2020

Usability of Portable EEG for Monitoring Students' Attention in Online Learning

Arisaphat Suttidee

Usability of Portable EEG for Monitoring Students' Attention in Online Learning

by

Arisaphat Suttidee

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in
Information Systems

College of Computing and Engineering
Nova Southeastern University

2020

We hereby certify that this dissertation, submitted by Arisaphat Suttidee conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

August 21, 2020

Ling Wang, Ph.D.
Chairperson of Dissertation Committee

Date

August 21, 2020

Souren Paul, Ph.D.
Dissertation Committee Member

Date

August 21, 2020

Inkyoung Hur, Ph.D.
Dissertation Committee Member

Date

Approved:

August 21, 2020

Meline Kevorkian, Ed.D.
Dean, College of Computing and Engineering

Date

College of Computing and Engineering
Nova Southeastern University

2020

An Abstract of a Dissertation Submitted to Nova Southeastern University
in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy

Usability of Portable EEG for Monitoring Students' Attention in Online Learning

by
Arisaphat Suttidee
August 2020

Current research demonstrates that distractions while participating in online courses affect students' performance in online tasks. Electroencephalography (EEG) devices are currently being used in education to help students maintain attention when engaged in online classes. Previous studies have focused predominantly on comparing EEG devices, EEG signal quality, and EEG effectiveness. However, there is no comprehensive study examining the usability of the portable EEG headset to monitor students' attention in online courses.

This study aimed to examine the usability of EEG devices while monitoring student attention levels during online educational tasks. Specifically, twenty (20) participants who intend to enroll in online courses were trained to use EEG devices with their smart phones and follow a checklist for EEG software installation and hardware connection. Participants wore the EEG device and ran the EEG software while they were engaged in an online learning task. While participants were engaged in the learning task, the researcher collected qualitative data based on Nielsen's 10 heuristics evaluation method by instructing participants to utilize the think-aloud method. When participants completed their online task, the researcher collected quantitative data via the System Usability Scale (SUS) survey that was completed by all participants.

The study explored both qualitative and quantitative analyses to support the research question that examines the usability factors influencing the adoption of portable EEG headset use for students in online courses. The qualitative data showed that participants rated the portable EEG headset positively. However, the quantitative results of the SUS revealed that participants were not satisfied with using the portable EEG.

The findings of this study have implications for the field of Information Systems and are of particular interest to human-computer interaction usability researchers and professionals. Additionally, those in the usability and educational research who are interested in understanding the factors that influence the adoption of the EEG headset for educational use can benefit from this research.

Acknowledgements

I would like to sincerely thank my advisor Dr. Ling Wang for her continued support, invaluable guidance, and understanding throughout my dissertation process.

I am appreciative of my Ph.D. dissertation committee, Dr. Inkyoung Hur and Dr. Souren Paul. I am thankful for their insightful, questions, and feedback.

I would like to thank my peer mentors, Vito Pelikan, and Mary Rotundo for their support with my English skill.

Finally, I would like to thank my mom, Chumnain Malison for her support and encouragement throughout my Ph.D program.

Table of Contents

List of Tables

Tables

List of Figures

Figures

Chapter 1

Introduction

Background

Online education in universities continues to increase with the latest estimates showing that over a quarter (28%) of American university students are enrolled in at least one online course (Babson, 2015). According to the Best Colleges Survey, a survey of higher education school administrators, 74% of respondents indicated that there is an increase in demand for online courses at their institutions (Best Colleges, 2018). Online education has demonstrated benefits that include being able to study remotely, completing assignments at one's own pace, and communicating with peers via a bulletin board system (BBS). By contrast, online courses also have drawbacks. Online education faces a high level of student dropout (Digital Learning Compass Report, 2017). In a survey of 1,774 college students in the U.S.A., Junco and Cotten (2012) reported that 51% used the Internet to text, 33% used it for Facebook & email, and only 21% relied on it for schoolwork. According to Karpinski et al. (2013), 85.9% of university students in the USA and 72.5% of students in Europe were being distracted from learning tasks when using the Internet due to Social Network Sites (SNS).

Studies indicate that students' attention is an important part of a successful learning approach because sustained attention enhances learning performance, particularly during online learning (Chen & Wang, 2017; Kuo et al., 2017; Wang & Hsu, 2014). Instructors and education scholars can monitor students' attention in a variety of forms, such as behavior observation signals, self-reporting methods, and questionnaire surveys. However, self-reporting surveys and questionnaires can be unreliable (Romero, 2014). Also, intrusive and behavioral observation signals may be difficult to interpret because they are not readily visible and less feasible to monitor (Macaulay & Edmonds, 2004). In a traditional classroom, instructors can directly observe students, but, in an online environment, it is difficult to evaluate student engagement in coursework. Previous studies indicate that online education is limited in that online instructors cannot immediately monitor the attention states of individual learners because face-to-face interaction is limited (Chen & Wang, 2017; Chen et al., 2017).

Previous studies have employed electroencephalography (EEG) as a tool to measure changes in attention states from brainwave signals. The EEG device is an electrophysiological monitor that measures and records electrical activity in the brain. EEG devices play an essential role in brain examination and study. Although EEG devices have been widely deployed in health and medical research, they are currently being used in educational research to improve students' performance. In recent years, researchers have used portable EEG headsets to assess the cognitive state of students as they engage in learning tasks (Xu & Zhong, 2018). Chen et al. (2017) used these headsets to monitor when attention signals in students are low and give audio feedback to promote them to stay on task. Similarly, Chen and Lin (2016) used the same headsets to measure changes in students' attention states. This research suggests that using EEG real-time cognitive monitoring can improve student performance on learning tasks. Despite the fact that EEG has been used recently in various settings, there are still many areas of study yet to be explored. Currently, there is insufficient information regarding the usability of EEG in a disciplined curriculum (Xu & Zhong, 2018).

One requirement of portable EEG is the accompanying software. Most software developers require some type of usability evaluation before the application is released for consumer use. The effectiveness of usability evaluation is the foundation of how well users can interact with a product (Greenberg et al., 2008). In other words, usability refers to the extent to which a system, product or service can be utilized by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context to use (ISO 9241-11). Previous studies have investigated the usability of portable EEG devices with a brain-computer interface (BCI) to better ensure technology transfer and acceptance (Hairston et al., 2014; Nijboer et al., 2015). However, researchers have posited that the technique is still in its early developing stages because of limitations such as sensitive noise and weak signal (Vourvopoulos & Badia, 2015).

Problem Statement

The portable EEG headset has emerged as an affordable and easy to use tool in education (Xu & Zhong, 2018). The portable EEG headset has already been tested in various applications concerning brain-computer interface (BCI), neuromarketing, and language processing (Grzegorz et al., 2015). Currently, there is no comprehensive study examining the usability of the portable EEG headset to monitor students' attention in online courses. The research must investigate the usability factors likely to impact the adoption of portable EEG headset use to monitor students' attention in their natural online learning environment.

Two factors are important to understand why usability for EEG requires additional research: online student distraction and lack of research on the usability of EEG to monitor students' attention. It is challenging to control the attention and behavior of students in an online learning environment because the Internet presents an abundance of opportunities for distraction. Failure to maintain focused attention has become a significant problem for online education. Previous studies have shown that students are more easily distracted when working unsupervised rather than being supervised by an instructor (Liu et al., 2013; Karpinski et al., 2013). Students who can focus attention on learning activities are likely to gain the information needed to succeed in their program. Some researchers have developed a system to enhance and evaluate students' attention in a learning environment (Chen & Huang, 2014; Chen et al., 2017; Kuo et al., 2017). These systems used portable EEG devices to measure changes in attention states according to brainwave signals. Slavin (2008) reported that portable EEG could automatically measure the learner's attention levels in real-time, which is necessary to conduct evidence-based education and evidence-based educational research.

Previous studies have focused predominantly on comparing devices, EEG signal quality, effectiveness, and datasets in after school settings (Xu & Zhong, 2018). There is currently insufficient knowledge of the usability of portable EEG headset to monitor students' attention in online learning. Nijboer et al. (2015) investigated the usability of three different portable EEG headsets with BCI application for communication. There are several studies that evaluate the accuracy and effectiveness of the portable EEG device (Grzegorz et al., 2015; Maskeliunas et al., 2016). Xu and Zhong (2018) suggested that the technology of portable EEG headset is still early in its development. Vourvopoulos and

Badia (2015) reported that the effectiveness of portable EEG and their cost is still unclear. It is uncertain whether they can deliver the same level of expertise as their more expensive counterparts. Lotte (2012) agreed that the BCI of portable EEG are hardly used outside the laboratory environment because the current BCI systems lack reliability and reliable performance.

Dissertation Goal

The goal of this study aimed to investigate the usability factors influencing the adoption of portable EEG headsets to monitoring students' attention in an online course. The researcher hypothesized that the EEG headset is well designed and highly usable for all students in measuring attention levels while completing online learning tasks. This included being perceived as essential and easy to use by participants. This study utilized the heuristic evaluation method by Nielsen (1993) and the think-aloud method by Ericsson and Simon (1993) to evaluate the usability of portable EEG use to monitor students' attention through online activities. For the purposes of this study, the portable EEG headset was used to monitor the real-time cognitive state of the participant. The portable EEG headset measured the electrical activity inside the participant's brain and monitored the real-time cognitive state of the student. NeuroSky is a company who has developed a non-invasive and low-cost EEG that is available to the consumer. It has Bluetooth functionality, allowing it to communicate wirelessly with its accompanying Test Bench Software (Scott & Romero, 2017).

This study recruited individuals to participate on a volunteer basis. Participants were asked to enroll in an online class through edX.com, which is a website that offers massive open online courses (MOOC). Participants wore portable EEG headsets during online instruction tasks, and their attention states were monitored through their EEG signals. This study utilized the Systems Usability Scale (SUS) questionnaire by Sauro and Lewis (2011) to generate quantitative data and the think-aloud method (Ericsson & Simon, 1993) to assess Nielsen's 10 heuristics evaluation. Participants were monitored using audio and video recordings while they used the portable EEG device and engaged in the online task.

Research Questions

This study examined the usability factors influencing the adoption of portable EEG headset use for students in online courses. The research question for this study is:

What are the usability factors that influence the adoption of portable EEG headset?

The research question was examined by using the heuristic evaluation method by Nielsen (1993); an approach based on qualitative research. This study applied the heuristic method to evaluate the portable EEG based on the Nielsen's 10 rules as follows:

1. Visibility of system status: User can install, use, and configure the EEG headset with ease.
2. Correspondence between system and the real world: The EEG headset and BCI software should speak the participant's language, with words, phrases, and concepts familiar to the participants, rather than system-oriented terms.
3. User control and freedom: The user can start and stop the headset.
4. Consistency and standard: The headset can function with other devices through current standards of technology such as Bluetooth and mobile devices.
5. Error prevention: The EEG headset can prevent the failure of the participant from accidentally clicking.

6. Recognition rather than recall: The application responds with intuitive action of the user.
7. Flexibility and efficiency of use: The headset supports the head size of the user. User can comfortably use the headset during activity.
8. Aesthetic and minimalist design: The headset design is simple and elegant.
9. Help users recognize, diagnose, and recover from errors: The application gives suggestions or guidelines when the user gives conflicting commands.
10. Help and documentation: The headset's troubleshooting documentation is accessible and user friendly.

The researcher provided participants a task list of instructions that guided them in their use of the EEG headsets. The task list was generated as a comprehensive guide for participants to complete the study and was designed to familiarize users with the headset device. Each participant followed a task list of instructions that was included with the EEG headset. The task list of instructions addressed Nielsen's (1993) 10 rules of heuristic evaluation and provided direction for the participant to become better acquainted with the EEG. The example instructions are as follows:

Table 1
Example of Task List for Evaluation of Portable EEG

Number of Steps	Task Description
Step 1	**Setup**: Install the application > Create account > Login
Step 2	**Power on and connect**: Turn on the portable EEG headset and Bluetooth on the mobile device. Pair the headset and mobile device via Bluetooth. Put on portable EEG headset and connect EEG sensors to the scalp.
Step 3	**Run software diagnostic**: On the mobile device, complete the software diagnostic to ensure that the portable EEG headset is working correctly.
Step 4	**Begin activity**: Press "Start" when ready to begin the learning activity

Number of Steps	Task Description
Step 5	**Engage in activity**: Engage in learning task. The software will alert the user with a sound and display a message when the attention level is low. The software also includes messages that motivate the user to stay on task e.g. "Keep going"
Step 6	**Online session:** The user will follow the think-aloud instruction and stay in an online session for 30 minutes.
Step 7	**Finish activity:** Press "Stop" on the mobile device to complete the session.
Step 8	**View summary**: Click the report to display a summary of the learning session.

The research question was examined by using the think-aloud method detailed by Ericsson and Simon (1993). Olson et al. (1984) stated that think-aloud technique is an effective method to assess higher-level thinking processes and suggested that it could be used to study individual differences in performing the same task. According to Charters (2003) the think-aloud method has a strong theoretical foundation and is a powerful way to explore individuals' thought processes.

Quantitative data was collected through the System Usability Scale (SUS) and was utilized to test the researcher's hypothesis that the EEG headset was well designed and highly usable for students and for measuring attention levels while completing learning tasks. This included being perceived as essential and easy to use by participants.

Relevance and Significance

Measuring attention and behavioral engagement during learning activities is a challenging task. However, the availability of new technology can evaluate a student's attention in real time using measurements from the EEG headset. Use of EEG technology in an online learning environment is ideal because it can maximize a student's ability to self-monitor their attention. This is necessary because learning performance can suffer in the absence of supervision by an instructor. Results from this research could help develop important guidelines to implement technology to monitor students' attention who enroll in an online course.

Usability heuristics have been established for different uses and applications as general guidelines for user interfaces (Nielsen, 1993). However, this does not exist for present day portable EEG technology in online courses.

Barriers and Issues

It is important to recognize a number of challenges to implementing the proposed research. The researcher had access to only one (1) NeuroSky MindWave. In order to accomplish the research, one participant at a time was able to use the headset and complete the online learning task. As a result, the data required more time to collect because the EEG instrument had to be passed from one participant to the next.

The NeuroSky MindWave device requires software on smartphones to monitor the attention of the user. This was a barrier because it required that participants be knowledgeable about smartphone use, smartphone app installation, and connection to Bluetooth devices. Furthermore, participants used their own computers to access the MOOC to complete the learning task. Therefore, a requirement is that participants must be knowledgeable on how to use a computer to access, register, and use a MOOC course to complete a task.

Assumptions, Limitations and Delimitations

Assumption

This research study utilized questionnaires with the assumption that participants are honest and unbiased in completing the survey. Furthermore, it is assumed that participants had the ability to utilize their smartphone devices and computers appropriately to partake in the study. This included navigating their smartphone devices, installing applications on their device, connecting with the EEG headset via Bluetooth, and navigating online courses and websites. It was assumed that participants had not completed the edX online courses offered in the past and that there are no language barriers present in the task list, survey, or learning task.

