Satakunnan ammattikorkeakoulu
Satakunta University of Applied Sciences

BANU GOURLAY

Multidisciplinary development of electroencephalogram (EEG)-based smart head piece prototype for everyday environments monitoring

DEGREE PROGRAMME IN WELFARE TECHNOLOGY
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ABSTRACT

Gourlay, Banu: Multidisciplinary development of electroencephalogram (EEG)-based smart head piece prototype for everyday environments monitoring
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The objective of this thesis was to create an EEG-based monitoring solution concept for consumers for everyday environments. This was done in collaboration with a project between Satakunta University of Applied Sciences (SAMK) and Tampere University (TAU). The thesis followed the Design Thinking method as a roadmap, which was found to be suitable but not without its limitations. Through user focus, collaboration, flexibility, and iteration a complex problem was turned into an innovative solution. Lack of structure, resources, and motivation were identified as the main drawbacks of the method.

The data was collected from a workshop and three focus group meetings. The arousal measurement concept was the main outcome from the ideation workshop. The first focus group outcome included the user interface (UI) prototype I, and head piece design specifications. The focus group II outcome included the first handmade prototype and an updated version with buttons to give a better adjustment, and UI prototype II. After focus group III, the initial design was changed to a modular EEG product design concept on a fabric, and UI design III and a user flowchart were created.

The solution had two components. The modular biosensors would collect real time EEG data and present it to the users in an arousal curve. UI biofeedback curve would show diminishing, optimal and increasing arousal levels in real time and alarm users when they are not in a desired range (sleep, apathy, optimal level, stress, anxiety, panic). The curve would monitor the user's brain activity status to help maintain optimal arousal levels.

Arousal monitoring biosensors and the software could be used for multiple purposes and applied in different use cases including sleep, stress, anxiety, or panic attacks, allowing a longer period of monitoring brain activity, which may not be possible in a laboratory setting. Depression, anxiety, and stress-related conditions are increasing. The primary risk to employee welfare has been found to be psychological, with mental health and stress being the top two causes of long-term absenteeism. Remote monitoring could lessen the cost of hospitalizations to community and reduce pressure on healthcare system. EEG for everyday environments could also allow users to monitor their well-being and adjust activities accordingly. More research needs to be done to validate these concepts.

Key words: Electroencephalogram (EEG), smart wear, sustainable clothing, arousal levels.

CONTENTS

1 INTRODUCTION

The objective of this thesis is to create an EEG-based monitoring solution for consumers for everyday environments whilst answering design challenge questions. The thesis is done in collaboration with a project “Co-creating an electroencephalogram (EEG)-based smart head piece prototype”, which is a multidisciplinary project between Satakunta University of Applied Sciences (SAMK) and Tampere University (TAU).

Conditions associated with stress, such as depression and anxiety, are growing (Ehrhardt et al., 2021). The main threat to employee wellbeing is now psychological, with mental health and stress being the top two causes of long-term absenteeism (CIPD, n.d.). Around 32.5 million working days were lost to work-related ill health in 2019 and 2020, 18 million of these were instigated by stress, anxiety, and depression in the UK (CIPD, n.d.). It is estimated that globally 792 million people have mental disorders, which is around 10.7% of the population (Dattani et al., 2021). Mental illnesses result in loss of productivity and the economic cost to Finland in 2016 was around 5.3% of GDP. Finland has the highest estimated occurrence of mental disorders in the EU with nearly one in five (OECDiLibrary, 2020). Technology is changing healthcare practices to become more preventative and personalized. Remote monitoring can lessen hospitalization's cost to community and reduce pressure on healthcare system (Hernandez et al., 2021).

Wearable technologies have become very common in recent years, connecting existing devices with smart phones and computers to track steps, average heart rate and more (GCF Global, n.d.). Wearables give instant feedback to users making it easier for individuals to monitor their wellbeing and do essential alterations (Newton, 2021). Smart textiles can accumulate physiological and psychological data from the body. The data can be integrated with internet of things (IoT), big data and machine learning systems (Chen, 2016).

Using EEG for everyday environments has a vast possibility as it allows brain activity to be monitored for a longer period. In a laboratory environment some critical signals might be missed out if the symptoms do not take place during the measurement session. The continuous EEG monitoring solution can be used for both diagnostics and for self-monitoring purposes. As part of the project a mock-up of an EEG wearable head piece was created using recycled cotton.

The structure of the thesis consists of five main headings. Chapter one introduces the goal, purpose, and justification. Chapter two gives details about the background theory. In chapter three the process description and data collection methods are explained. Chapter four presents the research results and answers the design improvement questions. The final sections consist of key findings and conclusions, and contribution to the theory and issues described in theory.

2 WEARABLE TECHNOLOGIES, WELLBEING AND EEG

The following chapter provides background information in relation to the topic of the project, including information about wearable technologies, EEG, Brain Waves, Open BCI, Mental Health, and User Experience (UX).

2.1 Wearable technologies

Wearable technologies have become very widespread in recent years. Wearable appliances can connect with smart phones and computers and trace the number of steps a user takes, their average heart rate, sleep quality and more. These devices can assist the consumer to better understand their daily activity and can be worn throughout the day (GCF Global, n.d.). The interest in using wearable technologies arises from the wish to remain safe and healthy and to lead a healthy lifestyle. Potential uses include products which can help a person stay safe on the job. The device, for instance, might have a panic push button or a way of intermittently verifying that the user is alright. For example, a wearable product can track a person's alcohol intake through their sweat. Many wearables give immediate feedback helping people to monitor and make needed alterations (Newton, 2021).

The internet of things (IoT) is a system which connects humans and machines by transmitting data over a network. IoT helps people live and work smarter, reduce labour costs and waste (Gillies, 2022). IoT promotes the use of the smart textile as an IoT device to connect to a network or IoT system and exchange data. A variety of industries such as health, military, aerospace, and sports are involved in smart textiles to improve the quality of human lives (Izdrui, 2021). There are various terminologies being used for electronic textiles such as smart wear, smart textiles, or intelligent fabrics, and they all mean having electronic components in some way embedded in the textile (Nanowerk, n.d.). In essence, smart clothing can gather physiological or psychological data from the body, and the data can be used as part of the Internet of Things (IoT), big data and machine learning systems (Chen, 2016).

People are living longer and as a result chronic and non-communicable disease volumes (NCDs) are rising. The healthcare system is under pressure to fulfil the demand. IoT, big data and artificial intelligence (AI) working on personalized solutions and remote monitoring systems intend to decrease the obligation on the healthcare industry (STL Partners, 2017). Digital health ecosystems connect a diverse range of products and services through a digital layer including hospitals, laboratories, universities, doctors, and patients to gather and share knowledge amongst different stakeholders, and wearable technologies can be used as part of the health ecosystem (Digital eHealth ecosystems, 2020). Wearable devices powered by IoT provide real-time health monitoring such as calories burnt, and sugar level and heart rate monitoring, and this allows health care professionals to monitor the real-time results of their patients

(Teksun, 2021). Figure 1 shows examples of different wearable IoT devices such as smart clothes, fitness tracker, Virtual Reality (VR) Kit, smart watches, smart rings, and smart shoes.

Figure 1. Health & wellness with wearable IoT devices (Teksun, 2021)

2.2 Electroencephalography (EEG)

The cells in the brain are known as neurons and they communicate with each other by transmitting electrical signals and waves (Potter & Bolls, 2011). Human brain has approximately 86 billion neurons. A group of neurons that transmit similar electrical signals at the same time can be monitored and measured by using EEG equipment (Attevelt et al., 2020). EEG can record brain wave patterns with the help of small non-invasive metal discs connected to the scalp (Ince et al., 2021). The EEG process is painless and reliable (NHS, 2022). EEG is a vital technique for studying brain activity and collects useful data regarding changes in the mental status (Attar, 2022). Figure 2 shows the EEG electrode placement locations on the head such as frontal lobe locations Fp1, Pp2 and Fpz.

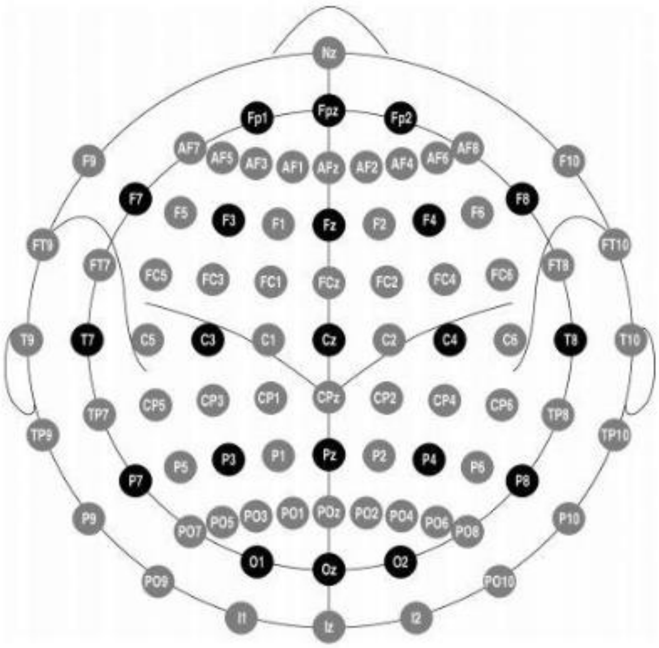
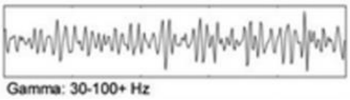


Figure 2. EEG Electrode placement (Müller-Putz et al., 2015)

The signal quality, comfort, and data collection period are all important features of the EEG product depending on the situation and the user's requirements. EEG is mainly being used in hospital settings for diagnostic purposes, but it is also becoming a consumer product. Individuals are using EEG-based products for meditation, sleep monitoring and even for gaming purposes. For example, Muse is an EEG headband, which uses real-time biofeedback to improve sleep and focus, and assists users with overall wellbeing (Muse, 2021). Figure 3 shows the usage applications of EEG in hospital and consumer settings.

