web application that uses your brain activity (i.e. EEG)?**

   - Very uncomfortable
   - Uncomfortable
   - Neutral
   - Comfortable
   - Very comfortable

8. **How interested are you in learning more about EEG or Brain-computer-interface research?**

- Very uninterested
- Uninterested
- Neutral
- Interested
- Very interested

9. **How familiar are you with Brain Computer Interfaces (BCI) concepts?**

- Very unfamiliar
- Unfamiliar
- Neutral
- Familiar
- Very familiar

10. **How trusting are you of general BCI research?**

- No trust at all
- Little trust
- Neutral
- Trusting
- Very Trusting

11. **How accepting are you of general BCI research?**

- Very unaccepting
- Unaccepting
- Neutral
- Accepting
- Very accepting

12. **How experienced are you with EEG studies?**

- Very unexperienced
- Unexperienced
- Neutral
- Experienced
- Very experienced

13. **How many EEG studies have you participated in before this?**
    - 0
    - 1 – 3
    - 3 – 5
    - 5+

APPENDIX C. Post-Study Survey Questions

Section1:

General Questions

1. **Please enter the Participant Id that was given to you while using Sans Tracas:**

2. **Please indicate your level of expertise with regards to computer programming and technical knowledge:**

   - Beginer
   - Intermediate
   - Expert

3. **Please indicate your level of expertise with regards to using the Muse EEG device:**

   - Beginer
   - Intermediate
   - Expert

4. **Please provide your impression about the platform:**

5. **What aspects/features of the platform did you like?**

6. **What aspects/features of the platform did you dislike?**

7. **Please provide your feedback and suggestions for improving the platform:**

8. **On a scale from 1 to 10 (1 being the lowest and 10 being the highest), how would you rate your technical knowledge?**

   Enter your rating here:

Section2:

Specific questions regarding your experience with Sans Tracas

9. **While using the platform, how many attempts did it take you to successfully connect with the Muse EEG device?**

   Enter the number of trials here:

10. **Did you have issues with Muse (e.g., disconnecting / losing signal) during the experiment?**

    - ○ Yes, please specify the issue(s) you faced in the box below
    - ◉ No

11. **Were you able to complete at least 1 (one) EEG experiment using the platform?**

    - ○ Yes
    - ○ No, please specify the reason for it in the box below

12. **Did you need to download or install any additional software or hardware to complete an EEG experiment using the platform (e.g., a BLE (Bluetooth Low Energy) dongle)?**

    - ○ Yes, please specify the additional software/hardware you needed in order to conduct the experiment(s) in the box below
    - ○ No

13. **Were you able to download your EEG data at the end of the experiment?**

- Yes
- No

14. **If you answered 'NO' in the previous question, please answer this question:**

    Did you see the option to download your data?

    - Yes
    - No

    Please specify any other reason why you were not able to download the data.

15. **Did you require any external guidance or help while taking part in the EEG experiment on the platform?**

    - Yes, please specify on which part(s) you needed help with and who assisted you / what external resource did you use in the box below
    - No

16. **Please select the type of device you used to access the platform:**

    - Computer (personal/work)
    - Smartphone
    - Tablet

17. **What type of device would be your preference to access the platform in the future?**

    - Computer (personal/work)
    - Smartphone

- Tablet

18. **Please rank the following types of devices from Most Preferable to access the platform to Least Preferable to access the platform:**

	Least Preferable	Neutral	Most Preferable
Computer (personal/work)	☐	☐	☐
Smartphone	☐	☐	☐
Tablet	☐	☐	☐

19. **Please indicate the operating system that you used to access the platform:**

- Android
- iOS/iPadOS
- Windows
- Mac
- Linux
- Blackberry
- Others (please specify) ______

20. **How willing are you in performing more EEG experiments using the Sans Tracas platform?**

- Very unwilling
- Unwilling
- Neutral
- Willing
- Very willing

Section3:

Motivational Appeal Test for End Users.