Limitations

The participants in the study had different levels of education or experience with online courses which could impact the results of the study. Participants had difficulty with technical requirements such as application installation on smartphone devices. EEG feedback can be affected by the emotional state of participants, i.e. a participant who had meditated prior to the task may have different results than a participant who was feeling anxious.

Delimitations

This study did not measure biometric changes in participant's brain waves, attention levels, or emotional states. This study did not evaluate the efficacy of edX online courses. This study did not assess whether usage of EEG devices positively or negatively affected results from online courses. Research was limited to observation and survey instruments.

Definition of Terms

- Electroencephalography (EEG) – The type of psychophysiological measurement used to examine the relationships between mental and bodily process (Xu & Zhong, 2018)

- Portable EEG – The small electroencephalogram (EEG) that the users are able to move around and connect with smart devices. Most of them offer a wireless, ergonomic, low-cost and pain-free EEG monitoring solution for researchers and users who are interested in neurological examination (Xu and Zhong, 2018).
- Brain-Computer Interface (BCI) – The platform that establishes a connection between a human and an external device. The BCI enables us to understand human brain activities through the operation of the brainwaves (Chen, 2017).
- Brainwaves – The different frequency bands of the brain signal associated with a particular mental state (Chen, 2017).
- Massive Open Online Courses (MOOC) – The online courses that unlimited participation and open access via the Internet.

Summary

EEG devices have been widely deployed in health and medical research. Now, they are being used in educational research to improve students' performance as they engage in learning tasks (Xu & Zhong, 2018). For the purpose of this study, researchers focused on usability factors that affected the adoption of EEG for online educational tasks. This study aimed to broaden this area of research. Researchers provided participants with EEG headsets, directions for connecting to smartphone devices, and access to an online course.

Chapter 2

Review of the Literature

Overview

The purpose of this chapter is to present a review of the literature that covers the major topics applicable to EEG technology: EEG Technology, EEG devices in education research, usability in EEG technology, usability evaluation method, and the gap in the research that this study attempted to address. Each topic provided background information and support to the investigation of the factors that influence the adoption of portable EEG headset.

EEG Technology

Electroencephalography (EEG) is an electrophysiological monitoring method. It is typically noninvasive. With the electrodes placed over the scalp, it measures and records electrical activity in the brain called brainwaves. EEG signal fluctuations from brainwave frequencies occur within several frequency bands and these fluctuations have been associated with focused attentional processing, engagement, and frustration (Mostow et al., 2011). These frequency bands are an indicative of learning (Beker et al., 2010). The recent availability of simple, low-cost, and portable EEG monitoring devices expands the availability of the technology and allows its application to be extended out of the laboratory and directly to consumers (Wang et al., 2013).

The Portable EEG and Brain-Computer Interface

The NeuroSky MindWave is a portable headset with audio and a single-channel EEG sensor. The sensor can measure brainwaves from electrodes placed around the head. While EEG devices in labs require gel or saline for use, the NeuroSky MindWave does not. Developed for consumers, it is comfortable to wear and simple to use. The headset can detect multiple different brainwave states including attention and meditation (NeuroSky, 2015). Figure 1 below for the NeuroSky MindWave.

Figure 1. The NeuroSky MindWave

The portable EEG (NeuroSky MindWave) is placed on the head and sensors are attached to various regions around the scalp to detect brain waves. Brain waves are categorized into five different bands or frequency types known as alpha, beta, gamma, delta, and theta. Each frequency is associated with a mental state. Table 2 lists the frequency bands and their associated mental states.

Table 2
Types of Brain Waves

Band Name	Frequency	Mental State
Delta	0-4 Hz	Deep sleep, unconscious
Theta	4-8 Hz	Creativity, dream sleep, drifting thoughts
Alpha	8-12 Hz	Relaxation, calmness, abstract thinking
Low Beta	12-15 Hz	Relaxed focus, integrated
Midrange Beta	15-20 Hz	Thinking, aware of self, high alertness
High Beta	21-30 Hz	Alertness, agitation
Gamma	30-100Hz	Motor functions, higher mental activity

Brain wave signals are detected by the EEG headset and transmitted to a computer or mobile device via the brain-computer interface (BCI) (Chen & Huang, 2014). The BCI is a software that processes and analyzes the EEG brain wave data. The BCI software displays a real-time map of participant activity in four significant brainwave frequency bands (Delta, Theta, Alpha, and Beta). Through the BCI program, EEG feedback can be displayed numerically or graphically in real-time (Chen & Huang, 2014; Chen & Wu, 2015). Users can view and interpret the EEG feedback data in a form that is easily understandable such as graphics or icons.

Brain-Computer Interface Software

The Brain-Computer Interface (BCI) software called Effective Learner is the application that display brain wave activity in a readily available and easy to comprehend format for the user. Effective Learner application displays brain wave data graphically. It uses colors and numbers to communicate to the user whether attention levels are high or low. The colors that Effective Learner displays are blue, green, orange, yellow, and red. These colors are associated with the user's level of concentration. See Figure 2 for the different of colors and their associated concentration levels.

Figure 2. The Concentration Levels

Effective Learner also includes messages that motivate the user to stay on task e.g. “Keep going! and “Get back on task!”. When the user is effectively concentrating on their task, Effective Learner will display a positive message in blue encouraging them to continue. If the user distracted, Effective Learner will alert the user with a sound and display a message in red, indicating that they need to concentrate more. Effective Learner can also display a summary of information regarding the user’s concentration levels during a learning session. A user can view this information to assess how well they concentrate over time. See Figure 3 for example of Effective Learner application.

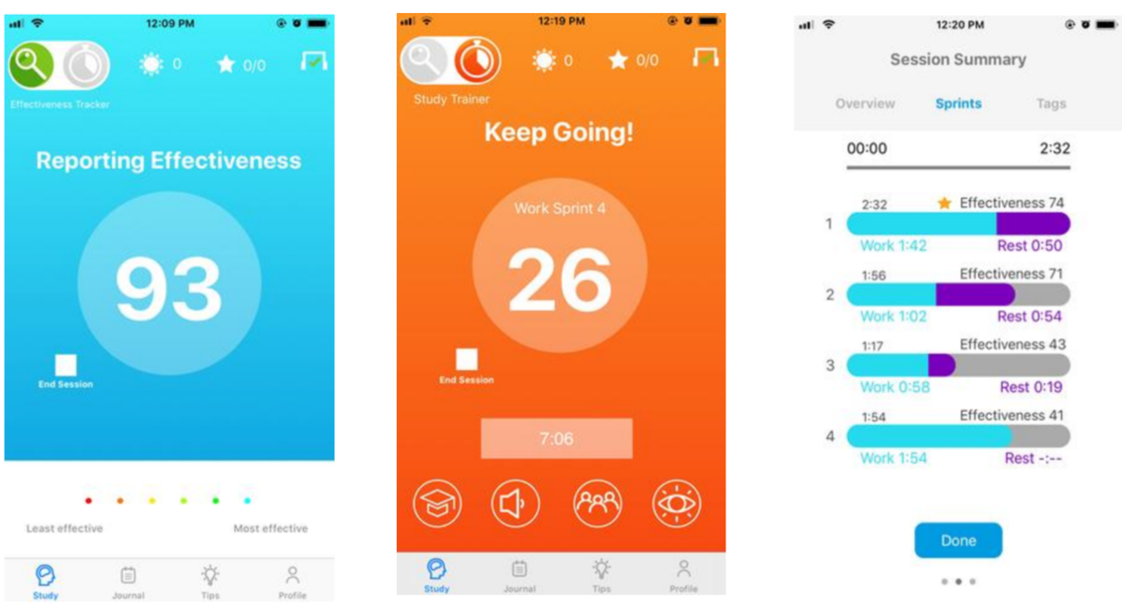


Figure 3. The Effective Learner Application

EEG Device in Education Research

As mentioned in Chapter 1, the abundance of distractions readily available Internet can be a barrier for students who study in online education. Student attention during the learning process has been recognized as an important factor of effective learning (Chen, 2017; Kuo et al., 2017). Previous studies have successfully used EEG devices to evaluate students' level of attention include:

Chen (2017) used an EEG based methodology to examine differences in Game-Based Learning (GBL) and traditional learning. Participants wore an EEG headset and engaged in both traditional learning and GBL. Results from brainwave data confirmed that differences between GBL and traditional learning on sustained attention and relaxation were minimal. The author also found that students who were not familiar with the content tended to pay more attention during GBL because it represented a radically different learning approach. These results exhibit a basis for participant feedback on their own attention patterns while using EEG in the learning environment.

Chen and Huang (2014) developed the Attention-based Self-Regulated Learning Mechanism (ASRLM). ASRLM uses brainwave detection and was designed to enhance the sustained attention of learners while engaging in a reading task. The authors found that monitoring and prompting by the ASRLM can assist learners to achieve Self-Regulated Learning (SRL) goals and read more actively online. This resulted in enhanced reading performance and achievement of goals due to the feedback of SRL. This research is an important step in investigating EEG use with self-learning which is often the basis for online learning.

Chen and Wu (2015) explored how three commonly used video lecture styles influenced sustained attention, emotion, cognitive load, and learning performance of participants. The video lecture styles showcased verbalizers and visualizers in an autonomous online learning scenario. They conducted a two-factor experimental design, that included brainwave detection via EEG, emotion-sensing equipment, cognitive load scale, and learning performance test sheet. This study identifies participants varying attention levels based on different online content while confirming that the consumer level EEG device can detect differences in attention levels through brain wave monitoring.

Sun and Yeh (2017) explored the potential benefits of using portable EEG by providing audio feedback based on individuals' brainwave signals during learning tasks. The authors used audio feedback to provide timely and appropriate cues when participant's brainwave signals indicated that their attention level was low. The authors found that the audio feedback signal had a significant effect on the mean attention index of overall brainwaves. This study highlights the significant effect of regulating participants attention states via EEG while they are engaged in a learning task.

Usability

Usability refers to the extent to which a system, product or service can be applied by specified users to achieve certain goals with effectiveness, efficiency, and satisfaction in a particular context (ISO 9241-11). Nielsen (2012) presented that usability is an attribute that examines how easy user interfaces are to use. It also refers to methods for improving the ease of use during the design process. Nielsen's (2012) five quality attributes are as follows:

- Learnability – Level of difficulty the user will have performing tasks the first time they encounter the design.
- Efficiency – How quickly users can perform tasks once they are familiar with the design.
- Memorability – How easily the user can become reacquainted with the design after a period of nonuse.
- Errors – Quantity, severity, and recoverability of errors.
- Satisfaction – Level of users' satisfaction with the design.

The previous study has shown that the usability evaluation has a significant role in the user interface design. Usability evaluation focuses on how users can learn and use the product to achieve their goals. Greenberg et al. (2008) explained the importance of determining an appropriate evaluation method and how harmful it could be if applied incorrectly.

Usability Evaluation Method

Nielsen's 10 Heuristic Evaluation

Heuristic evaluation is a usability testing method aiming to improve the user interface design. Heuristics can direct the design or evaluate the usefulness of a user interface. Nielsen's heuristic method (1993) examines 10 different domains of usability to ensure that each domain is inspected carefully and identify potential problems. While heuristics alone can be a beneficial method for analysis of usability, this study also used think-aloud method (Ericsson and Simon, 1993) for a more complete analysis. Below, Nielsen's heuristic method was elaborated followed by the think-aloud method. The set developed by Nielsen (1993) consist of 10 rules which include:

- Visibility of system status: Users remain informed about what’s happening with the system in real time through appropriate feedback.
- Correspondence between system and the real world: The system speaks the users' language, with words, concepts, and phrases familiar to the user.
- User control and freedom: Users can easily undo and redo. Users always have an emergency exit to leave an unwanted state.
- Consistency and standard: The system is easy to understand and is intuitive to the user because it is based on a current standard of use
- Error prevention: Error-prone conditions are eliminated, and confirmative actions are committed by the user.
- Recognition rather than recall: The user does not have to remember information from one dialogue to complete the next. Necessary information is always made available on prompts, actions, and other options.
- Flexibility and efficiency of use: The system caters to both inexperienced and experienced users.
- Aesthetic and minimalist design: User is not exposed to irrelevant information.
- Help users recognize, diagnose, and recover from errors: User can easily comprehend error messages.
- Help and documentation: User can easily find documentation for help.

Think-Aloud Method

The think-aloud method is a research method in which participants verbalize any words or thoughts that come into their mind as they complete a task (Charters, 2003). The think-aloud method was introduced in the usability field by Lewis (1982) and developed based on the techniques of protocol analysis by Ericsson and Simon (1993). The researcher asked the participant to verbalize thoughts that emerge as a task is being completed. The method aims to elicit the information required for task performance and, consequently, the verbalizations should reflect the thoughts being attended to at the time (Salkind, 2010).

Olson et al. (1984) reported that using think-aloud technique was effective in assessing higher-level thinking processes. It could also be used to observe and record how individuals react differently to a system. Ericsson and Simon (1980) reported that verbal reports from think-aloud data are a “thoroughly reliable” source of information about what the individual is experiencing in the moment (p. 247). One criticism of this method is that task performance may be altered by the action of continual verbalization by the participant. However, Ericsson and Simon (1993) argued that participants’ verbalizations do not affect their thought processes.

The System Usability Scale (SUS)

The System Usability Scale (SUS) is a tool for measuring usability. It consists of a ten (10) item questionnaire with five (5) ratings for respondents that range from strongly disagree to strongly agree. SUS scores range between 1-100 and 68 is considered the average score, and anything below 68 is below average (Sauro & Lewis, 2011). The original SUS was created by Brooke (1996) and allowed the researcher to evaluate a wide variety of products and services including hardware, software, mobile devices, websites, and applications. It used both positive and negative wording to maximize validity by reducing acquiescence, which is a tendency for a respondent to concur with the question and extreme response biases, which are a tendency to respond with extremes (i.e. strongly agree or strongly disagree). However, Sauro and Lewis (2011) posited that there are two disadvantages of the original SUS: respondents accidentally agree with negative items (mistakes) and researchers forget to reverse the positive and negative scales during analysis (miscoding). Sauro and Lewis (2011) concluded that the researchers can use the all-positive version with confidence because respondents are less likely to make mistakes on the questionnaire, researchers are less likely to make errors in coding when analyzing, and the scores will be similar to the standard SUS. Sauro and Lewis (2011) developed an updated SUS with only positive questions rather than alternating between positive and negative questions. A list of the updated positive questions can be seen below:

- I think that I would like to use this system frequently.
- I found the website to be simple.
- I thought the website was easy to use.
- I think that I could use the website without the support of a technical person.
- I found the various functions in the website were well integrated.
- I thought there was a lot of consistency in the website.
- I would imagine that most people would learn to use the website very quickly.
- I found the website very intuitive.
- I felt very confident using the website.
- I could use the website without having to learn anything new.