Figure 3. EEG for medical use (Alsir, n.d.) & Muse headband for consumer use (Muse, 2021)

Brain waves can be divided into different speeds, such as fast, medium, and slow. They have their own distinct “sound” and are often compared to musical notes (MyndLift, 2018). EEG frequencies are named as Alpha, Beta, Delta, Gamma, and Theta. Alpha wave – ranging from 8 to 12 Hertz – is the resting status of the brain and appears when a person feels calm. Beta wave – ranging from 12 to 32 Hertz – presents itself when a person is alert, involved in problem solving or decision making. Theta wave, from 3 to 8 Hertz, occurs mainly in sleep but also in deep meditation (Brainworks, n.d.). The brain wave patterns and functions are displayed in Figure 4.

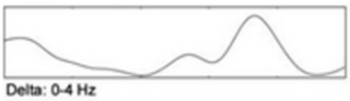


Gamma brain waves are the fastest and mainly occur when high-level alertness is required (30-100+Hz.)

Beta occurs when focusing on a task or engaging in activities (12-30Hz.)

Alpha waves are mainly associated with being calm and relaxed (8-12Hz.).

Theta is the drowsy or sleepy state of mind (4-7Hz.).



Delta is the deep sleep and relaxation status. These are the slowest brain waves (0-4Hz.).

Figure 4. NeuroSky (2015). Excellent brain. Comparison of EEG band.

Brain disorders such as epilepsy, tumours, stroke, Alzheimer’s disease, psychoses, sleep disorders, trauma, drug intoxication, brain injury, brain inflammation, and epilepsy can be diagnosed and monitored via EEG (John Hopkins Medicine, 2022). The qEEG, which is also called ‘brain mapping’, tests and measures the electrical activity in the brain. The q stands for ‘quantitative’ and the test measures the number of brain waves in comparison to the normal brain activity. Brain mapping can show which part of the brain functions normally or abnormally and can help uncover anxiety, depression, seizures, insomnia, epilepsy, head injuries, tumours, and memory problems. It can also identify problems such as difficulty in managing one's emotions, impulsive behaviour, and the struggle of paying attention (Stoneridge, n.d.). The qEEG produces a brain map which allows to quantify the power, distribution, and ratio of different brain waves, which can read the brain's activity and frequency patterns and produce the relevant data (Neuro Health, n.d.).

2.3 Open brain computer interface (Open BCI)

Open BCI is an open-source neuroscience and computer interface platform. The board can be used for measuring and recording electrical activity produced by brain. Open BCI is aiming to introduce the technology into the consumer market in an ethical way (Open BCI, n.d.). Open BCI systems can be used in medical settings as well as in various areas of research such as neuro marketing, advertisement, games, and entertainment fields (Abdulkader et al., 2015). Modern open brain-computer interface (BCIs) measures brain activity using EEG and then processes it by machine learning algorithms to recognize patterns in the EEG data (Liyanage, et al., 2020). Figure 5 presents an example of the open BCI headset and the attached Ganglion, a bio-sensing device for collecting physiological data. The product and the Ganglion are required to work together.

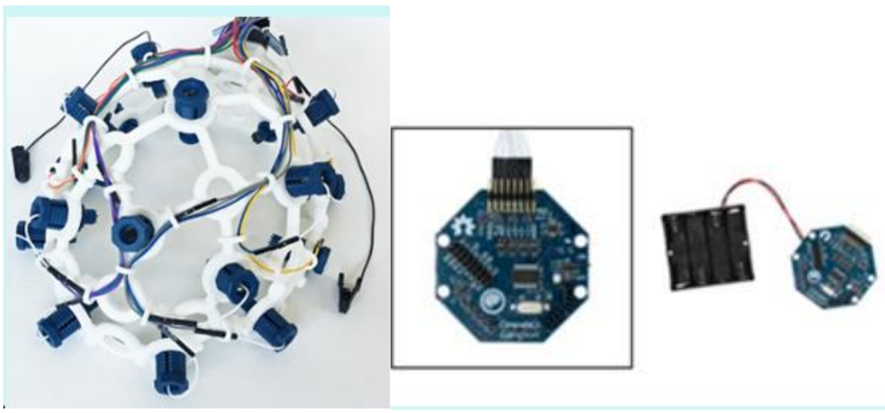


Figure 5: Open BCI headset example and Open BCI low cost biosensing starter kit (Ganglion) (Open BCI Shop, n.d.)

2.4 User experience (UX) and user interface (UI) design

EEG devices primarily target the consumer market instead of the professional medical environment. Thus, the UX and UI designs become essential part of the product design. User Experience (UX) design focuses on understanding the users and their needs, what they value and their limitations whilst taking into consideration business aims. Main factors affecting user experience are whether the consumers find the solution useful, usable, desirable, valuable, findable, accessible, and credible. The innovated solution should be original, fulfil a need, user friendly, desirable, able to cater people with diverse abilities, and trustworthy (Usability.gov, n.d.). UX incorporates all aspects of the end user interaction with the product and service. Fulfilling the need of the customer, creating simple, elegant, and seamless high-quality experience is essential. To achieve high quality user experience integration of the multidisciplinary services, such as marketing, engineering, graphical and industrial design, is required to work together (Norman et al, 2022). User Interface Design (UI) is the point of human computer interaction, where user interacts with an application, and it should be easy to access, understandable and user friendly. UI collaborates with diverse fields such as product design, visual design, and information architecture. The best practice for designing an interface is keeping the design simple, creating consistency, being purposeful, and making sure the system communicates what is happening (Usability.gov, n.d.). Usability is the quality attribute of the UI, whether the system is easy to learn, efficient, and pleasant to use (Norman et al, n.d.).

Consumer reviews indicated that some of the challenges with existing consumer EEG products were low signal quality, problems with the software application, problems with the product design, dropouts during the meditation session, products being too expensive, connectivity issues, products could not be worn whilst lying down, and, for example, open BCI products looking too complex (Amazon, n.d.). In general, plastic single piece EEG items are marketed to consumers. In this thesis the multidisciplinary project team conducted workshop and focus group discussions and after these meetings the thesis writer considered various aspects of the UX, UI and usability and applied in the product and service design concepts as much as possible. These can be found in the prototype section in more detail.

3 METHODOLOGY

This section aims to give a summary of the research approach, research strategy, development process, data collection instruments and techniques, participants, and data analysis. It also contains methodological literature to justify the choices whilst considering validity and the reliability of the study.

The focus of the study was to create an EEG-based monitoring solution concept for consumers for everyday environments whilst answering design challenge questions. As part of the thesis the following questions were defined as design challenges:

1. How EEG-based smart textile can be created following the design thinking process?
2. Which are the most promising use cases for smart EEG/Open BCI head piece for home and remote use?
3. Which characteristics are important for the headpiece design and the data for user interface in the most promising use cases and why?

The research design was a qualitative study. Qualitative research focuses on words and meanings and increases the overall understanding of the quality and characteristics of the research topic. The common features are the research object's surroundings, background, aims and meanings (Koppa, 2010). The pros of qualitative data can be that it allows flexibility, the methods can be adjusted as new knowledge is developed, and the research can be conducted with small samples. The cons of the qualitative research are that it cannot be examined statistically, it cannot be standardized or generalized, and in general there is considered to be a higher risk for bias (Scribbr, n.d.).

The research strategy was applied research. Applied research technique can be used when developing a new product and when trying to find usable solutions to real life problems (Cherry, 2022). The product development process follows the design thinking method as a roadmap. Design thinking aims to solve complex problems in a user centric way so that the solution is technically feasible, economically viable, and desirable for the user (Stevens, 2020).

Nonprobability sampling was used in the process. Probability sampling requires random selection, whereas nonprobability sampling needs non-random selection. Nonprobability sampling is a purposive sampling; it is often used in qualitative research. This type of sample is easier and cheaper to access but has a high risk of sampling bias; the researcher should aim to make the population as representative as possible (Scribbr, 2019). For the workshop fifteen participants representing different backgrounds were selected, and they were not chosen randomly. This was important so that different viewpoints and perspectives were collected for the project. The group included people from medical and engineering backgrounds, students, professors, and researchers. Primary data is being collected from workshops, subject expert meetings and observations. These were the main building blocks of the data collection method.

Throughout the project knowledge was shared via Microsoft teams. After the meetings the outcome of the meeting was sent to the participants to give visibility about the discussed content. In each meeting there was a presentation with the set goals, aim and information. All discussions were transparent to avoid any ethical concerns. The participants of the project were able to write their comments, share documents and their thoughts via this platform. The aim was to increase the validity and transparency of the research outcome whilst increasing knowledge amongst participants. Overall, the methods used were sufficient and provided a different perspective to achieve the set goals and aims.

3.1 Design thinking process

Design thinking aims to resolve genuine human needs in a creative way. The five stages of this method are empathize, define, ideate, prototype and test. The aim is to achieve practical solutions that are technically feasible, economically viable, and desirable for the users. (Stevens, 2020). Design thinking is a methodology for creative problem-solving and allowing people to use their own creative potentials whilst using design to create change and make an impact (Stanford University, n.d.). Design thinking intends to solve very complex problems. It allows creativity, innovation, and user centric design (Stevens, 2020).