21. **Please rate the following on a scale of 1 to 5:**

	1 - Strongly Disagree	2 - Disagree	3 - Neutral	4 - Agree	5 - Strongly Agree
Attention					
The system would capture and hold my attention.					
The system has some contents that stimulate my curiosity.					
Relevance					
The content of the system would be relevant to me.					
I can relate to the content of this system.					
The content of the system makes sense to me.					
The content of the system would be useful to me.					
Confidence					
It would be easy to understand and use the system.					
The system would help me to conduct an EEG experiment on my own. (i.e., without any external guidance and help)					
The system would build my confidence in my ability to conduct an EEG experiment on my own without any external guidance and help.					
Satisfaction					
I would really enjoy using the system (for conducting experiments using the system).					
It would be a pleasure to work					

with a system like this.					
The system would help me accomplish my goal of conducting an EEG experiment.					

Section4:

System Usability Scale (SUS).

22. **Please rate the following on a scale of 1 to 5:**

System Usability.

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

system.					

Section5:

Perceived Usefulness Scale.

23. **Please rate the following on a scale of extremely likely to extremely unlikely:**

Perceived Usefulness.

	Extremely Likely	Quite Likely	Slightly Likely	Neither	Slightly Unlikely	Quite Unlikely	Extremely Unlikely
Using Sans-Tracas would enable me to perform EEG experiments quickly.	○	○	○	○	○	○	○
Using Sans-Tracas would improve my ability to perform EEG experiments.	○	○	○	○	○	○	○
Using Sans-Tracas would increase my productivity for performing EEG experiments.	○	○	○	○	○	○	○
Using Sans-Tracas would enhance my effectiveness in performing EEG experiments.	○	○	○	○	○	○	○
Using Sans-Tracas would make it easier	○	○	○	○	○	○	○

to perform EEG experiments.							
I would find Sans-Tracas useful in performing EEG experiments.	○	○	○	○	○	○	○

Section6:

Perceived Ease of Use Scale.

24. **Please rate the following on a scale of extremely likely to extremely unlikely:**

Perceived Ease of Use.

	Extremely Likely	Quite Likely	Slightly Likely	Neither	Slightly Unlikely	Quite Unlikely	Extremely Unlikely
Learning to operate Sans-Tracas would be easy for me.	◉	○	○	○	○	○	○
I would find it easy to get Sans-Tracas to do what I want it to do.	○	○	○	○	○	○	○
My interaction with Sans-Tracas would be clear and understandable.	○	○	○	○	○	○	○
I would find Sans-Tracas to be flexible to interact with.	○	○	○	○	○	○	○
It would be easy for me to become skillful	○	○	○	○	○	○	○

at using Sans-Tracas.							
I would find Sans-Tracas easy to use.							

APPENDIX D. Interview Questions

1. Have you ever participated in an EEG experiment before and what was your experience?

2. How do you feel about your experience using the platform?

3. If you have used or participated in an EEG experiment before, how do you compare it with the current platform?

4. Where you concerned about anything while using the platform?

5. Please mention your top 3 most liked things about the platform.

6. Please mention your top 3 least liked things about the platform.

7. Did you encounter any difficulties using the platform and what were they? How did you resolve it?

8. What other features would you have liked to be included in the platform?

9. Will you recommend the platform to someone else? Why?

10. What other device and experiments compatibility would you have preferred in addition to the current device and experiments compatibility?

11. If you were to make your own platform, what would you do differently?

12. Will you be interested in using Sans Tracas in your free time to contribute your data in the name of science without any compensation?

13. How easy or difficult was it for you to use this platform on your own? Did you need an additional help to be able to you it?

14. On a scale from 1 to 10, how would you rate your technical knowledge?

15. Do you have any other feedback?

APPENDIX E. Research Ethics Board Approval Letter

Social Sciences & Humanities Research Ethics Board
Letter of Approval

December 03, 2021
Ronit Umeshbhai Desai
Computer Science\Computer Science

Dear Ronit,

REB #: 2021-5762
Project Title: Sans Tracas: A cross-platform tool for online EEG experiments.

Effective Date: December 03, 2021
Expiry Date: December 03, 2022
The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Effective March 16, 2020: Notwithstanding this approval, any research conducted during the COVID-19 public health emergency must comply with federal and provincial public health advice as well as directives from Dalhousie University (and/or other facilities or jurisdictions where the research will occur) regarding preventing the spread of COVID-19.

Sincerely,

Dr. Karen Foster, Chair