Usability in EEG technology

The use of portable EEG device and brain-computer interface (BCI) have recently become more frequent in research (Grzegorz et al., 2015). Usability design is a necessary step in the production of a product that seeks to improve a product before it is sold to consumers. Previous studies have evaluated the usability of portable EEG devices as follows.

Izdebski et al. (2016) evaluated the usability of EEG systems by comparing seven (7) EEG devices and focusing on user experience (UX). The authors found that user fatigue has significant effects on EEG signal quality and task performance. The differences in comfort level of users were suggested to be a factor that induced fatigue and interfered with the integrity of the data due to uncontrolled variables. The authors suggested that it is important to consider participants' comfort as part of experimental design. The authors also suggested for future research that it would be beneficial to investigate the relationship between mobility and user experience.

Nijboer et al. (2015) compared the usability of three different portable EEG headset-based BCI applications. The authors found that the acceptance of portable EEG devices is based on the usability of the sensors of the headset. The authors recommended that the design of headsets should aim to leave hairstyles intact and avoid materials on or near the face. The authors also recommended that future studies utilize within-subject designs because participants can provide beneficial insight from their personal comparisons. Interviews with open questions and qualitative analysis may be needed to better understand individual adoption of portable EEG device.

Hairston et al. (2014) evaluated the usability of four commercial EEG systems in terms of participant comfort issues. The authors reported that the EEG systems are assessed on five design elements: adaptability of the system for differing head sizes, subject comfort and preference, variance in scalp location for the recording electrodes, stability of the electrical connection between the scalp and electrode, and timing integration between the EEG system, the stimulus presentation computer, and other external events. The author reported that more systematic study of usability factors would benefit future EEG system development. The author also concluded that participant comfort changes over time with portable EEG headsets and is important to consider as comfort at one hour may be discomfort at three hours.

Vourvopoulos and Badia (2015) evaluated the effectiveness of portable EEG devices with a BCI system. The authors found no significant differences in online performance among the three EEG headset. The devices were reported to have similar effectiveness and no perceived difference in terms of comfort, appearance, speed/ease of setup, and overall workload in actual system performance.

The Gap in Current Research

Although there is current research reporting portable EEG comparisons, effectiveness, and signal quality, there is currently a gap in the literature understanding the usability of portable EEG devices. Nijboer et al. (2015) compared only EEG devices by sensors, product quality, and product effectiveness with individuals who were reading the alphabet. Vourvopoulos and Badia (2015) tested signal quality when a participant wore a portable EEG headset and compared the quality of various headsets. Hairston et al. (2014) tested usability for EEG headsets and focused on system design, usability factors, and participant comfort issues.

Previous studies have shown the benefits of utilizing EEG devices research. However, expansion EEG use and adoption towards general use is still in development. This study evaluated the usability of EEG headsets in a casual setting to monitor students' attention while completing online learning tasks. More research is needed to examine usability factors for the portable EEG both quantitatively and qualitatively in order to better understand aspects that influence adoption of the device. Suggestions for future aspects of research include: Hairston et al. (2014) who suggested that future research should focus on real-world applications of portable EEG devices, and Vourvopoulos and Badia (2015) recommends consideration of user performance and experience in order to increase the application of EEG headsets for daily and general use.

Summary

In Chapter 2, an overview of literature relevant to the discussion of portable EEG usability was presented which included: EEG technology, EEG devices in educational research, usability, usability in EEG technology, and usability evaluation methods. Nielsen's heuristic method and think-aloud method were discussed as ways in which to evaluate a product. This chapter concluded with a gap in research as it applies the adoption of portable EEG headset in online education.

Chapter 3

Methodology

Overview

This chapter describes the approach and methodology that were used to conduct this study. More specifically, this chapter expounds upon the procedures in this study which included heuristics and think-aloud method to investigate the usability factors that influence the adoption of portable EEG headset to monitor students' attention in online activity.

Approach

This study was conducted using Nielsen's 10 heuristic evaluation and think-aloud method (Ericsson and Simon, 1993) to investigate the usability of EEG monitoring to determine students' attention in online tasks. The researchers hypothesized that the EEG headset is well designed and highly usable for students and measuring attention levels while completing learning tasks. The significance of the study was to determine usability factors and student's satisfaction in utilizing the portable EEG headset in monitoring attention levels in online learning. The null hypothesis (H_0) was that all groups of students/users would determine the portable EEG headset to be equally usable and score the headset as statistically equally usable.

Participants were instructed to complete a learning activity while the researcher observed participants during the assignment. While working on the task, participants verbalized any feelings, opinions, or comments regarding the headset, task or concerning the study. While participants verbalized, the researcher utilized the think-aloud method to gather data on product usability. Following completion of the study, participants completed the System and Usability Scale (SUS) questionnaire to provide quantitative data on usability of EEG monitoring during learning tasks.

Research Techniques Utilized

The Heuristics Evaluation and Think-aloud Method

The researcher utilized the heuristic evaluation form by Nielsen (1993) and think-aloud task (Ericsson & Simon, 1993) to qualitatively assess portable EEG usability (see Appendix A and B). The think-aloud method was used to record users' experience while utilizing the EEG headset during a learning task. The participant followed the task instruction (see Appendix B). When assessing usability with the think-aloud method, participants were video, and audio recorded by the researcher while they used the portable EEG headset. Participants used the portable EEG headset while continuously thinking out loud. Thoughts, procedures, ideas, error findings, and error recoveries were verbalized in the moment by the participant. The heuristic evaluation form was completed by the researcher (see Appendix A). The following heuristics were used in the evaluation of usability:

1. Visibility of system status: Participant can install, use, and configure the EEG headset with ease. Functions of BCI software are easy to see and constantly visible. Software will interact with users to provide feedback in real time.
2. Correspondence between system and the real world: The EEG headset and BCI software should speak the participant's language, with words, phrases, and concepts familiar to the participants, rather than system-oriented terms.

3. User control and freedom: The participant can start and stop the headset. BCI software allows users to control it when other notifications arise on mobile device. BCI software allows user to multitask.
4. Consistency and standard: The headset can function with other devices through current standards of technology such as Bluetooth and mobile devices. EEG and BCI software adhere to platform standards and is consistent in terms of controls, gestures, and other elements that are intuitive to the user.
5. Error prevention: The EEG headset can prevent the failure of the participant from accidentally clicking. The EEG headset and BCI software can function without error or bugs. Should errors occur, user can recover easily to prevent the user from getting disoriented.
6. Recognition rather than recall: The application responds with intuitive action of the user. Main functions of EEG headset and BCI software are easily accessible. Participant is not required to remember information in order to use functions of software.
7. Flexibility and efficiency of use: The headset supports the head size of the user. User can comfortably use the headset during activity. Size and fit of EEG headset is flexible and can change depending on the user's needs.
8. Aesthetic and minimalist design: The headset design is simple and elegant. Visual design of EEG headset guides user to important elements of function. Menu layout of BCI software is intuitive and easy to understand.
9. Help users recognize, diagnose, and recover from errors: The application gives suggestions or guidelines when the user gives conflicting commands. Error

messages are explained in language easy for the user to understand. Errors to not cause the user to restart MOOC task.

10. Help and documentation: EEG headset and BCI software is designed to reduce the need for help documentation. The headset's troubleshooting documentation is accessible and user friendly. Help documentation is easy to understand.

The System Usability Scale (SUS)

The quantitative data was obtained from the post-test questionnaire that followed the System Usability Scale (SUS) by Sauro and Lewis (2011) (see Appendix C). The SUS survey evaluated users' opinions to test the hypothesis that the EEG headset was well designed and highly usable for students in measuring attention levels while completing learning tasks. The positive SUS contained 10 items with five response options for respondents (see Table 3).

Table 3
The Positive Questions of the Standardized Usability Survey

Item #	Question
1	I think that I would like to use the EEG headset frequently when I have to concentrate my task.
2	I found the EEG headset to be simple to use to monitor my attention level.
3	I thought the EEG headset was easy to use for online students.
4	I think that I could use the EEG headset without the support of a technical person.
5	I found the various functions in the EEG headset were well integrated.
6	I thought there was a lot of consistency in the EEG headset when I try it on.
7	I would imagine that most people would learn to use this EEG headset very quickly to improve their learning experience.
8	I found the EEG headset very intuitive.
9	I felt very confident using the EEG headset to monitor my attention in an online class.
10	I could use the EEG headset without having to learn something new.

Participants

This usability study was conducted to determine effectiveness and ease of utilizing an EEG headset to assist in online learning, therefore, participants were not limited to any demographic group, as online learning is not limited by any parameters. However, the perceptive ease of use can be different depending on age of participant or experience with online courses and technology.

As stated previously, this study used both quantitative and qualitative research techniques. A convenience sample was used to gather participants in this study. Nielsen (1994) dictated that a qualitative study requires only 5 participants to glean impactful insights into design improvement; after the fifth user, many of the initial observations were repeated, and not much new information was gathered.

Furthermore, according to Nielsen (2006), when collecting quantitative usability metrics, testing should involve 20 participants to ensure sufficient statistical inference. The researcher utilized a convenience sample of participants through recruiting 20 volunteers from friends, coworkers, and university students who intend to take online courses within the next 5 years to participate in this study. Of the 20 participants, 5 were randomly chosen to be qualitatively measured through Nielsen’s 10 heuristic evaluation. Prior to beginning the study, Institutional Review Board (IRB) approval for the testing of human subjects was obtained.

Procedure

The major steps to conduct this study were as follows:

1. Prospective study participants were recruited based on their determination to begin online learning courses.

2. Participants reviewed and complete consent form for the study and audio and video recording.
3. Participants enrolled in the MOOC course.
4. The researcher explained the task description, general overview of setup for EEG headset and application is given.
5. Participants were introduced to the think-aloud method and instructed to verbally dictate any thoughts or comments that arise throughout the procedure and learning task.
6. The participants received the EEG headsets and were asked to engage in an assigned learning activity.
7. During the study, the researcher completed Nielsen's 10 heuristic evaluation form for each participant.
8. Following completion of the learning session, participants were given a post-study questionnaire by the System Usability Scale (SUS).

Data Analysis

The heuristic evaluation method by Nielsen (1993) was used to explore the usability of portable EEG headset. The think-aloud method by Ericsson and Simon (1993) was used to observe and record the user experience. Qualitative data was collected via Nielsen's 10 Heuristic Evaluation form and participants' thoughts during the study were transcribed via the think-aloud method (Ericsson & Simon, 1993).

Qualitative data was analyzed through thematic analysis. Raw data was broken down and organized by marking individual observations and recurring themes with specific codes in order to determine a significant or repeated theme. Themes are a description of a need, practice, or another occurrence that is repeated multiple times across participants that the data set reveals (see Figure 4).

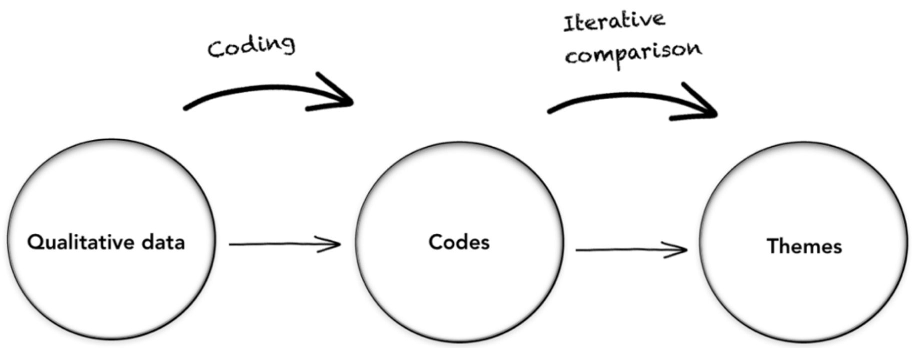
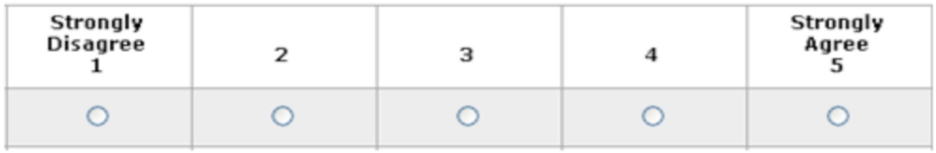


Figure 4. Thematic Analysis Process

The software for conducting thematic analysis in this study was Computer-Aided Qualitative-Data-Analysis software (CAQDAS). The heuristic evaluation transcripts and the think-aloud notes were uploaded into a software program. The program analyzed the text systematically through formal coding. This study used descriptive code types to describe what the data was about. The CAQDAS software helped with the discovery of themes by offering various visualization tools such as word trees or word clouds, that allowed the coded data to be presented in many different ways.

Quantitative data was collected from the responses on the SUS questionnaires. A one-tailed t-test was used to determine whether satisfaction scores were significantly equal to or greater than the mean SUS score of 68 (Sauro & Lewis, 2011). Ten questions on the SUS questionnaire are equally weighted and total 100 points. The SUS uses a 5-point scale to assess user attitudes (Likert, 1932) (See Figure 5).



Strongly Disagree 1	2	3	4	Strongly Agree 5
○	○	○	○	○

Figure 5. Standard SUS Reported Likert Scale

The individual scores for each question were processed and an overall score was generated via the following steps:

Step1: Convert the scale response into a value for each of the 10 questions

Strongly Disagree	1 Point
Disagree	2 Points
Neutral	3 Points
Agree	4 Points
Strongly Agree	5 Points

Step 2: Calculate

As mentioned in Chapter 2, this study used the updated SUS by Sauro and Lewis (2011) which contained positive questions rather than negative questions as well as the formula based on their study:

- X = Sum of the points for all odd questions - 5
- Y = 25 - Sum of the points for all even questions
- SUS Score = (X + Y) x 2.5

The SUS score presented the usability performance with regards to effectiveness, efficiency, and overall ease of use. The score from SUS was utilized to test the hypothesis that the students' satisfaction (SUS scores $\geq$ 68) was significant for students' adoption of the portable EEG headset in online tasks. As mentioned in Chapter 2, the average SUS score is 68 (Sauro & Lewis, 2011). The average SUS score falls at the 50th percentile rank. This indicates that any raw scores above 68 are above average (Sauro & Lewis, 2011) (See Figure 6).