Design thinking method is a non-linear development roadmap, and it should not be seen as a rigid approach to design as these stages can be switched, conducted in parallel, or gone over several times to generate an innovative solution (Stevens, 2020). As at any point in the process the design thinking stages can be run in parallel, repeated, and previous stages can be turned back to, the process does not have to be followed in order (Dam, 2022). This was one of the main challenges of this project as it was difficult to represent the findings in a desired way. The participants had different knowledge levels and changed during the process causing duplications, knowledge gap, and skills gap. The process was not simply straightforward, and it was challenging to describe the process in a concise and understandable way especially when combined with thesis data representation methods required. Figure 6 illustrates the design thinking method and how it can be utilized.

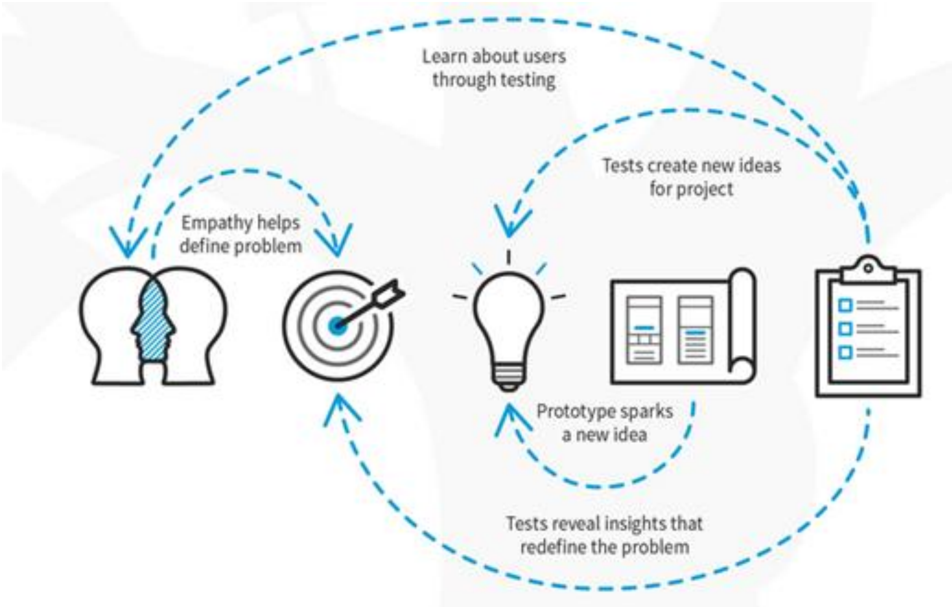


Figure 6. (Dam, 2022). Design thinking method

In this project it can be said that Empathy, Define and Ideate stages were mainly conducted in the workshop in which a neurologist and other experts participated. The Prototype stage was conducted via three focus group discussions. The first workshop tried to find an answer to Design Challenge Question 2 and focus group discussions tried to find answers to Design Challenge 1 and 3. However, there were overlaps and duplications and it was not a very clear cut as the process allowed flexibility for innovation purposes. This may cause problems for readers to understand the whole process clearly since the process is not linear and can overlap, duplicate, run in parallel, or stages can be combined.

- Empathize, stage 1. This part aims to understand the users and research their needs. User-centricity and empathy is the focus which means that people are the drivers of innovation. This is the first stage of the design thinking process. It aims to understand user’s needs and the problems from user’s perspective. Some of the methods that can be used to understand the user’s wants and needs are observation, brainstorming, interviewing users, sharing inspiring stories, creating empathy maps, customer journey maps and personas (Dam, 2022).

- Define, stage 2. This phase aims to state consumer needs and problems. Collaboration between multidisciplinary teams is important to give a different perspective.
- Stage 3, Ideate, create ideas. This phase aims to generate various ideas and a potential solution. In these three stages mainly workshop and literature reviews was used.
- Stage 4, Prototype, start to create solutions. This phase aims to turn ideas to a prototype.
- Stage 5, Test, try out the solution. It is a hands-on approach which aims to test tangible products and improve it further (Stevens, 2020). This was not the compulsory part of this project. It was excluded from the thesis as it required technical team's time and resources.

In Figure 7 the thesis process is summarised.

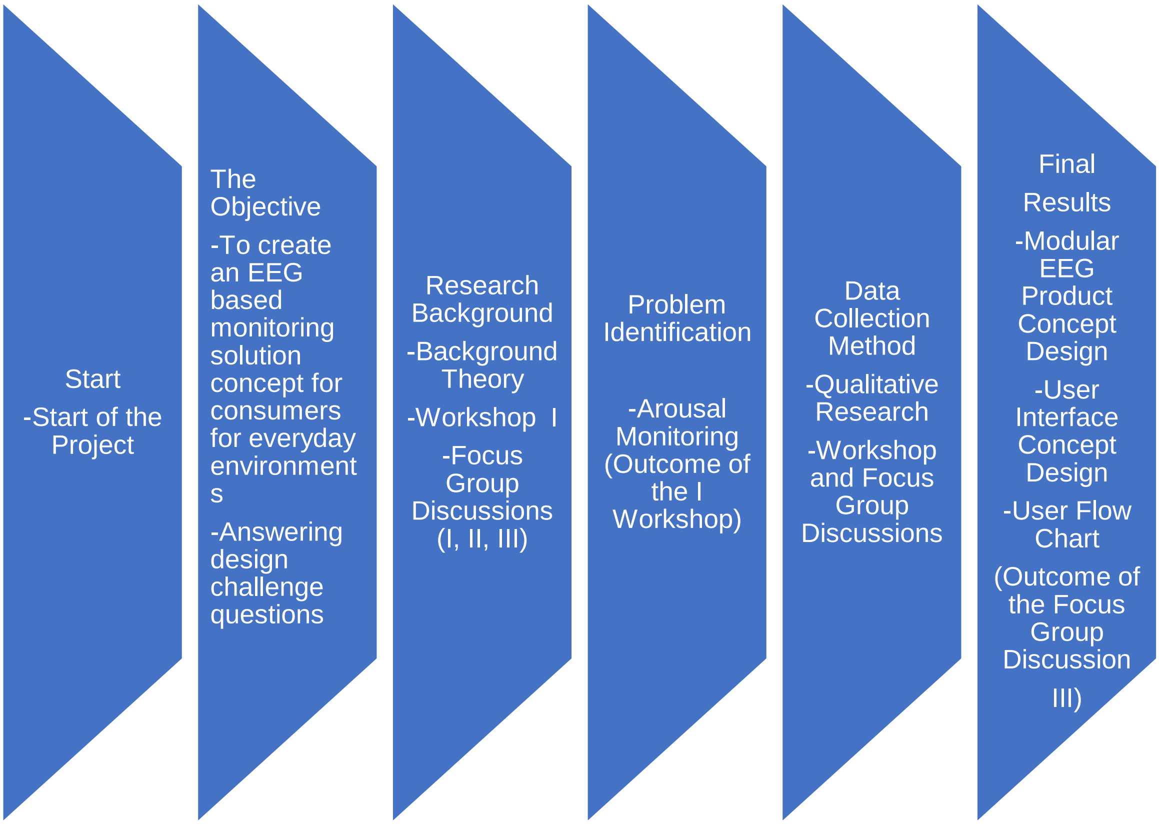


Figure 7. Development process

3.1.1 Data collection process

Methods used in qualitative data analysis can be mainly observations, unstructured interviews, and brainstorming sessions with different groups. The participants of focus groups should be selected based on the topic or issues for which the researcher wants actionable insights (Question Pro, n.d.). Focus group meetings are a type of qualitative research, and they are preferred when the researcher wants real time, unfiltered responses (George, 2021). Workshop means an arrangement where a group of people obtain new knowledge, find a creative resolution to a problem, or innovate new solutions. The researcher recognizes participants' reactions by collecting qualitative data through collaborative discussions and uncovering participants' blind spots (Orngreen et al., 2017).

In this thesis data was collected from workshop and focus group discussions. EEG can be complex; hence workshops and focus group discussions provided insightful information about the subject and a platform for learning new things. In summary, consent forms were sent to the participants before the workshop and participants' consent was collected. Before the workshop the thesis plan and the relevant presentation were prepared and checked with thesis supervisor. After the meetings the meeting outcome was shared with the participants via email and Microsoft teams. After, the thesis writer requested further meetings mainly with the engineers to check the feasibility of the project. As a result, three further focus group meetings were conducted to review the outcomes of the first workshop to look at the feasibility of the project. Before these meetings the thesis writer prepared presentations and afterwards shared all the relevant documents and the outcome on the Microsoft teams to allow visibility and knowledge sharing. Table 1 shows a summary of the workshop and focus group discussions as well as the aims and the method of each meeting.

Table 1. Summary of the data collection method

Workshop Number	Participants	Time and Date and Organization	Aims and Method
Workshop Number 1	15 were invited, 13 participated in a hybrid way	2 hours 21 April 2022 SAMK/TAU	Aim is to answer Design Challenge Question II, III. Design thinking Method Phase I – combined (Empathize, Define, Ideate)
Focus Group Meeting I	5 active participants	1,5 hours 10 June 2022 SAMK/TAU	Aim is to answer Design Challenge Questions (I, II, III). Design Thinking Method Phase II. (Prototype)
Focus Group Meeting II	4 active participants	1 hour 7 Jul 2022 SAMK/TAU	Design Challenge Questions I, II, III. Design Thinking Method Phase II. (Prototype)
Focus Group Meeting III	6 active participants	1 hour 26 August 2022 SAMK/TAU	Design Challenge Questions I, II, III. Design Thinking Method Phase II (Prototype)

3.1.2 The first workshop

The first workshop was conducted on the 21st of April 2022, in which thirteen people were actively participating in a hybrid way and the meeting lasted two hours. The multidisciplinary experts involved in "New technologies for the assessment and monitoring of brain health" project were recruited through e-mail. The agenda of the meeting included introduction, ideation, voting for ideas, choosing three potential ideas, and deciding which one was the most realistic to achieve and technically and economically viable.

The ideation phase can bring together different perspectives and uncover unexpected areas of innovation (Dam et al., 2020). Brainstorming gives opportunity to generate new ideas by leveraging collective thinking with the group, engaging with others, and listening their perspectives. This method involves focusing on one problem at a time while team members build on each other's responses with the aim of generating as many potential concepts as possible (Dam et al., 2020). In the workshop the group brainstormed to generate as many ideas as possible. Some of the participants met face to face at campus and the others participated online depending on availability. The group generated ideas via Microsoft teams. The video was recorded, and the ideas were shared via chat and discussions on the platform about the headpiece and software. After the idea generation workshop, the participants were asked to nominate three winning ideas which they thought would be the most realistic to achieve and the most beneficial for the users. In Table 2 the invitees and attendees of the workshop are listed.

Table 2. The workshop details

Numbers	Attendance List	Organization	Status
Participant 1	Professor	TAU	online
Participant 2	Professor	SAMK	at campus
Participant 3	Professor	TAU	at campus
Participant 4	Project Manager	TAU	at campus
Participant 5	Project Researcher at SAMK, Registered Nurse	SAMK	online
Participant 6	Engineer	SAMK	at campus
Participant 7	D. Soc.Sc. Special Researcher	SAMK	declined
Participant 8	Researcher Welfare Technology /Physiotherapist	SAMK	online
Participant 9	Adjunct Professor/ Medical Physicist	SAMK	online
Participant 10	Neurologist Dr.	SAMK	online
Participant 11	Engineer	TAU	online
Participant 12	Education Manager/Biomedical Sciences	TAU	no response
Participant 13	Adjunct Professor, Department of Clinical Medicine	TAU	no response
Participant 14	Thesis Writer	SAMK	online
Participant 15	Engineer	TAU	online

3.1.3 The details of the focus group discussions

The focus group meeting I 'Refining EEG ideas + prototyping' was held on the 10th of June 2022. The meeting lasted for 1 hour and 30 minutes. In Table 3 the attendees of the first focus group meeting are listed.

Table 3. Focus group meeting I participants

Numbers	Attendance List	Organization	Status
Participant 1	Electrical Engineer	TAU	Online
Participant 2	Software Engineer	SAMK	Online
Participant 3	Neurologist Dr.	SAMK	Online
Participant 4	Researcher/Physiotherapist	SAMK	Online
Participant 5	Thesis Writer	SAMK	Online

The focus group meeting 'Refining EEG ideas + prototyping II' was held on the 7th of July 2022. The group reviewed the relevant presentation and discussed about a variety of areas such as software development, personalized digital pills, 3D printing options and product design. The attendees of the second focus group are listed in Table 4.

Table 4: Focus group meeting II

Participants	Attendance List	Organization	Status
Participant 1	Engineer	SAMK	online
Participant 2	Researcher (TAU)/Psychology	SAMK	online
Participant 3	Researcher/Engineer	TAU	online
Participant 4	Thesis Writer	SAMK	online

The focus group meeting 'Refining EEG ideas + prototyping III' was held on the 26th of August 2022. The group reviewed the relevant presentation and discussed about a variety of areas such as software development, estimated cost of production, fabric choice, sustainability, microplastics and effects on environment and wellbeing. The attendees of the third focus group meeting can be found in Table 5.

Table 5. Focus group meeting III

Numbers	Attendance List	Organization	Status
Participant 1	Software Engineer (AI) Engineer (SAMK)	SAMK	online
Participant 2	Electrical engineer	TAU	online
Participant 3	Physiotherapist/researcher	SAMK	online
Participant 4	Physiotherapy/ student	SAMK	online
Participant 5	Nurse/researcher (guest participant)	TAU	online
Participant 6	Thesis writer	SAMK	online

4 RESULTS

This section gives a detailed view of the workshop and focus group discussions, and the outcomes and results of each meeting. The participant details can be found in the methodology section.

4.1 Workshop (Empathize, Define, Ideate)

The participants were encouraged to be free and expressive of their ideas and it was made clear that there was no judgement, so that everyone could speak up and express their opinions without restrictions. Areas and ideas discussed in the meeting are introduced next.

4.1.1 Panic attack

The first suggested idea was panic attack. Panic attacks generally happen suddenly and can be very frightening. When someone is having a panic attack, they may feel that they are having a heart attack. Some of the warning signs can be chest pain, headaches, and fear of death (Mayo Clinic, 2018). The participants stated that it would be good to detect panic attack and identify it before it starts and then notify the person. The idea was that the panic attack application can be combined with a meditation app. The aim would be to train the user's brain in the long run and reduce the impact of panic attacks.

4.1.2 Sleep quality and sleep apnoea

Participants acknowledged the importance of restorative sleep. Even if people sleep longer hours, if they are snoring their sleep quality is not restorative. It was suggested that measuring restorative sleep is important because the quality of sleep can affect people's overall health and wellbeing. Sport watches and rings offer similar products, but the EEG version is not widespread yet. In the meeting it was mentioned that currently airline pilots are being checked for drug and alcohol use but not checked if they are too tired. However, tiredness can also be equally dangerous and can affect the security and safety of passengers. Especially drivers or pilots could benefit from this product as it would also have an impact on passenger safety and security. The product could be embedded into eyepatches and could monitor sleep quality at night. Sleep has links with depression and a healthy immune system. Poor sleep is linked to inflammation in the body and chronic inflammation can cause obesity, heart diseases, type 2 diabetes, Alzheimer's disease, and even certain cancers. In addition, sleep loss reduces the ability to regulate emotions and interact socially (Healthline, 2022).

4.1.3 Healing and training the brain

Another idea presented was healing the brain with music or physical stimulation after traumatic brain injuries or a concussion. People can train their brain to produce the desired brain waves and the product can be used as a form of digital medicine.

4.1.4 Tiredness, stress, and warning signals

If the person is too tired, a signal warns the users by identifying that they need to take a break. If the person is stressed, the system can play relaxing music in different frequency and can suggest other activities so that people's stress level will go down to an optimal level.

4.1.5 Smart homes and brain wave connection (M2M) communications

The idea was that people could do some basic tasks with their brain waves, such as turn lights on and off. There are alternative products on the market such as Google Home, but people who cannot use their voice cannot benefit from that product. The EEG product could also train users how to use their brain waves. Participants mentioned that with brain waves users could move small items and practice; these practices could also be meditative and relaxing. The types of tasks that people could do with their brain waves could be searched, and training and capability of users could be increased accordingly. Brain waves can also be integrated with smart homes and M2M technology.

4.1.6 Epileptic seizures and autistic tantrums

Participants also highlighted that it would be good to have some warning signals before an attack and notify the caretaker or the person themselves. One of the participants said that it was likely there were some EEG signal changes when people are having these attacks, and the product could check other autonomic responses such as frontal alpha asymmetry, which could indicate some warnings. To increase arousal and to detect changes in arousal could be applicable to autistic people as well as cases like stress, anxiety, and panic attack. The product could show green lights and then turn red if electrical activity levels went up so that people around them could prepare in advance.

4.1.7 Eating disorders and addiction

Obesity affects most of the body's systems and there are over one billion obese people worldwide, 650 million of them adults, 340 million of those are adolescents, and 39 million of those are children. The obesity problem affects heart, liver, kidneys, joints, type 2 diabetes, stroke, cardiovascular diseases as well as having problems with mental health. People with obesity are three times more likely to be hospitalized for COVID-19 (WHO, 2022).

Participants mentioned that eating disorders such as obesity and anorexia are very challenging and complex. Reward system is deeper in the brain, and it is difficult to measure and find them an alternative reward so that they would not crave that stimulus constantly.

4.1.8 Mood, emotions and anxiety

It was stated that it might be difficult to identify different people's emotions or even recognize one's own emotions, name them and communicate to others especially if people are old, sick, or disabled. Parkinson's disease is one of the severe cases.

The application could assist in learning to identify when a user feels angry or sad and detect both negative and positive emotions. These could also be combined with dating apps, or even combined with the panic attack application. Positive versus negative emotions could be identified and analysed and even used to train the brain to be more optimistic. In addition, it could be combined with eye movement, heartbeat, and pupillary dilation. If it was done in a context and additional signals were also measured the outcome would be more reliable.

4.1.9 Nominations and the winning idea

The group then voted and nominated three ideas. The criteria for the nominations were that the product should be aimed at consumer market and should be feasible to produce with the current technologies. These three ideas received the highest vote counts:

- Doing things with one's brain waves and combining it with smart home technology.

- Reminder app. When one is too tired the system alerts to take a break.
- For autistic people, get alerts before they get too aggressive. Users get notification beforehand. Arousal increase.

The winning idea was arousal monitoring. It was agreed unanimously by the participants. The idea is not just based only on autistic people but could be used for panic attack, anxiety, anger and in many more areas. One participant mentioned that arousal could potentially overlap in many areas. The app could produce a curve; when the curve is pointing downwards the system could suggest the user to have, for instance, a cup of coffee to bring the curve up to the optimal level. The system could also give the user some information about their condition, for example, 20% of users are feeling stressed or tired - you are not alone. The system would check escalating arousal, diminishing arousal, and optimal arousal levels and give feedback to the user to notify of any changes. It could also be used with controlling environment or getting notifications and taking breaks when too tired. It is measured from occipital cord, but one of the participants mentioned that for a better signal, it should preferably be measured from the whole head. But in this case, four electrodes in frontal area or maybe less could also give good signals.