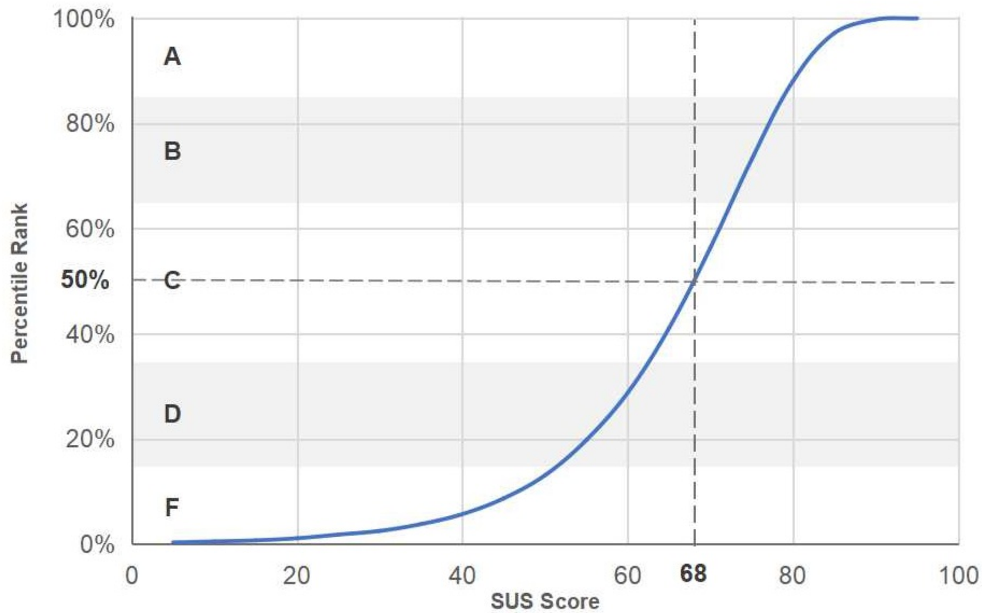


Figure 6. Raw SUS Scores and Percentile Rank

Format for Presenting Results

Data from the usability tests and user satisfaction surveys were transferred to spreadsheet format. Video footage was saved digitally in separate video files for each participant. Both written information and video footage were analyzed to assess usability factors based on user experience. Qualitative data gathered by the heuristic evaluation method came in two forms: notes of users' dialogues taken by the observer and video footage of subjects using the portable EEG headset. The transcript of the users' dialogues was gathered on a computer in a text file by the researcher.

Resource Requirements

Institutional Review Board (IRB) approval for the testing of human subjects was obtained. The researcher provided the NeuroSky MindWave for investigating the adoption of portable EEG headsets in online learning. The researcher required users to install programs that connected to the EEG device headset on their smartphone. Participants needed to provide their own working computer, smartphone, and Internet connection. The following resources required to perform this study were as follows:

Hardware

- The portable EEG headset (NeuroSky MindWave)
- iPhone
- Computer Laptop

Software and Systems

- The Effective Learner Application (BCI Software)
- SPSS Software
- 3 frees online courses from edX.com
- The qualitative data analysis software NVivo 12
- The IBM SPSS Statistics Version 26
- The Minitab

Summary

In order to determine the usability factors that influence the adoption of portable EEG headsets, 20 participants were recruited to assess the usability of portable EEG headsets. Participants installed software on their mobile devices that were needed to connect with the portable EEG headset. Participants wore the portable EEG headset while engaging in an online task from a MOOC. Qualitative data and quantitative data from participants were evaluated by two methods and one questionnaire: Nielsen’s (1993) heuristic method, Ericsson and Simon’s (1993) think-aloud, and Sauro and Lewis’s (2011) SUS questionnaire used to assess in SPSS and CAQDAS used to analyze data.

Chapter 4

Results

Overview

This chapter describes the results of the data analysis procedures stated in Chapter 3. This study attempted to provide answers to the research question with the primary purpose of investigating the usability of portable EEG headset use for monitoring students' attention in online activity.

Qualitative Analysis

The qualitative result was obtained from observations based on the heuristic evaluation method by Nielsen (1993) and the think-aloud method by Ericsson and Simon (1993). The researcher familiarized the participants with the task list (see Appendix B) before the test. The researcher encouraged the participants to think aloud during the activity in order to obtain qualitative data. Each participant completed the task list within 30 minutes. Some participants encountered problems during the task, such as complications with registering a new user due to BCI software connection error. The researcher replaced dysfunctional devices with working devices and directed the participant to screen-capture an image of the problem for troubleshooting (see Figure 7). Connection issues between BCI software and smartphone devices affected data collection by requiring participants to repeat steps 1-3 in order to proceed with the task list. Furthermore, assessment ratings were affected negatively by participant's struggle with EEG headset connection issues.

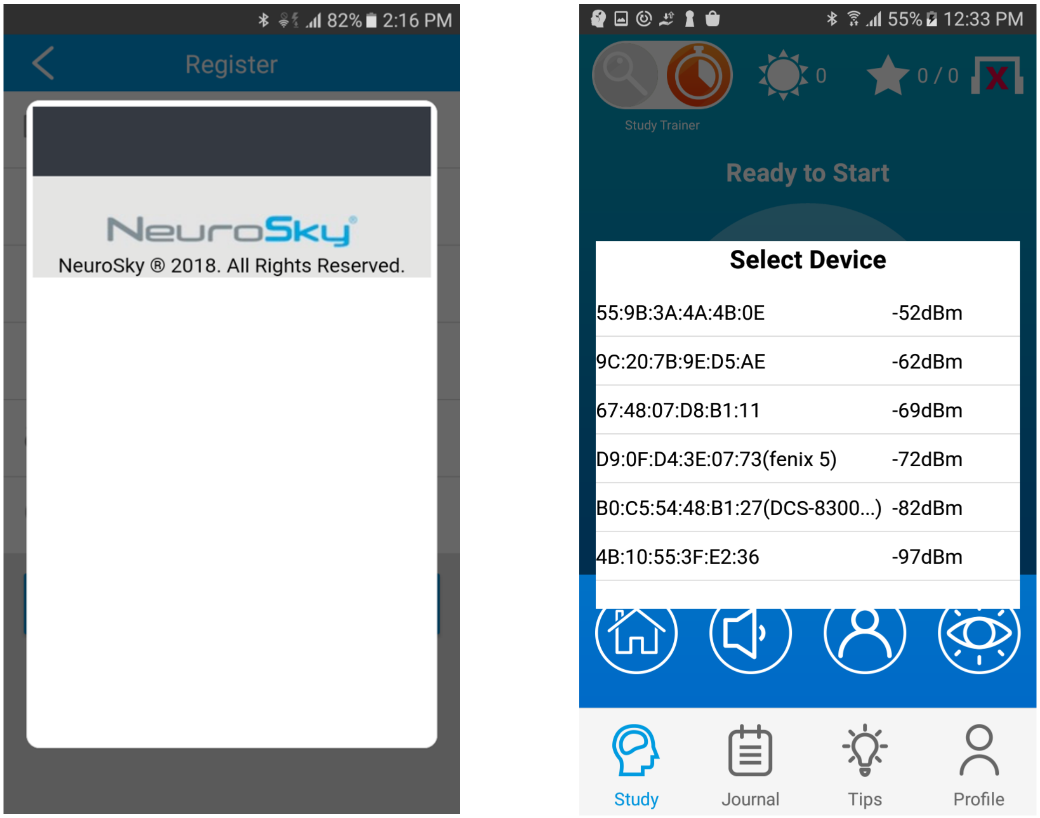


Figure 7. The Problem Issue of The EEG Headset

When the participant arrived at the test area, the researcher explained the task list and familiarized the participant with activity procedures. Then, the participant began the activity by following each step from the guidelines of the task list. Next, the participant put on the headset and began the learning activity in a MOOC online course. During the test, the researcher observed each participant individually and recorded results on the heuristics evaluation based on Nielsen (1993) (see Appendix A). In total, data from 5 randomly chosen participants (Participant #2, Participant #3, Participant #5, Participant #7, and Participant #16) were collected through Nielsen's 10 heuristic evaluation and the Ericsson and Simon's (1993) think-aloud method. The researcher presented instructions equally to all five participants (see Appendix B).

Nielsen's (1994) severity ratings were used to identify the most serious problems of the portable EEG headset assess the need for additional usability efforts. Low severity ratings would indicate that the portable EEG headset is not ready for consumer use. However, if ratings merely result in cosmetic issues, they could indicate that the portable EEG headset may be ready for release. According to Nielsen (1994), the severity of a usability problem is a combination of three factors:

- The frequency with which the problem occurs
- The impact of the problem if it occurs
- The persistence of the problem

Based on Nielsen (1994), this study ranked each of 10 rules by severity ratings for usability problems as follows:

- Positive: Results are beneficial to the participant's ability to perform their given task.
- Cosmetic issue: Affects the participant's performance superficially and should be fixed only if time permits.
- Minor issue: Hinders the participant's ability to navigate and should be fixed when possible.
- Major issue: Frustrates or confuses participants and requires repair as soon as possible.
- Catastrophic issue: Prohibits participants from performing their given task and requires an immediate modification.

The Nielsen's Ten Usability Heuristics and severity ratings were used for coding in the software NVivo 12. Ten of Usability Heuristic consist of five rankings: positive, cosmetic, minor, major, and catastrophic. The researcher's observation and the participant's think-aloud were coded into the five rankings. Open-ended questions were used by the researcher to guide the participant to elicit more detail of their experience. The researcher created an individual document for each participant interview and imported it to the qualitative analysis software. All five (5) documents were coded into 10 themes. Each theme consists of five sub-themes. The coded are illustrated below (see Figure 8 and Figure 9).

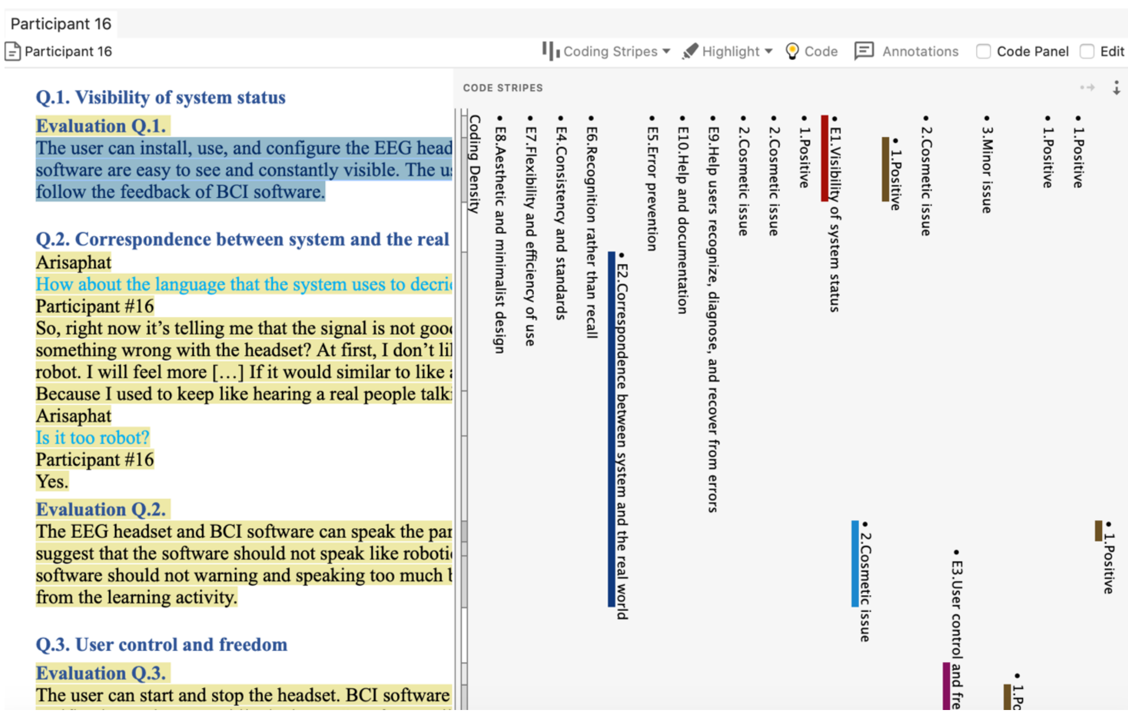


Figure 8. Example of Coded Evaluation Document in The NVivo Software

Name	Files	Referen...	Created on	Created...
▼ E1.Visibility of system stat...	5	5	5/12/20, 5:08 PM	AS
1.Positive	3	3	5/15/20, 2:13 AM	AS
2.Cosmetic issue	1	1	5/15/20, 2:13 AM	AS
3.Minor issue	0	0	5/15/20, 2:14 AM	AS
4.Major issue	1	1	5/15/20, 2:15 AM	AS
5.Catastrophic issue	0	0	5/15/20, 2:15 AM	AS
▼ E10.Help and documentat...	5	5	5/12/20, 6:19 PM	AS
1.Positive	5	5	5/15/20, 2:16 AM	AS
2.Cosmetic issue	0	0	5/15/20, 2:16 AM	AS
3.Minor issue	0	0	5/15/20, 2:16 AM	AS
4.Major issue	0	0	5/15/20, 2:16 AM	AS
5.Catastrophic issue	0	0	5/15/20, 2:16 AM	AS
▼ E2.Correspondence betw...	5	5	5/12/20, 5:11 PM	AS
1.Positive	5	5	5/15/20, 2:16 AM	AS
2.Cosmetic issue	2	2	5/15/20, 2:16 AM	AS
3.Minor issue	0	0	5/15/20, 2:16 AM	AS
4.Major issue	0	0	5/15/20, 2:16 AM	AS
5.Catastrophic issue	0	0	5/15/20, 2:16 AM	AS

Figure 9. Example of Coding Based on The Nielsen's Ten Usability Heuristics and Severity Ratings

After importing the data and coding in NVivo, the researcher used the Visualize/Hierarchy Chart feature in NVivo to explore the coding reference themes (see Figure 10). After importing the data and coding in NVivo, the researcher used the Visualize/Hierarchy Chart feature in NVivo to explore the coding reference themes (see Figure 10). These results presented the 10 themes that were created from Nielsen's (1993) Ten Usability Heuristics and five sub-themes created by severity ratings. All themes were rated positively (E1-E10), three themes rated cosmetic issue (E1, E7, E9), two themes rated minor issue (E4, E5), and two themes rated major issue (E1, E4). There were no catastrophic ratings in any of the themes. The 10 themes and five sub-themes (Positive, Cosmetic, Minor, Major, and Catastrophic) were further described in the qualitative findings section of this chapter.

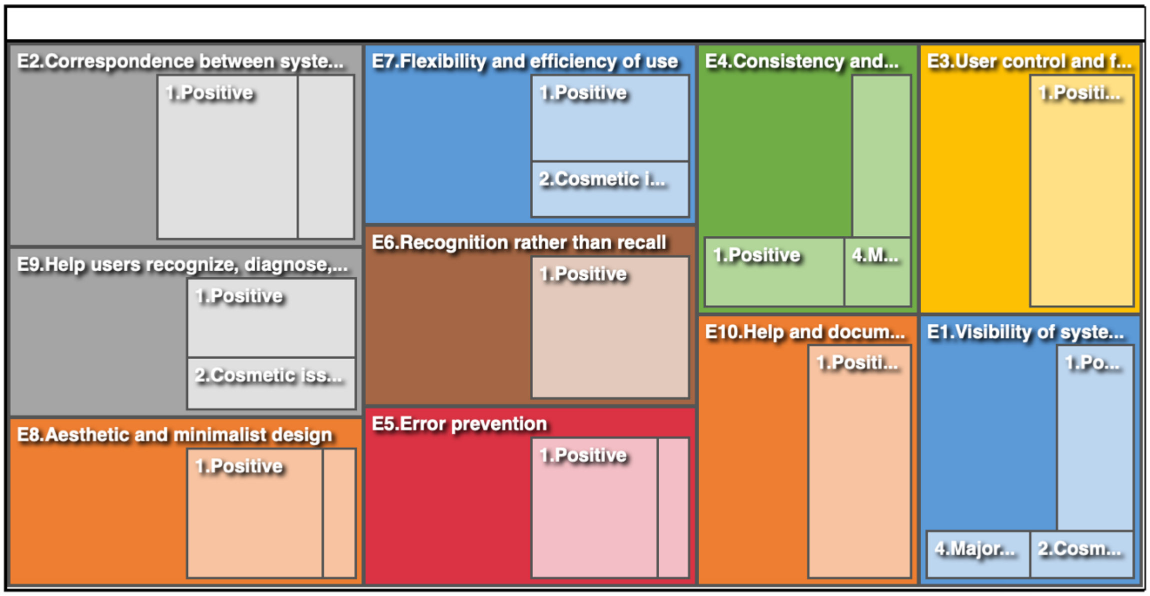


Figure 10. Hierarchy Chart in NVivo Analysis

The Word Cloud was generated from the participants' interview. These results presented the frequent words used by participants in this study (see Figure 11). The results of the top ten frequent words (e.g., headset; evaluation; software; application; understand) were part of the study context, therefore, frequently mentioned by the researcher evaluating the participant as they engaged in the online activity. The frequent words also include the participant's thoughts from the think aloud method. The resulting Word Cloud illustrates the core of the data obtained by the heuristic evaluation and the participant's thought.

Figure 11. Word Cloud in NVivo Analysis

Quantitative Analysis

Twenty (20) participants engaged in MOOC course and completed the activity as per directions in task list (See appendix B). After participants completed the task, the researcher assessed participants with the SUS questionnaire which examined user satisfaction of the EEG headset. Results were gathered by the researcher and quantitative data was prepared.

SUS Scores Analysis

The overall SUS score was calculated by multiplying the sum of the scores by 2.5. Figure 12 (below) illustrates the results of SUS calculations from all twenty (20) participants.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Odd Question - 5	25 - Even Question	Sum	SUS Score
Participant 1	1	1	3	3	3	3	2	3	2	1	6	14	20	50
Participant 2	4	5	3	5	3	2	5	3	3	5	13	5	18	45
Participant 3	3	5	4	5	3	2	4	4	2	4	11	5	16	40
Participant 4	4	4	4	5	3	4	4	4	4	4	14	4	18	45
Participant 5	3	4	4	5	3	3	3	3	2	3	10	7	17	43
Participant 6	5	5	5	4	5	5	5	4	5	5	20	2	22	55
Participant 7	5	5	5	4	5	5	5	5	5	5	20	1	21	53
Participant 8	5	5	5	4	5	5	4	5	4	5	18	1	19	48
Participant 9	4	3	5	4	5	4	5	3	4	5	18	6	24	60
Participant 10	4	4	5	5	5	3	5	4	5	5	19	4	23	58
Participant 11	5	5	4	4	5	5	5	4	5	5	19	2	21	53
Participant 12	1	5	5	3	4	3	4	3	4	2	13	9	22	55
Participant 13	4	3	4	3	4	3	4	3	3	3	14	10	24	60
Participant 14	3	4	4	3	3	3	5	4	3	4	13	7	20	50
Participant 15	5	5	5	5	5	5	5	5	5	5	20	0	20	50
Participant 16	1	3	4	4	4	3	3	2	2	3	9	10	19	48
Participant 17	3	4	4	4	4	4	4	4	4	3	14	6	20	50
Participant 18	3	4	4	4	3	3	4	4	3	4	12	6	18	45
Participant 19	1	5	5	5	5	5	5	5	3	5	14	0	14	35
Participant 20	3	3	2	2	3	4	2	3	2	2	7	11	18	45

Figure 12. SUS Scores

Statistics Analysis and Hypothesis

The one sample t-test was used in this study. The significance of the study is to determine usability factors and student's satisfaction in utilizing the portable EEG headset for monitoring attention levels in online learning. The hypothesis in this study as follows.

$$H_0: \mu < 68$$
$$H_1: \mu \geq 68$$

According to Sauro and Lewis (2011), a SUS score of 68 indicates an average rating. A SUS score above 68 would be considered above average and a SUS score below 68 would be considered below average. The score from SUS was utilized to test the hypothesis (H_1) that the students' satisfaction (SUS scores ≥ 68) is significant for students' adoption of the portable EEG headset in online tasks. The researcher rejected the hypothesis (H_0) if the SUS score is below 68. Table 4 (below) illustrates a summary of the satisfaction SUS scores for the EEG headset.

Table 4

Descriptive Statistics for User Satisfaction of The EEG Headset

	N	Minimum	Maximum	Mean	Standard Deviation
SUS Score	20	35.00	60.00	49.40	6.51638

Figure 13 (below) illustrates the descriptive statistics of SUS calculations from all twenty (20) participants.

Frequencies

Statistics

SUS Score

N	Valid	20
	Missing	0

SUS Score

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	5.0	5.0
	40.00	1	5.0	5.0	10.0
	43.00	1	5.0	5.0	15.0
	45.00	4	20.0	20.0	35.0
	48.00	2	10.0	10.0	45.0
	50.00	4	20.0	20.0	65.0
	53.00	2	10.0	10.0	75.0
	55.00	2	10.0	10.0	85.0
	58.00	1	5.0	5.0	90.0
	60.00	2	10.0	10.0	100.0
	Total	20	100.0	100.0	

Figure 13. Descriptive Statistic from The SUS Scores

Qualitative Findings

After the coding of the transcript from all five (5) participant documents into 10 themes (E1 to E10) and five sub-themes (Positive, Cosmetic, Minor, Major and Catastrophic). The qualitative findings are summarized below (see Table 5).

Table 5

Summary of Heuristics Evaluation Findings

Heuristics	Positive	Cosmetic	Minor	Major	Catastrophic
1. Visibility of system status	#5, #7	#16, #2	-	#3	-
2. Correspondence between system and the real world	#16, #5, #7, #2, #3	-	-	-	-
3. User control and freedom	#16, #5, #7, #2, #3	-	-	-	-
4. Consistency and standards	#5, #7	-	#16, #2	#3	-
5. Error prevention	#16, #5, #7, #2	-	#3	-	-
6. Recognition rather than recall	#16, #5, #7, #2, #3	-	-	-	-
7. Flexibility and efficiency of use	#5, #7, #2	#16, #3	-	-	-
8. Aesthetic and minimalist design	#5, #7, #2, #3	#16	-	-	-
9. Help users recognize, diagnose, and recover form errors	#5, #7, #3	#16, #2	-	-	-
10. Help and documentation	#16, #5, #7, #2, #3	-	-	-	-

The five (5) sub-themes help identify usability issues that can affect participant adoption of portable EEG headset. They rank user experience from Positive to Catastrophic. By capturing participant's thoughts while using the portable EEG headset and ranking them into the five (5) sub-themes, the researcher can answer the research question by assessing factors that affect the likelihood of adoption of portable EEG headset.

The five (5) sub-themes can be described as follows: Positive sub-theme indicated that there is no usability problem at all. Cosmetic sub-theme indicated that there is an issue, but it only needs to be fixed if time allows. The Minor sub-theme described a usability problem that was a low priority. The Major sub-theme described a usability that was a high priority. Lastly, a Catastrophic sub-theme described usability issues that must be fixed before product release. The findings that emerged from this study are as follows:

Positive Sub-Theme

1. Visibility of system status. Two (2) participants can install, use, and configure the EEG headset with ease. The functions of BCI software are easy to see and constantly visible. The participant can register and interact and follow the feedback of BCI software. Example of quotes from the participants as follows.

- Participant #5 reported that the system is easy to install, use, and configure the headset.

"I would say it is not difficult. It is quite easy. It just few steps not many steps and the headset are just turn it on and put it right at your head. It is not difficult at all"

- Participant #7 reported that the systems wasn't difficult.

"It was pretty easy. It wasn't difficult."

2. Correspondence between system and the real world. The EEG headset and BCI software can speak the user's language. All five (5) participants can understand and follow the application. Example of quotes from the participants as follows.

- Participant #2 reported that he can understand and follow the application.

"Yes, I understand it well."

- Participant #7 also reported as follows.

"The language application? It is very directed."

3. User control and freedom. All five (5) participants can start and stop the headsets. BCI software allows user to control it when other notifications arise on mobile device. BCI software allows user to multitask. Example of quotes from the participants reported as follows.

- Participant #5 reported that the headset is easy to control.

"Yes, it is pretty easy because they tell you what to do. Where to tap […]. When something happens. So, pretty easy. I can understand them by instruction you give to me."

- Participant #7 reported that the headset is easy to control.

"It is very easy to control"

4. Consistency and standards. Two (2) participants rated positively in this evaluation. The headset can function with the user device. The user's mobile phone can connect with the headset.

5. Error prevention. Four (4) participants rated positively. The headset can prevent the failure of the participant from accidentally clicking. The application has system sound that the user can follow. Example of quotes from the participants reported as follows.

- Participant #5 reported that the system did not show the error.

  "I don't see any error yet. It is still good to go."

- Participant #7 reported that the system did not show the error.

  "I didn't see anything. They work through all different devices."

- Participant #16 reported that the system did not show the error except the connection issue.

  "The error? it will be the connecting."

6. Recognition rather than recall. All five (5) participants rated positively. The application responds with intuitive action of the user. The user said the main function of EEG headset and BCI software are easily accessible. User is not required to remember information in order to use functions of software. Example of quotes from the participants reported as follows.

- Participant #16 reported that she can understand without knowing anything before use the headset.

"Um, I don't think so. I feel like you can just use this without knowing anything about the headset. Use this guide and get start with the headset. Like you don't have to know a bunch a lot about the headset. This guide is everything to me. Because when I first came, I didn't know anything, and I look at this guide. Of course, you demonstrated but looking this one also just helps like ok, you know, this is how to supposed to go over, how to suppose happen."

- Participant #7 reported that the application and the headset is easy to use.

"Not really. I don' know. I don't really understand what is going on at first until I start to use it."

7. Flexibility and efficiency of use. Three (3) participants rated positively. The headset supports the user's head size well. The user feels comfortable using the headset during activity. Size and fit of EEG headset is flexible and can adjust with the user.

- Participant #5 reported that the headset is comfortable to wear it.

"I would say my head size pretty big for myself. I would not complain about the headset. But it is pretty comfortable. It is easy to put it on."

- Participant #7 reported that the headset uses well than the normal EEG device.

"It's much better than the normal EEG systems. It has 2 pin point and 1 back here."

8. Aesthetic and minimalist design. Four (4) participants rated positively. The headset design is simple for the user. The layout of BCI software is intuitive and easy to understand for the user. Example of quotes from the participants reported as follows.

- Participant #7 reported that the design is very clean to use.

"It is very clean."

- Participant #2 reported as follows.

"Yes, it is easy to understand the layout of application. The first time I look at it seems easy and I have been using a lot of application from the past. I can tell that this one it is easy to use and understand for the first time of user. "

9. Help users recognize, diagnose, and recover from errors. Three (3) participants rated positively. The application gives a suggestion to the user to recover from error. The user can follow the error message without getting confused. Error messages are explained in language easy for the user to understand. Example of quotes from the participant #5 reported that the help feature is not difficult.

"I would say it is not difficult. It's kind of easy but you just have to fix it out what to do next some time."

10. Help and documentation. All five (5) participants rated positively. The participant feels that help documentation is easy to understand. Example of quotes from the participants as follows.

- Participant #2 reported that the help and documentation is good to look at.

"Oh, this thing. It is wonderful. This document is good to look at."

- Participant #3 reported that she loves the help document that have the picture to follow.

"Yes, because they have some picture to follow instruction. I can follow the guideline."

- Participant #5 reported that it is easy to understand the installation document.

"It is easy to understand this picture because it just not the word. So, we can just follow easily. So, yes, it is pretty good. The layout is pretty good, instruction to follow."

Participant #7 also reported that the start guide is easy to understand.

"The quick start guides. The only thing I would add to is the exploration how to use it. Other than that, the part of how to use it very well."

Participant #16 reported that she has positive with the start guide.

"I feel like it pretty useful. It well detail and I love it with the picture. You know, I love visual step. To me, this is very great. It explained it thoroughly. Scuff picture of every of each of the step. I feel like it very details."

Cosmetic Issue Sub-Theme

1. Visibility of system status. The EEG headset has connection problems with the user's device. Two (2) participant found that the BCI software has a white screen error when registering a new user and reported that the software was not functioning correctly. Example of quote from the participant as follows.

- Participant #2 reported that the headset is easy to install but it is still having a white screen error when he tries to create a new account.

"Yes, it is easy to install the program. I just almost done. But they have a white screen here. It is a bug of software. Maybe I will try again. It is still error. It doesn't to be expected. "

- Participant #16 reported that the system was not recording properly.

"The error? it will be the connecting. Because every now right now, see every now and then the connection gets lost. So, how it is going to measure our thinking or learning when they no connection. How that is effective. Because it is going to be like if even fit like two second that mean that you know two second lost. It didn't record what is going on. So, I don't think that it is effective in that matter. If the connection like 100%, no connection lost, no anything. I would say maybe effective. But I still can't understand very well."

2. Flexibility and efficiency of use. Two (2) participants feel that the headset is not supporting the user head size. The user feels uncomfortable using the headset during activity. The user said that the size and fit of the EEG headset is not flexible for the user. They reported discomfort on their foreheads. Example of quotes from the participants as follows.

- Participant #3 reported that she doesn't like the headset. She feels uncomfortable to wear the headset.

"I think I cannot wear this for longtime. It is fit my head. It is comfortable but I cannot wear it like for longtime because this thing is hurt my forehead little bit. It like annoying. A little bit annoying but it is ok. I don't like this thing. It's just annoyed. Because it like something put my forehead all the time. It's put all the time."

- Participant #16 reported that she feels like the headset is not secure and don't like to use the headset for monitor her attention.

"I feel like it is not secure. Like this part right here is touching my forehead but I feel like here it is not secure enough. It is like going to fall."