4.1.10 Product and application ideas

In the workshop the participants suggested that the product could be used or integrated with a tablet or a phone. People mentioned that they did not want an extra equipment, and ideally it should be integrated with an existing equipment, for example, glasses or sleeping eye patches, or even earphones. Measurements could be done during a longer period as well. The product or the software could have some type of a chart with a curve or a vertical barometer showing the movement of the electrical activity of the brain. Printed technology on a sticker, paper or a cloth could also potentially be an option, although it was not mentioned in the meeting.

4.1.11 Summary of the outcomes of the workshop

A meeting plan was produced, and a presentation was prepared prior to the workshop. The health and wellbeing problems were categorized under three main headings, and these were mental health, physical health, and overall wellbeing as described below. The group discussed and reviewed these problems in the workshop, but not necessarily in this order.

- Mental Health (stress, depression, anxiety, anger, eating problems, sleep problems, self-esteem, self-harm, trauma, ADHD, psychosis, paranoia, mood disorders, eating problems, drugs, and alcohol abuse).
- Physical Health (Alzheimer's disease, dementia, tumours, concussion, inflammation, encephalitis).
- Overall Wellbeing (Loneliness, social isolation, emotions, recommendations app, deep learning, mental energy).

The desired outcome of the meeting was to achieve the objectives described below and to have all the aims fulfilled:

- Choose the primary idea
- Create features and benefits of the product
- Think creatively about the head piece
- What value it brings to the users
- Create ideas about the app

A summary of areas being discussed in the meeting included:

- Panic Attack – Physical health
- Epileptic seizures – Physical health
- Sleep Quality, restorative sleep - Physical health
- Tiredness – Physical health
- Brain injuries, concussion: train the brain and brain waves – Physical health

- Security: check the tiredness – Overall wellbeing
- Enhance your memory: via deep sleep – Overall wellbeing
- Alcohol, gambling and drug abuse, reward system monitoring - Mental health
- Obesity and anorexia – Mental/Physical health
- Smart Homes and EEG – Overall wellbeing

Arousal and wellbeing could be investigated further for the new product development purposes. Below are some combinations of suggested fields which could be explored in future research:

- arousal and sleep disorders
- arousal and depression
- arousal and stress
- arousal and tiredness, reaching to an optimal level
- arousal and anxiety, panic attack disorders
- arousal and cognitive abilities

4.1.12 Summary of the literature review related to the winning idea of arousal

Arousal was the winning idea. The reason for choosing arousal was mainly because it could overlap with many other health issues. Arousal is a state of consciousness, awareness, attention, or intensity of distraction and stress. How a person can perform a task in a timely and effective manner depends on the arousal levels (Skybrary, n.d.).

There is no perfect arousal level which is appropriate for every condition, thus matching arousal levels with environment and tasks are important. This match is also called regulation. Individuals with sensory differences can find these adjustments challenging as they can get sensory input overload which can unfavourably affect attention levels (Griffin Occupational Therapy 2020). Factors impacting arousal are workload, task complexity, personal stress, health, motivation and working environment (Skybrary, n.d.).

The relationship between high and low arousal performance levels is called Yerkes-Dodson law. This law states that an optimal level of arousal is required to do well when performing a task. There is a relationship between performance and arousal levels such as in athletic performances; when the player gets too stressed, they can miss the shot or in exams high anxiety can harm student's ability to concentrate (Cherry, 2022). If the human's arousal level is at a low level, they can feel sleepy or sluggish. If the arousal level is elevated it can manifest itself in panic, aggression, and mood swings (Skybrary, n.d.). Figure 8 shows the arousal levels from low to high and their relationship with performance levels. The lowest arousal level is sleep, the highest arousal level correlates with panic and the middle represents the optimal level (Klados et al., 2013).

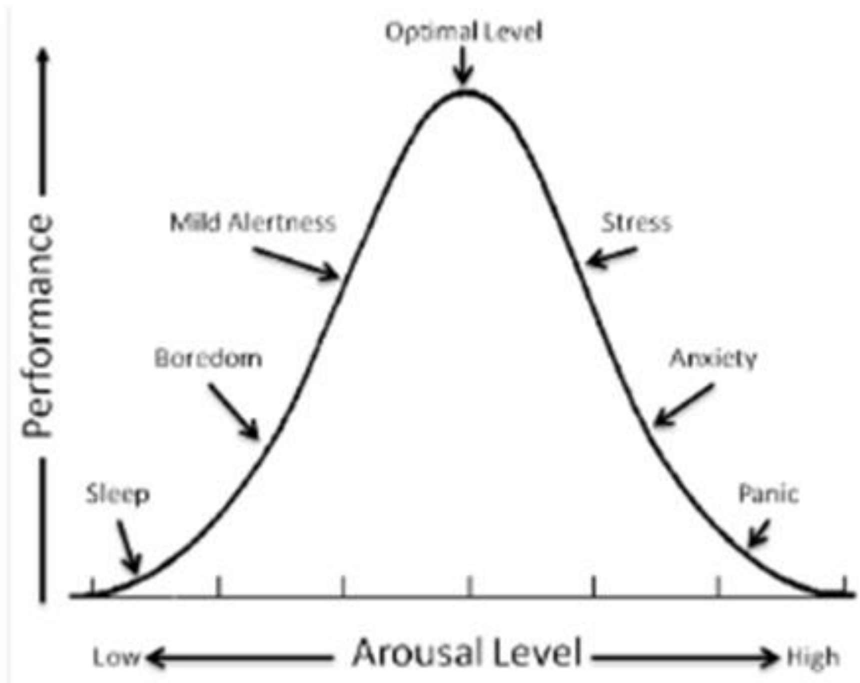


Figure 8. (Klados et al., 2013) The relationship between performance and arousal

Individual's conscious mind can manage 40 bits of information per second, whereas the unconscious mind can cope with 40 million bits per second (Safereli, 2017). Reticular Activating System (RAS) decides what information is critical and only lets around 130 pieces per second in the conscious mind. This amounts to what the central nervous system can handle at one time (Dabrowski, 2016). The RAS and the arousal levels are impacted by different things such as what one eats and drinks, emotions, and neurotransmitters (chemical messengers) in the brain (Mitchell, 2021). Brain functions such as memory and learning are closely linked to glucose levels and how efficiently body can use the glucose as an energy source (Harvard Medical School, 2016). The food people eat and the gut bacteria play an important role in both physical and mental health and it can cause anxiety, depression, and brain inflammation (Edermaniger, 2021).

Mental health problems are on the rise globally, affecting around 11% of the population (Dettani et al., 2021). In America one in five adults experiences a mental health issue (MentalHealth.gov, 2022). Arousal levels are intertwined with emotions. A highly aroused individual with negative emotions can express anger or distress. Low negative emotions can manifest themselves as tiredness or depression (Tay et al., 2019).

Stress-related disorders, depression, anxiety, and cardiovascular diseases are on the rise (Ehrhardt et.al. 2021). High stress levels can lead to sickness and reduction in productivity (Skybrary, n.d.). High arousal levels can affect stress levels and cause anxiety whereas low arousal levels can cause lethargy and concentration problems (Mitchell, 2021). The rhythmic activity of the brain changes in response to stress; this can manifest itself as a decrease in alpha and an increase in beta activity (Ehrhardt et.al. 2021). Human bodies can cope with stress in small amounts, but when stress becomes long-term or chronic, it causes serious health problems (American Psychological Association, 2018). People who cannot get enough sleep can suffer from high levels of stress (Grant, 2018). Stress can lead to psychological and behavioural disorders and can cause heart attacks, stroke and even death. (Attar, 2022).

Monitoring stress levels, sleep quality, anxiety levels, and alerting people can be beneficial to consumers and businesses.

The arousal monitoring solution could be utilized by students, drivers, or surgeons to monitor and stay in an optimal level, as over or under arousal level could affect the performance levels adversely. It could be used for stress monitoring or for sleep quality purposes. More research is needed to check the effectiveness of the software. Figure 9 illustrates how stress levels can decrease the quality of life, wellbeing, and performance levels and cause problems like experiencing burnout, headaches, tight muscles, and loss of appetite.