"So, I don't mind if something is there to monitor me, but I wouldn't want to have this headset on every time I'm studying because some time, I can go out or just studying, and sometimes I need to put my headphone on. This might be in the way, plus I just don't like the feelings of this one on me all the time. I feel like over the long run. It feels like uncomfortable."

3. Aesthetic and minimalist design. One (1) participant feels uncomfortable wearing the headset while doing a task. The headset could be the distraction for the participant. Example of quotes from the participants as follows.

- Participant #16 reported that the headset could make her distraction more than help her to focus the online activity.

"Um, it looks fine. I feel like it is detail. I like all the color this staff. It makes me know ok what really, what my brain is doing. But then in the way it like distraction to me, plus the background, the voice speaking to me. For example, I'm trying to do this, and this always alert like "keep going", "you are doing well". I'm like huh?"

"To me? No. Because it is too often. if it feed me like every 30 minutes, or every hour, maybe but this it is too often. To me, especially if I'm doing something like reading, or memorizing, I don't want to keep hearing, even some noises, even the dishwasher. I don't want to hear it. So, for this is telling every time what is going on. It is distracting me from learning to listening to this score. I have to pay attention what is happening here. [Point the smartphone]"

"I would like to know how it really working to measure see how would thinking because at time right now see I'm trying to talk to you. I'm trying to think of what to say. It is not I'm not thinking. But it goes on the way down. It is just measuring our learning. It is not our thinking. Right? It makes me feel good that this thing is show me that I'm be

effective or no. But then when I'm studying, when I'm doing homework. I don't' like noises. It could be like distraction to me."

4. Help users recognize, diagnose, and recover from errors. Two (2) participants said that they feel that the system voice is too robotic which can distract the user during the activity. Example of quotes from the participants as follows.

- Participant #2 reported that the voice of the application is too robotic. It could be noise for him.

"I think it is adorable, but I think the voice, the robotic voice it should not sound like [think] I don't want this sound like my mother say this thing to me. You know, right? I want it to be sound like relaxing. That just my opinion. I am not sure how to say that"

Minor Issue Sub-Theme

1. Consistency and standards. Two (2) participants have minor issues. The headset is difficult to function with the user device. The headset has a connection problem. The participant had to connect the device multiple times before success. One (1) of the participants cannot connect with the headset. Example of quotes from the participants as follows.

- Participant #16 reported the headset still have issue of the connection.

"So, what the problem encountering right now. I personally won't want to use it. Because I feel like it a lot of time. It might be good but connection that you have to make sure your connected and then it's kind of like software technology issue. So, I feel like it takes some of my time. I couldn't use my time to maybe like do something more useful instead of setting try to say. Ok, did I, yes, well connected. Did I put my headset on right? So, that my feelings right now at the moment. And then, you know, the connection gets lost every now and then so how we know that it's measuring or testing as right. Because the connection is not always there."

2. Error prevention. One (1) participant has an issue with connecting; software shows a white screen with no guidelines for the user to continue the application. Example of quotes from the participants as follows.

- Participant #3 reported that she can understand the systems but the feature for register doesn't work.

"Yes, I can understand how what happened. So, I click register they show screen like this. Is it doesn't work?"

Major Issue Sub-Theme

1. Visibility of system status. One (1) user cannot install and configure the EEG headset. The user cannot register a new user because the BCI software still has a connection error. Example of quotes from the participants as follows.

- Participant #3 reported that the register feature still has major issue. She cannot create a new account.

"This is very new for me. I never saw before. It is easy but I am not a technology person. I can't create my account. So, I cannot put the password. I mean it is not my password."

"They say the account is not exits. What does that mean? Oh! Register right here [laugh]. When I try to fill my information sometimes it like kick me off. It is easy but it takes a few minutes because I am not a technology person. Now, I can login by another account. The system still has a problem for creating a new user."

2. Consistency and standards. One (1) user has major issue. The headset cannot function with the user device. The headset also cannot install the application.

Catastrophic Issue Sub-Theme

The results show that no participants have catastrophic issues in this study.

Quantitative Findings

In total, twenty (20) quantitative measures were collected from the responses on the SUS questionnaires. The researcher applied the SUS formula to participants SUS scores and received a mean SUS score of 49.40. Considering that a SUS score of 68 or greater is known to reflect consumer satisfaction, the researcher can conclude at this time that participants were dissatisfied with using the EEG headset for online learning.

The results show that the satisfaction score of the EEG headset (M:49.40, SD=6.51) the mean SUS score of 68, [t (1.729), p<0.001]. (see Appendix D and Appendix E). Figure 14 and Figure 15 (below) illustrates a one- tailed t-test results of the study.

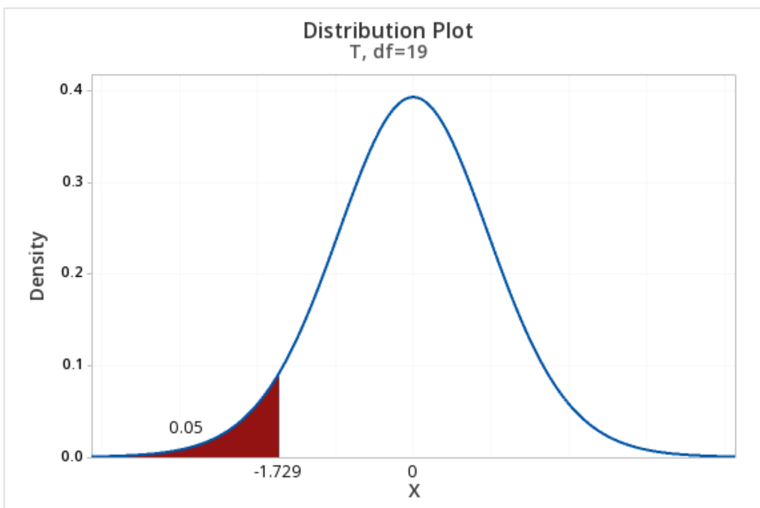


Figure 14. A One- Tailed t-Test of Hypothesis

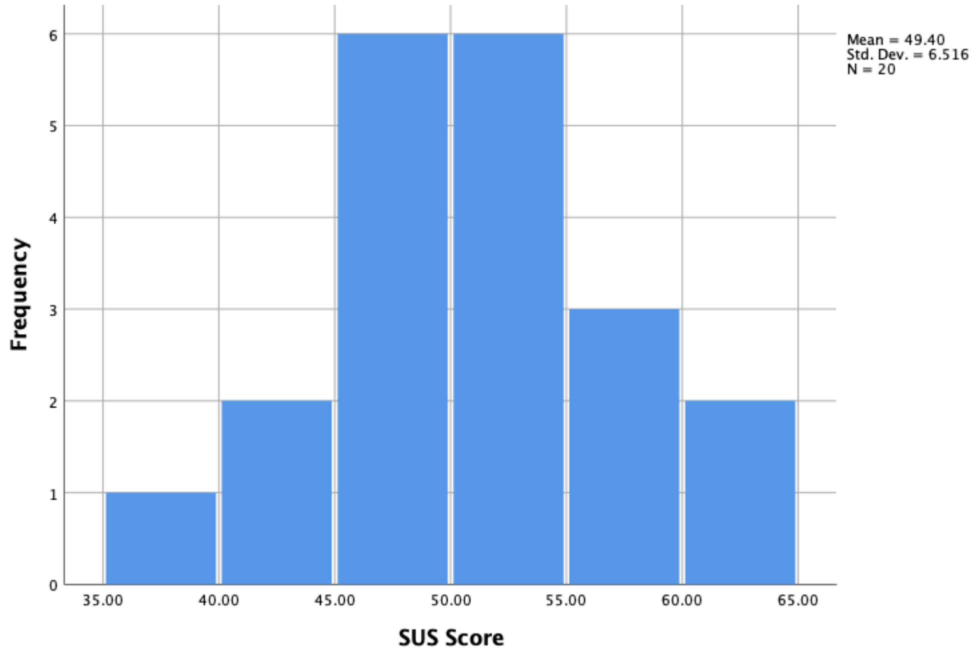


Figure 15. Histogram of the SUS Scores

Upon closer inspection of the data, participants rated connection issues as a barrier to product satisfaction. Participants scored low on Q1 which assessed participant's desire to use the EEG headset frequently when engaging in an online learning task. Participants also scored low on Q9 which assessed participant's confidence in using the EEG headset to monitor attention in an online class. Participants did feel confident in the EEG headset's ability to increase their attention levels nor did they feel likely to use the headset when engaging in an online task. Participants scored highly on Q3 which assessed ease of use. Participants felt that the EEG headset was easy to use for online learning.

Summary

The data collected, analyzed and reported in this chapter show that the participants in the study found the EEG headset easy to use but did not enjoy using it. Qualitative findings from the Nielsen (1993) and Ericsson and Simon (1993) assessments rated highly in most areas and no questions were rated as a catastrophic issue. This showed that participants had few issues with the EEG headset's usability because few errors occurred during use and, if an error occurred, it was easily overcome. Quantitative data showed that participants rated poorly on questions that assessed if participants felt comfortable using the EEG headset or could see themselves using it for online learning.

Both the quantitative and qualitative assessments showed that participants felt that using the EEG device was distracting to completing their task. Participants reported that the audio feedback for low attention was more distracting than useful. Participants also reported that wearing the headset was uncomfortable and that this was also a distraction.

Chapter 5

Conclusion, Implications, Recommendation, and Summary

Overview

The focus of this chapter is to review the findings made in this study; limitations and challenges discussed as well as the means of achieving the research goals. Implications of the findings as seen in Chapter 1 and their contributions are also discussed. Lastly, recommendations for future research are considered.

Conclusions

This study focused on investigating the usability factors that influence the adoption of portable EEG headset to monitor students' attention in online activity. The researcher utilized the heuristic evaluation form by Nielsen (1993) and think-aloud method (Ericsson & Simon, 1993) to qualitatively assess portable EEG usability. The SUS survey quantitatively evaluated users' satisfaction to test the hypothesis that the EEG headset was well designed and highly usable for students in measuring attention levels while completing learning tasks.

The qualitative data coding and analysis that was reported in Chapter 4 illustrated ten (10) themes and severity ratings. The researcher prioritized the heuristic findings by the severity of the impact on the participant's experience. Nielsen (1994) reported that it is difficult to get accurate severity estimates from the evaluators when they are more focused on finding new usability problems. However, severity ratings help to prioritize the recommended changes in tacking the usability defects (Wilson, 2010).

The participants' feedback of each of the five severity ratings were presented in the Findings section of Chapter 4. The participants had few issues with the EEG headset's usability. All five (5) participants rated positively in most areas. These results imply that the participants felt that the EEG headset was beneficial for monitoring students' attention in online learning. However, participants reported issues with signal and technology connection. These results are similar to Vourvopoulos and Badia (2015) who reported that the technology of EEG headset is still in the early developing stages because of limitations such as sensitive noise and weak signal. Xu and Zhong (2018) also found that the technology of portable EEG headset was still early in its development.

The quantitative data that was collected, analyzed, and reported in Chapter 4 indicated that the students' satisfaction (Mean=49.40, t=1.729, $p<0.001$) was below the average score on the SUS. According to Sauro & Lewis (2011), a SUS score above a 68 would be considered above average and anything below 68 is below average (Sauro & Lewis, 2011), therefore the SUS result of students' satisfaction of 49.40 was below average. This score indicated that most participants did not enjoy using the EEG headset. Further, no participant rated the portable EEG headset above 68 in any one dimension which implied that no participant was satisfied with any of the EEG headset attributes. The data suggest that students are not likely to adopt the portable EEG headset in online tasks due to dissatisfaction.

An interesting finding is that while most participants felt that the EEG headset was easy to use, they did not want to use it due to dissatisfaction with it. As indicated in Chapter 4, the participants rated poorly on questions that assessed if they felt comfortable using the EEG headset or could see themselves using it for online learning. However, participants rated highly in factors of usability such as intuitiveness and ease of use.

These results suggested that the EEG headset should address issues regarding consumer acceptance for use in daily life. Participants in this study felt uncomfortable using the EEG headset and reported that it did not help focus on online tasks. The usability of the EEG headset needs further development in comfort and design for monitoring students' attention in an online course. In conclusion, this dissertation study revealed that the EEG headset was rated positively for use in monitoring students' attention in an online course, whereas user satisfaction was not.

Limitations

The participants in this study had varying levels of experience with smartphone technology and online courses which impacted the results of the study. Some participants had difficulty with technical requirements such as application installation on smartphone devices. Ease of use varied depending on age of participant and experience with online courses and technology. EEG feedback was affected by participants' stress and discomfort when wearing the headset.

This study targeted 20 adults who intended to take online courses within the next 5 years. However, the researcher could not know whether they were still interested in taking the course online in the future or not. The participants only presented that they were interested and comfortable testing the portable EEG headset in this study.

Implications

This study has implications for the field of Information Systems and are of particular interest to human-computer interaction usability researchers and professionals.

Additionally, those in the usability and educational research who are interested in understanding the factors that influence the adoption of the EEG headset for educational use can benefit from this research as well.

This study provides support for educational research to improve students' performance by using new technology. Measuring attention and behavioral engagement during learning activity is a challenging task. The availability of new technology could evaluate a student's attention in real time using measurements from the EEG headset. Use of EEG technology in an online learning environment is ideal because it can maximize a student's ability to self-monitor attention. This is necessary because learning performance can suffer in the absence of supervision by an instructor. Results from this research could help develop important guidelines to implement technology that can aid students in online courses.

The results of this study are most useful to researchers and professionals in the area of educational research, usability, mobile usability, and portable EEG headset users. For those interested in developing the portable EEG, this data can be useful in that it clearly shows that consumer satisfaction is a larger barrier to adoption than usability.

Recommendations for Further Research

Future research could be conducted on another portable EEG device to compare and corroborate findings. Further research is needed to evaluate different EEG devices in both online and traditional classrooms. The BCI application can be developed further so that it could be tested on a small device such as the Internet of Things (IoT). Standardization of technology and device connecting can be improved to reduce technological issues. The device design can be improved by increasing comfort and ease of use by likening the design more to ear devices rather than headsets.

Summary

Studies indicated that students' attention is an important part of successful learning because it enhances learning performance, particularly during online learning (Chen & Wang, 2017; Kuo et al., 2017; Wang & Hsu, 2014). In a traditional classroom setting, instructors can directly observe students in order to sustain their attention levels during a lesson, but, in online courses, it is difficult to assess student engagement because of the physical disconnect between student and educator. In the online learning environment, face to face interaction is limited to teleconference sessions with camera and audio which limits the interaction between educator and student (Chen & Wang, 2017; Chen et al., 2017). This limit on interaction has a negative effect on student’s attention levels during online tasks (Chen & Wang, 2017; Kuo et al., 2017; Wang & Hsu, 2014).

In recent years, researchers have used portable EEG headsets to assess the brain frequencies of students as they engage in learning activities (Xu & Zhong, 2018). Previous studies have explored the usability of portable EEG devices with brain-computer interface (BCI) to substantiate technology connection and consumer acceptance (Hairston et al., 2014; Nijboer et al., 2015). However, researchers have reported that the portable EEG headset is in its early developing stages because of technological limitations such as signal and interference (Vourvopoulos & Badia, 2015).

Usability heuristics have been established by Nielsen (1993) which are useful in determining general guidelines for user interfaces. However, no studies have explored usability heuristics for portable EEG technology in online courses. There are two factors that are important to understand why additional research is needed for usability of portable EEG headset: online student distraction and lack of research on the usability of EEG to monitor students' attention. Because the Internet presents an abundance of distractions in the form of Social Networking Sites (SNS), news, and games, it is difficult to sustain the attention of students in an online learning environment. Failure to maintain focused attention has become a significant problem for online education.

Liu et al., (2013) and Karpinski et al., (2013) have shown that students are more easily distracted when working unsupervised rather than being supervised by an instructor. Students who can focus attention on learning activities are likely to retain information from the lesson and are more likely to succeed in their program. Chen & Huang, (2014), Chen et al., (2017), and Kuo et al., (2017) have developed a system to enhance and evaluate students' attention in a learning environment. These systems used portable EEG devices to observe brainwave signals to measure changes in attention states. Slavin (2008) reported that brainwave signals could be monitored in real time by portable EEG headsets, a necessary component to conducting evidence-based education and evidence-based educational research.

The research question for this study was: *What are the usability factors that influence the adoption of portable EEG headset?* The research question was examined qualitatively by using the heuristic evaluation method by Nielsen (1993). Quantitative data was collected through the System Usability Scale (SUS) and was utilized to test the researcher's hypothesis that the EEG headset was well designed and highly usable for measuring students' attention levels while completing learning tasks. This included participant ratings of ease-of-use and whether the portable EEG headset was perceived as necessary.

The methodology was discussed in Chapter 3. The methodology was targeted at answering the research question. Twenty (20) participants were trained in using the portable EEG headset and BCI software. Participants were instructed to complete and online learning activity while using the portable EEG headset to monitor attention levels. During the activity, five (5) participants were assessed qualitatively by Nielsen (1993) and Ericsson and Simon (1993) to determine ease-of-use of the headset. After completion of learning activity, twenty (20) participants completed the SUS questionnaire which quantitatively assessed participant satisfaction with the headset.

The research findings presented in Chapter 4 assisted in accomplishing the main goal of this research. Based on the results of Nielsen (1993) and Ericsson and Simon (1993), the researcher found that participants rated the portable EEG headset positively. They found that it was intuitive and easy to use. However, the results of the SUS revealed that participants were not satisfied with using the portable EEG headset due to discomfort and needlessness; participants reported that using the headset during an online activity was a distraction itself.

Students' attention is an important part of successful learning. A high level of online students drops out from online courses due to distractions like Social Network Sites (SNS) (Digital Learning Compass Report, 2017). The portable EEG headset could help students monitor their attention levels without the help of an instructor. For this reason, the researcher has evaluated how the portable EEG headset can be used to help students in online courses. However, the result showed that the usability and the effectiveness of the new technology was still challenged by the low levels of consumer acceptance.

The findings answered the research question of usability heuristics that most participants rated positive with the usability of the portable EEG headset. The findings also showed that the portable EEG headset rated poorly on participant's satisfaction. Some limitations in this study included varying levels of experience with smartphone technology and online courses, difficulty with technical requirements, variation of age of participants, and participants' stress and discomfort when wearing the headset. Further research is needed to evaluate different EEG devices in both online and traditional classrooms. Device connection can be improved to reduce technological issues. Device design can be improved by increasing comfort.

Appendix A

Heuristic Evaluation Form

Heuristics Evaluation of Portable EEG
By Arisaphat Suttidee Date …../…../……..

---

1. Visibility of system status
Users remain informed about what's happening with the system in real time through appropriate feedback.
Detail: User can install, use, and configure the EEG headset with ease. Functions of BCI software are be easy to see and constantly visible. Software always interacts with users to provide feedback in real time.
Evaluation Notes:

---

2. Correspondence between system and the real world
The system speaks the users' language, with words, concepts, and phrases familiar to the user.
Detail: The EEG headset and BCI software should speak the participant's language, with words, phrases, and concepts familiar to the participants, rather than system-oriented terms.
Evaluation Notes:

---

3. User control and freedom
Users can easily undo and redo. Users always have an emergency exit to leave an unwanted state.
Detail: The user can start and stop the headset. BCI software allows users to control it when other notifications arise on mobile device. BCI software allows user to multitask.
Evaluation Notes:

---

4. Consistency and standards
The system is easy to understand and is intuitive to the user because it is based on a current standard of use.
Detail: The headset can function with other devices through current standards of technology such as Bluetooth and mobile devices. EEG and BCI software adhere to platform standards and is consistent in terms of controls, gestures, and other elements that are intuitive to the user.
Evaluation Notes:

---

5. Error prevention
Error-prone conditions are eliminated, and confirmative actions are committed by the user.
Detail: The EEG headset can prevent the failure of the participant from accidentally clicking.
Evaluation Notes:

6. Recognition rather than recall
The user does not have to remember information from one dialogue to complete the next. Necessary information is always made available on prompts, actions, and other options.
Detail: The application responds with intuitive action of the user. Main functions of EEG headset and BCI software are easily accessible. User is not required to remember information in order to use functions of software.
Evaluation Notes:

7. Flexibility and efficiency of use
The system caters to both inexperienced and experienced users.
Detail: The headset supports the head size of the user. User can comfortably use the headset during activity. Size and fit of EEG headset is flexible and can change depending on the user's needs.
Evaluation Notes:

8. Aesthetic and minimalist design
User is not exposed to irrelevant information.
Detail: The headset design is simple and elegant. Visual design of EEG headset guides user to important elements of function. Menu layout of BCI software is intuitive and easy to understand.
Evaluation Notes:

9. Help users recognize, diagnose, and recover from errors
User can easily comprehend error messages.
Detail: The application gives suggestions or guidelines when the user gives conflicting commands. Error messages are explained in language easy for the user to understand. Errors to not cause the user to restart MOOC task.
Evaluation Notes:

10. Help and documentation
User can easily find documentation for help.
Detail: EEG headset and BCI software is designed to reduce the need for help documentation. The headset's troubleshooting documentation is accessible and user friendly. Help documentation is easy to understand.
Evaluation Notes:

Appendix B

Task List Instructions (Think-aloud)

Please follow each task below in order and please talk about what you are doing out loud. Please remember to “think aloud” as you perform these tasks.

Participant Number……………. Date ………………

Task List for Evaluation of Portable EEG

Number of Steps	Task Description
Step 1	**Setup**: Install the application > Create account > Login
Step 2	**Power on and connect**: Turn on the portable EEG headset and Bluetooth on the mobile device. Pair the headset and mobile device via Bluetooth. Put on portable EEG headset and connect EEG sensors to the scalp.
Step 3	**Run software diagnostic**: On the mobile device, complete the software diagnostic to ensure that the portable EEG headset is working correctly.
Step 4	**Begin activity**: Press “Start” when ready to begin the learning activity
Step 5	**Engage in activity**: Engage in learning task. The software will alert the user with a sound and display a message when the attention level is low. The software also includes messages that motivate the user to stay on task e.g. “Keep going”
Step 6	**Online session:** The user will follow the think-aloud instruction and stay in an online session for 30 minutes.
Step 7	**Finish activity:** Press “Stop” on the mobile device to complete the session.
Step 8	**View summary**: Click the report to display a summary of the learning session.

Please fill out the post-test questionnaire. Thank you for your participation.

Appendix C

Post-Test Questionnaire

Participant Number……………. Date ………………

The System Usability Scale (SUS)

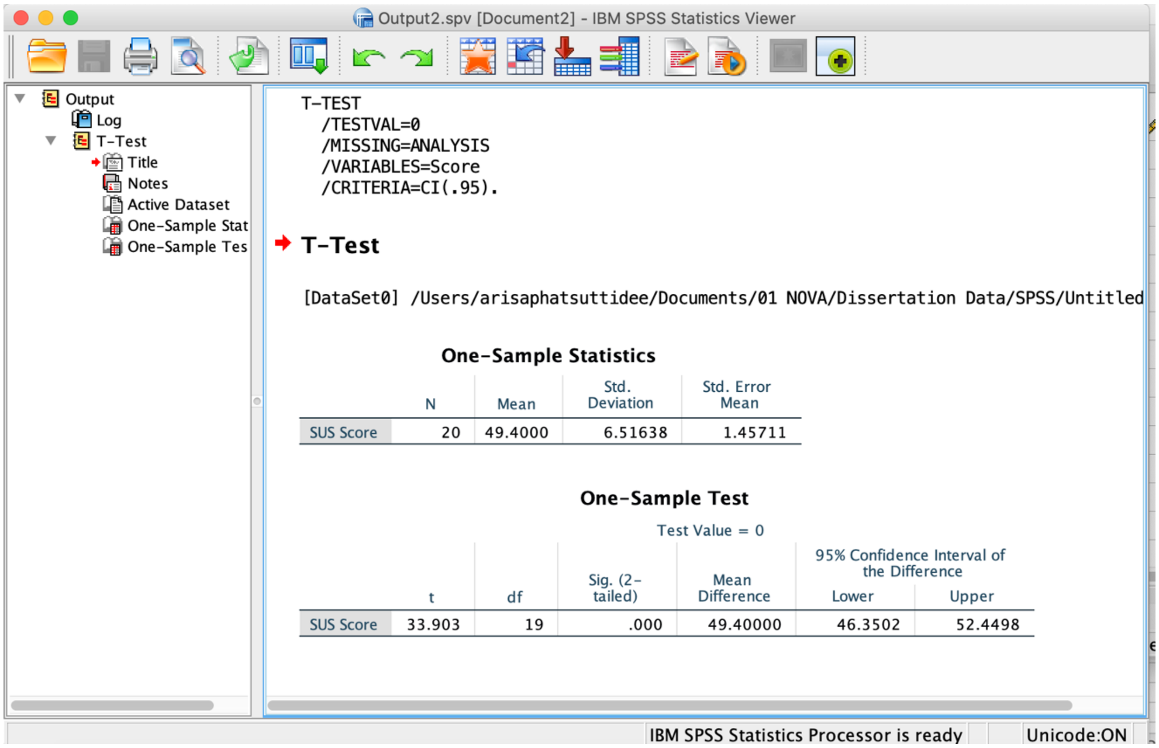
Instructions: For each of the following statements, mark one box that best describes your reactions to the portable EEG today.

		Strongly disagree 1	2	3	4	Strongly agree 5
1	I think that I would like to use the EEG headset frequently when I have to concentrate my task.	☐	☐	☐	☐	☐
2	I found the EEG headset to be simple to use to monitor my attention level.	☐	☐	☐	☐	☐
3	I thought the EEG headset was easy to use for online students.	☐	☐	☐	☐	☐
4	I thought that I could use the EEG headset without the support of a technical person.	☐	☐	☐	☐	☐
5	I found the various functions in the EEG headset were well integrated.	☐	☐	☐	☐	☐
6	I thought there was a lot of consistency in the EEG headset when I try it on.	☐	☐	☐	☐	☐
7	I would imagine that most people would learn to use this EEG headset very quickly to improve their learning experience.	☐	☐	☐	☐	☐
8	I found the EEG headset very intuitive.	☐	☐	☐	☐	☐
9	I felt very confident using the EEG headset to monitor my attention in an online class.	☐	☐	☐	☐	☐
10	I could use the EEG headset without having to learn something new.	☐	☐	☐	☐	☐

Questionnaire format follows the System Usability Scale (SUS) (Sauro & Lewis, 2011)

Appendix D

Quantitative Statistics Results



```
T-TEST
  /TESTVAL=0
  /MISSING=ANALYSIS
  /VARIABLES=Score
  /CRITERIA=CI(.95).
```

T-Test

[DataSet0] /Users/arisaphatsuttidee/Documents/01 NOVA/Dissertation Data/SPSS/Untitled

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
SUS Score	20	49.4000	6.51638	1.45711

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
SUS Score	33.903	19	.000	49.40000	46.3502	52.4498

Appendix E

Descriptive Statistics Results

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SUS Score	20	35.00	60.00	49.4000	6.51638
Valid N (listwise)	20				

Frequencies

Statistics

SUS Score

N	Valid	20
	Missing	0

SUS Score

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	5.0	5.0
	40.00	1	5.0	5.0	10.0
	43.00	1	5.0	5.0	15.0
	45.00	4	20.0	20.0	35.0
	48.00	2	10.0	10.0	45.0
	50.00	4	20.0	20.0	65.0
	53.00	2	10.0	10.0	75.0
	55.00	2	10.0	10.0	85.0
	58.00	1	5.0	5.0	90.0
	60.00	2	10.0	10.0	100.0
	Total	20	100.0	100.0	

Appendix F

General Informed Consent Form for Participant in the Research Study

General Informed Consent Form
NSU Consent to be in a Research Study Entitled
Usability of Portable EEG for Monitoring Students' Attention in Online Learning

Who is doing this research study?

College: Collage of Computing and Engineering

Principal Investigator: Arisaphat Suttidee

Faculty Advisor/Dissertation Chair: Ling Wang, Ph.D.

Site Information: Apichat Thai LLC
1228 W University Ave, Gainesville, Florida 32601

Funding: Unfunded

What is this study about?

This study is to evaluate the usability factors influencing the adoption of portable EEG headsets to monitoring students' attention in an online course. Because student distraction affects online performance, acceptance of EEG for use in online courses might increase students' attention and improve online task performance.

Why are you asking me to be in this research study?

You are being asked to be participate in the research study because you have potential to take online courses within the next 5 years. This study might help you to increase your attention and improve online task performance. There will be twenty (20) adult in the study.

What will I be doing if I agree to be in this research study?

While you are taking part in this research study, you will receive the EEG headsets and asked to engage in an assigned learning activity for 30 minutes.

Research Study Procedures - as a participant, this is what you will be doing:

- The researcher will explain the task description, general overview of setup for EEG headsets and application is given.

General Informed Consent Form
NSU Consent to be in a Research Study Entitled
Usability of Portable EEG for Monitoring Students' Attention in Online Learning

- You will receive the EEG headset and setup follow the task description to connect the application on your smartphone
- You will enroll the online sample course in the edX.com
- You will engage in online course while wear the EEG headset
- During the study, the researcher will be observed and evaluation your activity
- After finish the activity you will fill the post-study questionnaire

<u>Are there possible risks and discomforts to me?</u>

This research study involves minimal risk to you. To the best of our knowledge, the things you will be doing have no more risk of harm than you would have in everyday life.