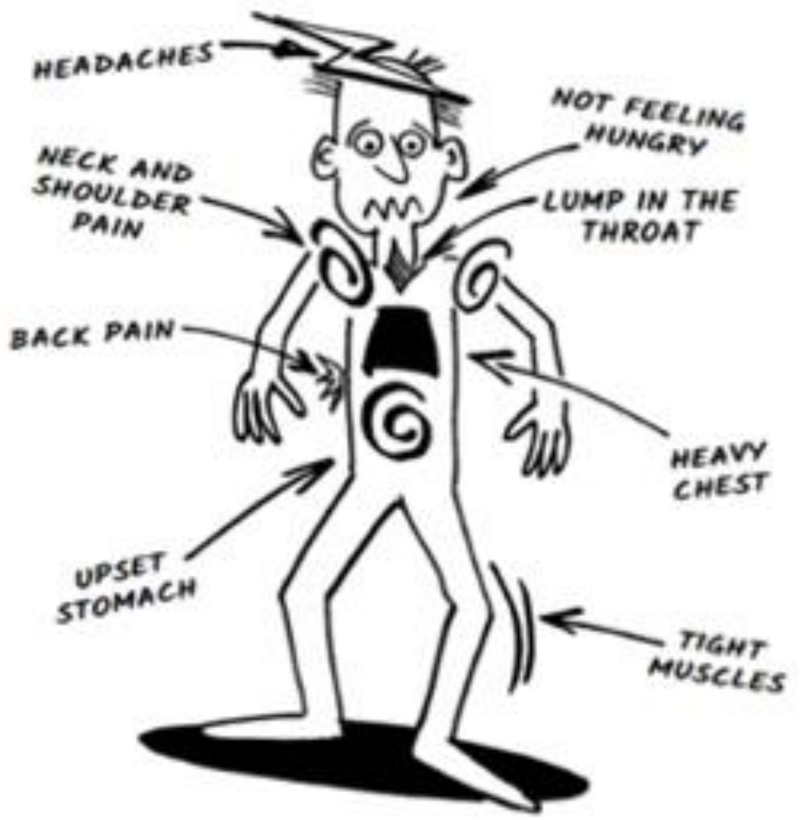


Figure 9. Stress effect on body (WHO, 2020)

An empathy map helps visualize what is known about users and helps build an understanding of client’s needs and facilitates decision making. It can help with user experience design (UX) (Gibbons, 2018). The empathy map in Figure 10 visualises some of the additional challenges users might face such as feeling worried, lonely, stressed out, anxiety, difficulty with sleeping, tiredness, or concentration problems. The empathy map aims to empathize and visualize some of the problems users might have and how monitoring the brain activity could help them control and manage their daily lives a bit better. For example, if the user’s arousal levels were getting low, the app could prompt the user to drink coffee to bring them back to the optimal arousal level.

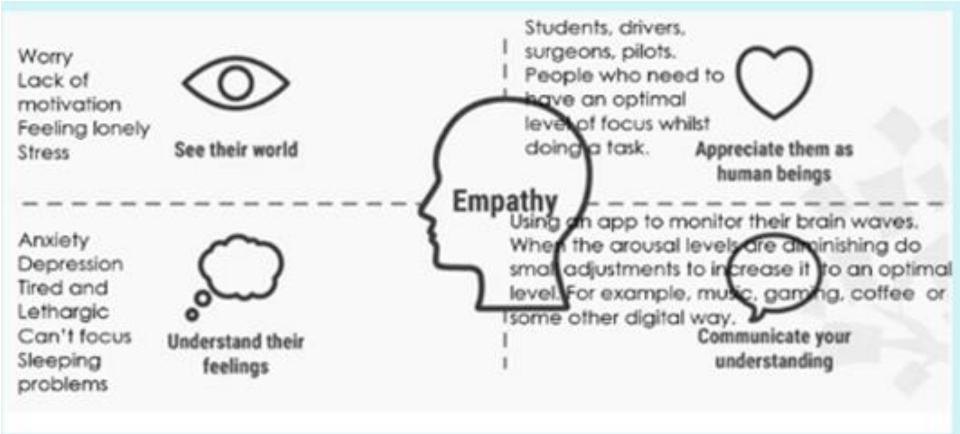


Figure 10. The arousal empathy map (Interaction Design Foundation, 2022)

The end users can be given a clear picture of what the new product can do with the value proposition chart (Net Solutions, 2022). Table 6 shows the value proposition of the product.

Table 6. Product value proposition table (Net Solutions, 2022)

Questions	Answers
Who are you developing the product for?	Consumers who would like to monitor their wellbeing via EEG technology.
What is the problem the users are facing	People who feel stressed, tired, having anxiety problems, and would like to monitor the EEG activity.
What is the Unique element that distinguishes our product?	EEG-based smart technology monitors and alerts user when they are not in the optimal range. The user can set up the preferred range or use the pre-set settings.
How it solves the key problem of the customer?	Allows real time bio monitoring of arousal status i.e.. stress, anxiety, or lethargy.
How your product is different from the already existing alternatives?	There is not a commercially available 24x7 EEG bio monitoring system which allows users to monitor their wellbeing in real time.

4.2 Prototype phase and the outcome of the focus group discussions I, II, III

This is an experimental stage and aims to identify the best possible solutions for the need identified in the previous stages. The prototype phase investigates further how potential users think, feel, and behave about the product prototype and tries to identify limitations and problems (Dam, 2022). In the workshop it was suggested that the product could be used or integrated with existing mobile technology products, as participants mentioned that they did not want an extra equipment; ideally it should be integrated with an existing equipment, for example, items such as glasses or sleeping eye masks, or even earphones or earbuds. They wanted that the measurement is done 24x7x365 in real time and the bio feedback curve is showing the arousal status on their mobile phone. In the prototype phase three focus group discussions were held to identify the requirement analysis and what was feasible from the technical point of view. The details and the outcome of these focus group meetings follow.

4.2.1 Focus group discussion I “refining EEG ideas + prototyping” outcome

In this meeting the focus group discussed the location of the channels and the design of the head piece product. A neurologist confirmed that ideally four and a minimum of two active electrodes would need to be placed on the forehead. This would be the F lobe, that is Fp1, Fp2, and Fpz. Then a reference electrode would need to be placed on one of the earlobes. This is the inactive electrode used for referencing. The idea of placing two electrodes at the back of a head was dropped due to hairs interfering with the signal quality, as well as placing an inactive electrode on the forehead next to active electrodes, as it may interfere with the signal quality.

Engineers confirmed that open BCI had 4, 8, and 16 channel options and could use one channel for EEG recording. Engineers were working on 2x2cm by 3mm small square electrodes and said they might be able to reduce the size to 10mm and the battery sizes could also be reduced. The electrodes were to be produced from silver and copper and provide a good quality signal. Engineers said that doing it all wireless or integrating electrodes into Airpods would be challenging. The design requirement was a minimum of two active electrodes placed on the forehead as well as an inactive electrode on the ear for referencing as confirmed by the neurologist. After debating the group favoured headband and ear warmer type of products which cover both the forehead and ears. The requirements were that the material should not be elastic but be firm and comfortable.

The first design suggestion was to cut a 56cm x 15 cm x 2 cotton fabric piece and create pockets for batteries, cables and electrodes and hide them inside the fabric as much as possible. When the location of every piece has been decided the ends can be sewn together. To create a 10cm extension between fabrics can be achieved by sewing an elastic band to give an extension to fit different head sizes (4cm x 3). When all the sections are sewn together the product would look like a tube. The product could be unisex, ideally one size, environmental, ethical, and naturally sourced and this could be its unique selling point. Figure 11 shows the potential fabric material and the elastic band to be used for the protype.

Figure 11. Potential Marimekko cotton garment & 2inc. (50mm) black and white knit elastic bands

The product could be used at home, for example, whilst studying or outside whilst driving. The product could alert the user when arousal levels are diminishing, so that the user could listen to music, play a game, or have a cup of coffee to increase their arousal levels to an optimal level. The software would be a curve presenting escalating and diminishing arousal levels. Figure 12 shows the potential software prototype I.

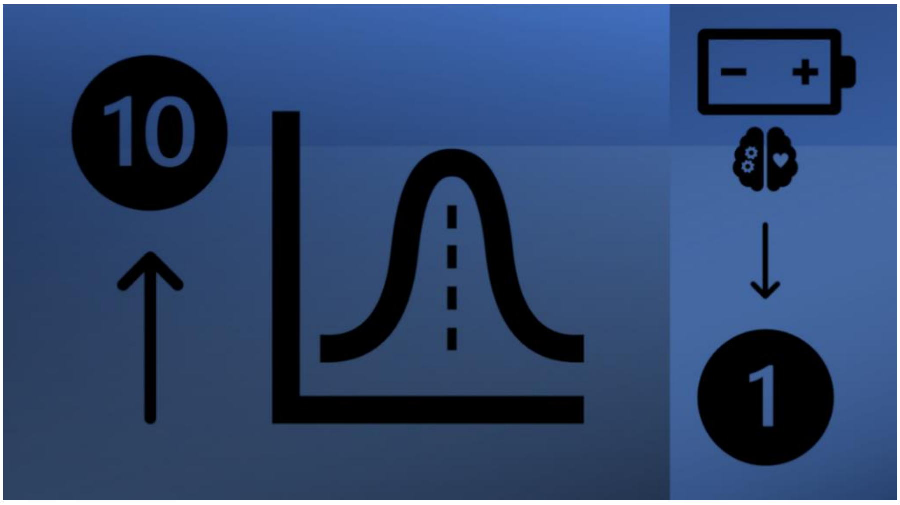


Figure 12. Potential software prototype I

When the user is in an optimal range, dominant Beta waves (12-30 Hz.) will be present. When the arousal levels are diminishing it will show Alpha (8-12Hz) or theta (4-8 Hz) and when the arousal levels are escalating it will show Gamma (30+) (NeuroSky, 2015). It was decided that in this project one of the engineers, electrical engineer, would focus on measurement and analytics and the software engineer would focus on the software development. However, the engineering team worked together and understood each other's work.

4.2.2 Focus group discussion 'refining EEG ideas + prototyping II' outcome

The first prototype was hand-made from an old, recycled cotton pillowcase, which was a 52cm by 22cm x 2 of fabric cut and sewn together. A 10cm elastic band was sewn at the back. The front forehead of the headpiece had three active electrodes located on the F lobe. On the ear there would be an inactive electrode for referencing. In Figure 13 the active electrodes are indicated in green, and the inactive electrode is in blue colour. The main reason for a double-sided fabric was that it hides some of the cabling and batteries from the user's view to be used with the Open BCI Ganglion.

Figure 13. First product prototype. Front (on the left) and back (on the right).