<u>What happens if I do not want to be in this research study?</u>

You have the right to leave this research study at any time or refuse to be in it. If you decide to leave or you do not want to be in the study anymore, you will not get any penalty or lose any services you have a right to get. If you choose to stop being in the study before it is over, any information about you that was collected **<u>before</u>** the date you leave the study will be kept in the research records for 36 months from the end of the study and may be used as a part of the research.

You have the right to leave this research study at any time, or not be in it. If you do decide to leave or you decide not to be in the study anymore, you will not get any penalty or lose any services you have a right to get. If you choose to stop being in the study, any information collected about you **<u>before</u>** the date you leave the study will be kept in the research records for 36 months from the end of the study but you may request that it not be used.

What if there is new information learned during the study that may affect my decision to remain in the study?

If significant new information relating to the study becomes available, which may relate to whether you want to remain in this study, this information will be given to you by the investigators. You may be asked to sign a new Informed Consent Form, if the information is given to you after you have joined the study.

<u>Are there any benefits for taking part in this research study?</u>
The possible benefit of your being in this research study is increase your attention and improve learning performance in online education. There is no guarantee or promise that you will receive any benefit from this study. We hope the information learned from this research study will benefit other people with similar conditions in the future.

General Informed Consent Form
NSU Consent to be in a Research Study Entitled
Usability of Portable EEG for Monitoring Students' Attention in Online Learning

Will I be paid or be given compensation for being in the study?

You will not be given any payments or compensation for being in this research study.

Will it cost me anything?

There are no costs to you for being in this research study.
Ask the researchers if you have any questions about what it will cost you to take part in this research study (for example bills, fees, or other costs related to the research).

How will you keep my information private?

Information we learn about you in this research study will be handled in a confidential manner, within the limits of the law and will be limited to people who have a need to review this information. This data will be available to the researcher, the Institutional Review Board and other representatives of this institution, and any regulatory and granting agencies (if applicable). If we publish the results of the study in a scientific journal or book, we will not identify you. All confidential data will be kept securely in the researcher computer. All data will be kept for 36 months from the end of the study and destroyed after that time by delete from the computer.

Will there be any Audio or Video Recording?

This research study involves audio and/or video recording. The recordings are necessary for the data collection and analysis because the method of Think-Aloud needs to have the audio/video recordings to analyze the data of user experience in the online course. This recording will be available to the researcher, the Institutional Review Board and other representatives of this institution. The recording will be kept, stored, and destroyed as stated in the section above.

Whom can I contact if I have questions, concerns, comments, or complaints?

If you have questions now, feel free to ask us. If you have more questions about the research, your research rights, or have a research-related injury, please contact:

Primary contact:
Miss Arisaphat Suttidee can be reached at (954)439-3392, or email as3360@mynsu.nova.edu

General Informed Consent Form
NSU Consent to be in a Research Study Entitled
Usability of Portable EEG for Monitoring Students' Attention in Online Learning

Research Participants Rights
For questions/concerns regarding your research rights, please contact:

Institutional Review Board
Nova Southeastern University
(954) 262-5369 / Toll Free: 1-866-499-0790
IRB@nova.edu

You may also visit the NSU IRB website at www.nova.edu/irb/information-for-research-participants for further information regarding your rights as a research participant.

Research Consent & Authorization Signature Section

Voluntary Participation - You are not required to participate in this study. In the event you do participate, you may leave this research study at any time. If you leave this research study before it is completed, there will be no penalty to you, and you will not lose any benefits to which you are entitled.

If you agree to participate in this research study, sign this section. You will be given a signed copy of this form to keep. You do not waive any of your legal rights by signing this form.

SIGN THIS FORM ONLY IF THE STATEMENTS LISTED BELOW ARE TRUE:
- You have read the above information.
- Your questions have been answered to your satisfaction about the research.

Adult Signature Section

I have voluntarily decided to take part in this research study.

Printed Name of Participant	Signature of Participant	Date
Printed Name of Person Obtaining Consent and Authorization	Signature of Person Obtaining Consent & Authorization	Date

Appendix G

IRB Approval Memorandum

NSU NOVA SOUTHEASTERN UNIVERSITY
Institutional Review Board

MEMORANDUM

To: **Arisaphat Suttidee**

From: **Wei Li, Ph.D,**
Center Representative, Institutional Review Board

Date: **March 16, 2020**

Re: **IRB #: 2020-131; Title, "Usability of Portable EEG for Monitoring Students' Attention in Online Learning"**

I have reviewed the above-referenced research protocol at the center level. Based on the information provided, I have determined that this study is exempt from further IRB review under **45 CFR 46.101(b) (Exempt 2: Interviews, surveys, focus groups, observations of public behavior, and other similar methodologies)**. You may proceed with your study as described to the IRB. As principal investigator, you must adhere to the following requirements:

1) CONSENT: If recruitment procedures include consent forms, they must be obtained in such a manner that they are clearly understood by the subjects and the process affords subjects the opportunity to ask questions, obtain detailed answers from those directly involved in the research, and have sufficient time to consider their participation after they have been provided this information. The subjects must be given a copy of the signed consent document, and a copy must be placed in a secure file separate from de-identified participant information. Record of informed consent must be retained for a minimum of three years from the conclusion of the study.

2) ADVERSE EVENTS/UNANTICIPATED PROBLEMS: The principal investigator is required to notify the IRB chair and me (954-262-5369 and Wei Li, Ph.D, respectively) of any adverse reactions or unanticipated events that may develop as a result of this study. Reactions or events may include, but are not limited to, injury, depression as a result of participation in the study, life-threatening situation, death, or loss of confidentiality/anonymity of subject. Approval may be withdrawn if the problem is serious.

3) AMENDMENTS: Any changes in the study (e.g., procedures, number or types of subjects, consent forms, investigators, etc.) must be approved by the IRB prior to implementation. Please be advised that changes in a study may require further review depending on the nature of the change. Please contact me with any questions regarding amendments or changes to your study.

The NSU IRB is in compliance with the requirements for the protection of human subjects prescribed in Part 46 of Title 45 of the Code of Federal Regulations (45 CFR 46) revised June 18, 1991.

Cc: Ling Wang, Ph.D.
Ling Wang, Ph.D.

References

Babson Survey Research Group. (2015). *2015 Online Report Card: Tracking Online Education in the United States.* Retrieved from https://onlinelearningconsortium.org/read/online-report-card-tracking-online-education-united-states-2015/

Baker, R., D'Mello, S., Rodrigo, M. M., & Graesser, A. C. (2010). Better to be frustrated than bored: The incidence, persistence, and impact of learners' cognitive-affective states during interactions with three different computer-based learning environments. *International Journal of Human-Computer Studies, 68(*4), 223-241.

Best Colleges. (2018). *2018 Online Education Trends Report in the United States.* Retrieved from https://www.bestcolleges.com/perspectives/annual-trends-in-online-education/

Brooke, J. (1996). SUS: A "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & A. L. McClelland (Eds.), Usability Evaluation in Industry. London: Taylor and Francis.

Charter, E. (2003). The use of think-aloud methods in qualitative research an introduction to think-aloud methods. *Brock Education 12*(2), 68-82

Chen, C. C. (2017). Measuring the differences between traditional learning and game-based learning using electroencephalography (EEG) physiologically based methodology. *Journal of Interactive Learning Research, 28*(3), 221-233

Chen, C. M., & Huang, S. H. (2014). Web-based reading annotation system with an attention-based self-regulated learning mechanism for promoting reading performance. *British Journal of Educational Technology, 45*(5), 959-980.

Chen, C. M., & Lin, Y. J. (2016). Effects of different text display types on reading comprehension, sustained attention and cognitive load in mobile reading contexts. *Interactive Learning Environments, 24*(3), 553-571.

Chen, C. M., & Wu, C. H. (2015). Effects of different video lecture types on sustained attention, emotion, cognitive load, and learning performance. *Computers & Education, 80*, 108-121.

Chen, C. M., & Wang, J. Y. (2017). Effects of online synchronous instruction with an attention monitoring and alarm mechanism on sustained attention and learning performance. *Interactive Learning Environments, 25*(7), 1-17.

Chen, C. M., Wang, J. Y., & Yu, C. M. (2017). Assessing the attention levels of students by using a novel attention aware system based on brainwave signals. *British Journal of Educational Technology, 48*(2), 348-369.

Digital learning compass. (2017). *The Distance Education Enrollment Report*. Retrieved from http://digitallearningcompass.org/

Ericsson, K. A., & Simon, H. A. (1980). Verbal Reports as data. *Psychological Review, 87*(3), 215-251.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data (Revised edition)*. Cambridge, MA: MIT Press.

Grzegorz, M., Wierzgala, P., & Gajos, A. (2015). Evaluation of Emotiv EEG neuroheadset. *Bio-Algorithms and Med-Systems, 11*(4), 211-215.

Greenberg, S., & Buxton, B. (2008). Usability evaluation considered harmful (Some of the time). *Proceedings from the SIGCHI Conference on Human Factor in Computing system '08,* Florence, Italy.

Gruzelier, J. H., Foks, M., Steffert, T., Chen, M. J., & Ros, T. (2014). Beneficial outcome from EEG-neurofeedback on creative music performance, attention and well-being in school children. *Biological Psychology, 95*, 86-95.

Hairston, W. D., Whitaker, K. W., Ries, A. J., Vettel, J. M., Bradford, J. C., Kerick, S. E., & McDowell, K. (2014). Usability of four commercially-oriented EEG systems. *Journal of Neural Engineering, 11*(046018), 1-14

ISO 9241-11. (2015). Ergonomics of human-system interaction – Part 11: Usability: Definitions and concepts. International Organization for Standardization. Retrieved from

Izdebski, K., Oliveira, A. S., Schlink, B. R., Legkov, P., Karcher, S., Hairston, W. D., …Konig, P. (2016). Usability of EEG systems: User experience study. Proceedings from *the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments (PETRA '16).* New York, USA.

Junco, R., & Cotten, S. R. (2012). No A 4 U: The relationship between multitasking and academic performance. *Computers & Education, 59*(2), 505-514.

Karpinski, A. C., Kirschner, P. A., Ozer, I., Mellott, J. A., & Ochwo, P. (2013). An exploration of social networking site use, multitasking, and academic performance among United States and European university students. *Computers in Human Behavior, 29*(3), 1182-1192.

Kuo, Y. C., Chu, H. C., & Tsai, M. C. (2017). Effects of an integrated physiological signal-based attention-promoting and English listening system on students' learning performance and behavioral patterns. *Computers in Human Behavior, 75*, 218-227.

Lewis, C. H. (1982). *Using the "Thinking Aloud" Method in Cognitive Interface Design* (Technical report). IBM. RC-9265.

Liu, N. H., Chiang, C. Y., & Chu, H. C. (2013). Recognizing the degree of human using EEG signals from mobile sensors. *Sensors, 13*, 10273-10286.

Lotte, F. (2012). On the need for alternative feedback training approaches for BCI. *Berlin Brain-Computer Interface Workshop, Sep 2012*, 1-3.

Maskeliunas, R., Damasevicius, R., Martisius, I., & Vasiljevas, M. (2016). Consumer-grade EEG devices: Are they usable for control tasks? *PeerJ,* 4*:*e1746.

Macaulay, M., & Edmonds, E. (2004). Does frontal EEG beta have application in anxiety monitoring during computer-based learning? *Journal of Educational Computing Research, 30*(3), 229-241.

Mostow, J., Chang, K. M., & Nelson, J. (2011). Toward exploiting EEG input in a reading tutor. *International Journal of Artificial Intelligence in Education, 22*, 230-237.

Nijboer, F., Laar, B. V. E., Gerritsen, S., Nijholt, A., & Poel, M. (2015). Usability of three electroencephalogram headset for brain-computer interfaces: A within subject comparison. *Interaction with Computer, 27*(5), 500-511.

Nielsen, J. (1993). *Usability engineering*. New York: Academic Press.

Nielsen, J., & Mack, R. L. (1994). *Usability Inspection Methods.* New York, NY: John Wiley & Sons.

Nielsen, J. (2006). *How many test users in a usability study?* Retrieved from https://www.nngroup.com/articles/how-many-test-users/?lm=usability-testing-w-5-users-roi-criteria&pt=youtubevideo

NeuroSky. (2015). MindWave Mobile: User guide. NeuroSky, Inc.

Olson, G. J., Duffy, S. A., & Mack, R. L. (1984). Think-out-loud as a method for studying real time comprehension processes. In D.E. Kieras & M. A. Just (Eds.). *New methods in reading comprehension research* (pp. 253-286). Hillsdale, NJ: Erlbaum.

Romero, E. (2014). Measuring Cognition in computer-based instruction using an EEG: A review of the literature. *Proceeding from the EdMedia + Innovate Learning 2014*, Waynesville, NC: Association for the Advancement of Computing in Education (AACE)

Salkind, N. J. (2010). *Encyclopedia of research design.* Thousand Oaks, CA: SAGE Publications, Inc.

Sauro, J., & Lewis, J. R. (2011). When designing usability questionnaires, does it hurt to be positive? *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2215-2224.

Scott, J. & Romero, E. (2017). Assessing the learning experiences of geriatric learners during web-based instruction with neurophysiological methods. Inc.

Sun, J. C. Y., & Yeh, K. P. C. (2017). The effects of attention monitoring with EEG biofeedback on university students' attention and self-efficacy: The case of anti-phishing instructional materials. *Computers & Education, 106*, 73-82.

Slavin, R. E. (2008). Perspectives on evidence-based research in education-what works? issue in synthesizing education program evaluations. *Educational Researcher, 37*(1), 5-14.

Wilson, C. (2010). Chapter 11: Analysis and interpretation of user observation evaluation data. In, D. Stone, C. Jarrett, M. Woodroffe, & S. Minocha (Eds.), *User Experience Re-Mastered* (pp.327-357). doi: 10.1016/B978-0-12-375114-0.00014-1

Vourvopoulos, A., & Badia, S. B. (2016). Usability and cost-effectiveness in brain-computer interaction: Is it user throughput or technology related? *Proceeding from the7th Augmented Human International Conference 2016*, Geneva, Switzerland.

Wang, C. C., & Hsu, M. C. (2014). An exploratory study using inexpensive electro-encephalography (EEG) to understand flow experience in computer-based instruction. *Information & Management, 51*(7), 912- 923.

Wang, H., Li, W., Hu., Z., Yang, Y., Meng., & Chang., K. M. (2013). Using EEG to improve massive open online course feedback interaction. *Proceedings from the 16th Annual Conference on Artificial Intelligence in Education 2013*. Memphis, TN.

Xu, J., & Zhong, B. (2018). Review on portable EEG technology in educational research. *Computers in Human Behavior, 81*, 340-349.