The design requirement was that the EEG electrodes needed to be directly in touch with the skin. On the left-hand side there is an ear inactive electrode. It was decided with the neurologist that the EEG electrodes would be placed on F lobe and a minimum of two active electrodes would be used. The locations of the active electrodes suggested were Fp1, Fpz and Fp2. The real electrodes are to be made from silver and copper and would be attached to the working prototype. In Figure 14 strips of white Velcro are used to represent the positioning of electrodes to give an idea of the prototype. It was thought to add a button to give a better grip to the head when doing testing with the open BCI Ganglion. Figure 14 represents an inside view of the prototype and shows the exact locations of the Fp1, Fpz and Fp2. The prototype was produced from available recycled cotton fabric to experiment on different options. The elastic bands had holes on them so that the buttons could be inserted in. This could be worn as a bandana style garment. It was just done as a first trial of a product prototype from available recycled materials to give an idea.

Figure 14. Updated prototype II (Front and back) inside view

The idea about the user interface was to create a curve on which users could monitor diminishing arousal, optimal arousal, and escalating arousal levels, so that people could monitor and adjust their arousal levels to the tasks. If the person's arousal levels were getting low they could, for example, have a cup of coffee to increase it back to an optimal level. They could then monitor it from real time bio feedback curve to see whether they are back into the optimal range. The user interface two would show real time bio feedback as depicted in Figure 15 showing UI prototype II design including apathy and anxiety.

- Escalating arousal level (going up)
- Diminishing arousal level (going down)
- Optimal arousal level (the middle)

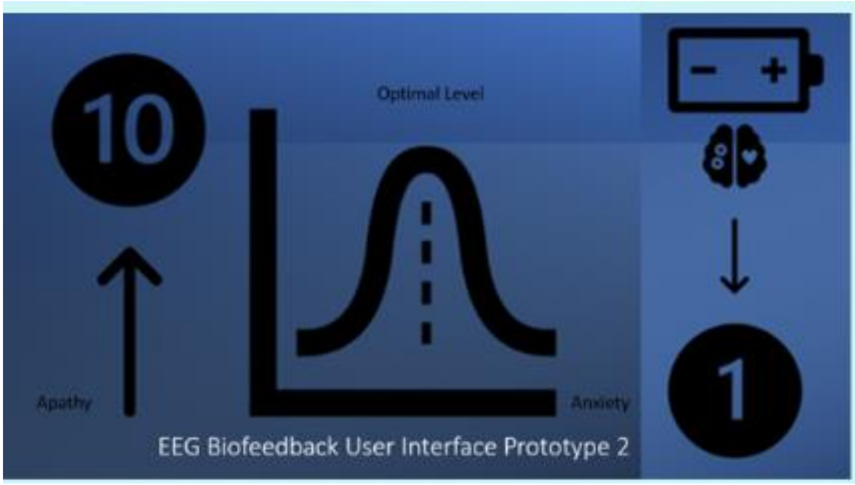


Figure 15. UI prototype 2. Apathy, optimal level, and anxiety

The project software engineer managed to get the real-life bio feedback from open BCI platform using a Python code. The software allows users to monitor the electrical activity of their brain and give different stimulus to themselves such as blinking eyes, drinking coffee, or listening to focus music to bring them back to the optimal level they desire. However, it was decided that an in-depth analysis of the raw data would not be analysed by Python as part of this project, but it could be done in future if required. An example of the software code and channel diagram developed by the engineers as part of the project is shown in Figure 16.

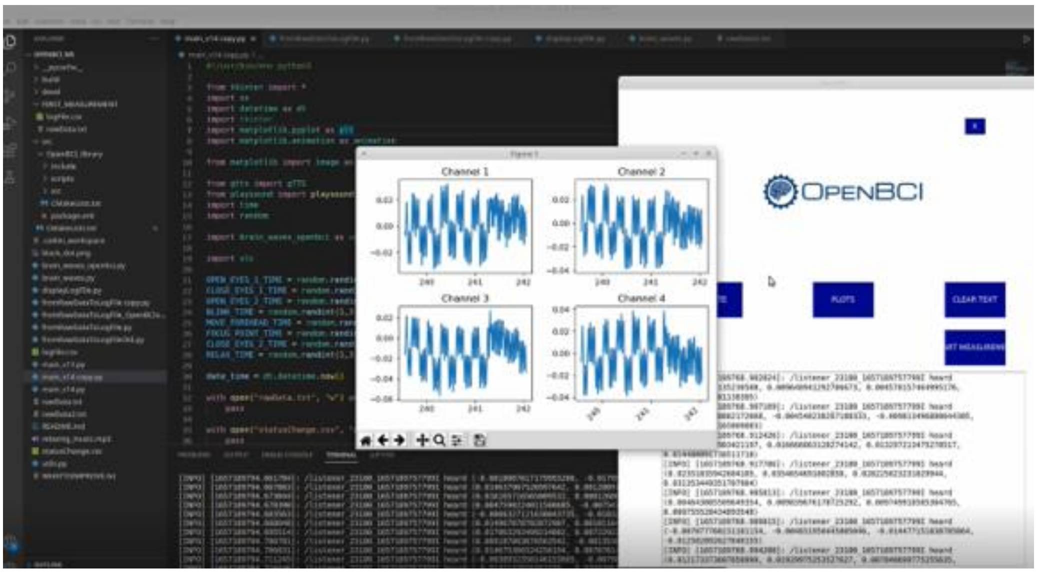


Figure 16. Example of the channel data diagrams

The summary of the meetings was as follows:

- Three active frontal electrodes required, and these are F1p, Fp2 and Fpz. Inactive electrode will be placed on the ear for referencing.
- The copper and silver EEG electrodes are being produced by Tampere University and it is in a working condition.
- A working real life bio feedback software has been produced by SAMK via using open BCI.
- Initial product and user interface prototypes concept was done by SAMK.
- The next meeting will be held in August to finalize the final prototype requirements before getting it produced.

Further requirements and improvements required are as follows. The working EEG electrodes need to be placed in the final prototype. The code needs to define the optimal range for customer user interface curve to be active. The range varies from 0.5 to 30+Hz. So, if the optimal range is said to be between 13 to 30Hz, the Apathy part can be below 13Hz, and Anxiety can be above 30Hz. The software can give a warning if possible. Alternatively, users can set their own range, depending on whether they want to focus on something or just to relax.

Future improvements and recommendations were as follows.

- Turning this into an individualized digital pill. For instance, Alzheimer’s patients can look at old movies or pictures when they are aggressive or experiencing anxiety. The product can be prescribed by doctors or psychologists.
- If the product continues, further data analysis can be done via Python, however, it is not in the scope of this thesis.
- If the product turns into a digital pill as well as being used as a consumer product, 3D printing options can be viable to reduce the cost of production.

4.2.3 Focus group discussion III

The initial workshop revealed that the participants desired a tiny electrode which could be integrated into their day-to-day items such as earrings, air pods, glasses, or baseball caps. They wanted this EEG product to monitor their arousal levels 24x7. They wanted user interface to be a curve shape, working together with the biosensor electrode. Biosensors are converting biological signal to a measurable response (Science ABC, 2022). The market for biosensor technology is developing at an extraordinary rate and the estimated value was expected to be around $22.5 billion in 2020 (NeuroSky, 2017). The experts revealed that given the time and resources available for this project, they were not able to produce a wireless small electrode which combines all the EEG requirements. Their analysis with the engineers and a neurologist revealed that the requirements for this prototype were:

- Minimum two active electrodes on the Frontal F lobe
- Minimum one inactive reference electrode on the ear

As a result of further discussions and analysis, after this meeting the requirements were set to:

- Three active electrodes on the Frontal F lobe (Fp1, Fp2, Fpz)
- Two inactive electrodes on the ear for referencing (the need increased from one to two after this meeting with the engineers)

The cost of producing one electrode is around 50 cents (euro) and it takes a couple of days to produce an electrode by the project engineer. It was noted that with the economies of scale the price could be reduced even further. The materials for electrodes were also produced from natural products such as silver and copper. In addition, the open BCI system seemed to require four AA-size batteries. However, this might be able to be changed into button batteries. Cabling is also required as part of the open BCI system. The prototype could be improved by purchasing more environmentally friendly material, such as fabric made from organic cotton and get it professionally sewn by a tailor.

However, at this stage this may not be necessary, and the team could do the testing on a hat with the open BCI system. In Figure 17 potential material from organic cotton can be found.

Figure 17. Organic Cotton Plus (n.d.). Potential materials for the head piece prototype.

In the focus group it was proposed that the design could be reviewed and improved further. So, the thesis writer considered the previous meetings and tried to empathize with the users and at the same time ideated what might be achievable from the technical point of view. In this design the idea was that the electrodes could be printed on a fabric using printed technology, or alternatively current electrodes could be attached onto fabric with a small sustainable Velcro. People could then attach and remove this item to fit into their day-to-day items such as sleeping eye masks, beanie, or ear warmers. The concept is shown in Figure 18. IHz. represents the prototype name. AE is the active electrode and Fp1 is the location of the electrode. The electrodes need to be in touch with the skin. The picture is the inside view of the product.

Figure 18. Concept of the new product design (inside view)

The basic estimated cost of production would be around a couple of euros, as price per yard of organic cotton fabric is costing around 15 euros and the electrode costs around 50 cents. So, this will make the product affordable, practical, ethical, and viable. The current team with the available resources is unlikely to be able to produce this wirelessly. If the team would like to produce the product wirelessly, they might require additional resources such as wireless engineers and a small amount of dedicated budget to produce organic cotton prototype.

The software was progressing well. The project software engineers managed to integrate timing into the software. User interface design was being worked on. The engineers also said that in the user interface the visualization of arousal status such as sleep, and panic attack could be included and be more specific instead of using diminishing arousal and escalating arousal.

It was also discussed as a further possibility to turn frequency directly into binary coding (0,1) as the EEG signal is measured in Hz and a computer communicates in binary numbers. In this case frequency refers to rhythmic repetitive activity in Hz. In EEG these activities can be rhythmic (approximately consent frequency), arrhythmic (rhythms are not stable) or dysrhythmic (not seen in healthy people, seen in patients) (The McGill Physiology Virtual Lab, n.d.). Binary coding is based on binary numbering system in which there are only two possible states, off and on, and these are represented in 0s and 1s. (Britannica, 2020). It was mentioned by engineers that Open BCI EEG data includes frequency (Hz) and amplitude (µV). The software was developed with the Open BCI biosensing Ganglion. The software design was updated as shown in Figure 19 including sleep, apathy, optimal level, stress anxiety and panic.

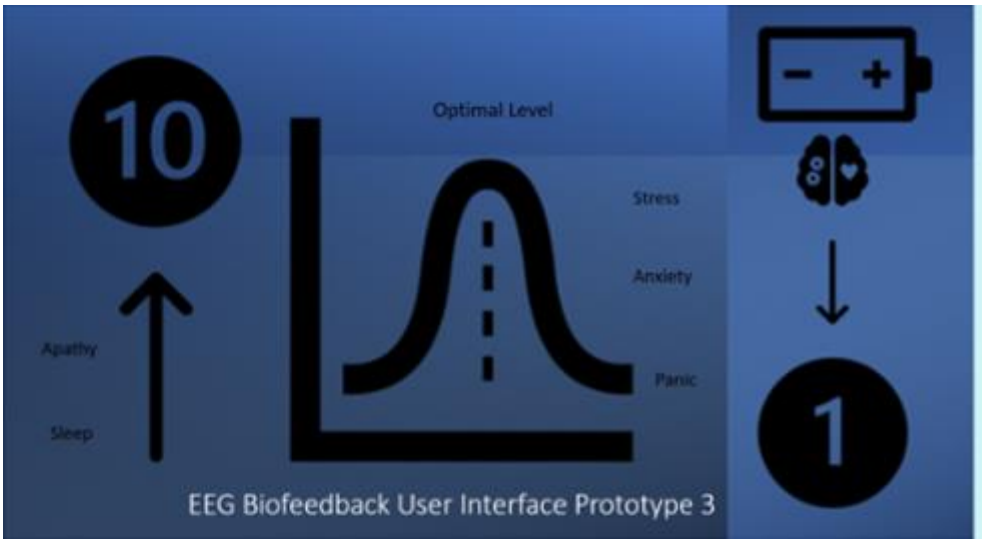


Figure 19. EEG biofeedback user interface prototype 3

The summary and the main outcome of the meeting was that the group discussed the bill of materials, estimated cost of production, software curves and electrodes, as well as design and sewing options:

- Electrodes are in a working condition
- Software is in a working condition
- The user interface is being developed
- Product material choice was decided to be ethical when possible. Although for the prototype this is not a must. If the prototype can be developed that would be nice to have.
- Inactive electrode requirements increased from one to two
- Timing was integrated into the bio feedback software
- The team might require fabric, someone with experience in sewing or a tailor to produce a more professional looking item. This may require some budget allocations and someone to coordinate.
- The engineering team can start testing the arousal software, user interface and the current electrodes with a hat and open BCI system.
- Prototype suggestion 1 or 2 or both can be developed if authorized by the supervisors.
- The main challenge seems to be producing the electrodes wirelessly whilst using this open BCI platform. The code and the user interface are

being developed as part of the open BCI system, so if the electrodes are required to work wirelessly without the aid of the open BCI system, the code may also need to be updated accordingly.

- Additional challenges can be to identify biomarkers to recognize different status of the mental performance. These can be heart rate fluctuations, eye movements, facial expressions, and muscle movements as well as ratio analysis of different brain waves such as alpha beta ratio analysis, which can increase the reliability of the product further. Certain biomarkers can be identified for each emotional status, in this case mainly for optimal arousal levels.

4.2.4 Sustainability

One of the key findings of the focus group III discussion was the sustainability. The group liked the idea of using recycled or organic cotton. A sustainable business model aims at improving environmental and social effectiveness and achieve sustainable competitive advantages (Geissdoerfer et al., 2016). The research has revealed that organic cotton is the most popular, eco-friendly, and sustainable fabric. This type of cotton is biodegradable, and pesticides are not used when producing. On the contrary, conventional cotton uses a vast amount of water and chemicals. This adversely affects biodiversity. By growing organic cotton instead of standard cotton farmers in theory can save up to 218 billion litres of water and 92.5 million kilograms carbon dioxide. Other ethical material choices are recycled cotton, organic hemp, organic linen and lyocell (Assoune, 2022).

4.3 The summary of the outcome

In Table 7 a summary of the meeting outcomes is presented including the design thinking method phase, data collection method, the outcome of the design thinking phase and challenges faced during each phase. The total meeting time was five and a half hours, and twenty-eight active participants were involved.

Table 7. Summary of the meeting outcome

Design Thinking Method	Data Collection Method	The Outcome	Challenges
Phase I (Empathize, Define, Ideate) (Aim is to answer Design Challenge Question II, III).	Background theory search from literature, observations, and Workshop I 13 Active Participants 2 hours meeting on the 21st April 2022	Workshop I outcome: Empathy Map, Problem Definition (Arousal Monitoring), Value Proposition Table	The design thinking method is a non-linear process, phases can overlap.
Phase II (Prototype) (Aim is to Answer: Design Challenge Questions I, II, III).	3 Focus Group Discussions were held I. Meeting had 5 active participants (10 June 2022, 1hr.30 min) II. 4 active participants (7 July 2022, 1 hour) III. 6 active participants 2022 (26 August 2022 1hour)	Focus Group Meeting Outcomes: I: User Interface Prototype Concept design I, Headpiece Design Specifications decided. II: The first handmade prototype built from recycled cotton, the product protype was updated further with buttons to give better adjustments. User Interface Prototype 2 (UI) III: The suggested prototype name IHz, modular EEG product design on a fabric, UI Prototype 3, User Flow Chart	Product Design suggestions were limited, building a tangible product prototype at home does not look professional or appealing. The designs mainly received good feedback from the participants. There was a gap between what people wanted and what the technical team said was achievable.
Total Time: 5.5 Hours Participants: 28 active participants			

4.3.1 Design challenge questions outcome

After the final focus group meeting the thesis writer reflected and summarised the design challenge questions outcome as follows.

Q1. How an improved version of EEG-based smart textile can be created following the design thinking process?

As stated before, EEG can be a complex topic, and indeed the aim of this thesis can be perceived as somewhat daunting or challenging. Thus, the design thinking method proved to be a suitable approach to address these challenges and more. As discussed before, the design thinking process is a problem-solving, human-centred approach focused on creating innovative solutions. Using the process included many benefits and learnings which helped in the completion of the thesis project.

Design thinking is focused on genuinely understanding the user's needs and thus helps create solutions which are more likely to appeal to the target user. In the thesis project the EEG-device was targeted at the consumer market, and therefore this user focus was an essential aspect of the process. It helped not only when identifying potential use cases of various illnesses and situations that users face, but also when developing solutions for the identified user needs and building concepts for the head piece and user interface whilst also considering user experience. Using design thinking approach also encouraged collaboration between participants to share ideas and to build on each other's ideas, which encouraged creativity and added value to the innovation process through different perspectives and skills. It can be said that participants learned from each other and appreciated user needs and problems from diverse points of view. Another benefit of the process was its flexibility and iterative nature. This allowed relatively quick prototyping and refining of the concepts as and when new data and requirements were identified such as the number of electrodes needed on the head piece and new features for the user interface. This flexibility in iteration would likely have been even more evident, if the testing phase had been a part of the process.

While design thinking approach overall helped in achieving the aim of the thesis, some downsides of the process were also identified. The process requires resources, mainly time but monetary as well, and participants' genuine commitment to the project. As the process was run as a thesis project, it is understandable that there were limits to the resources available, as well as conflicting priorities of time and to some degree lack of motivation and accountability to see the process through. A better resource allocation, for instance, would have allowed access to produce a more professional prototype of the head piece. Although design thinking encourages a non-hierarchical approach, it would be beneficial to have someone with a clear authority within the organisation to support and sponsor the process; this should not be the project manager or in this case the thesis writer. Changes in personnel during the project also complicated the project to some degree and contributed to the feeling of the design thinking process lacking structure, which may have affected some participants' focus and commitment to the project. Finally, the group dynamics play an important role in the process. As mentioned before, there was a variation in skills and knowledge between the participants, and as a result participants were likely to follow the dominant person. This may have led to the group conforming to the dominant ideas without fully exploring other alternative innovative solutions; this can adversely affect creativity which can be another downside of the design thinking process.

Despite the drawbacks mentioned above, the design thinking method nevertheless fitted the purpose of the project; through empathy, defining the problem, and ideation phases a rather complex problem was turned into an innovative solution and a prototype concept. Whilst in this case there were some obstacles in the resource allocation and execution part of the project, however, the design thinking method is likely beneficial and efficient in, for instance, a for-profit organisation with a high sense of urgency, ambition, motivation, budget, and support from management.

Q2. Which are the most promising use cases for smart EEG/Open BCI head piece for home and remote use?

Use case is a description of how users perform tasks. It shows the user goal and how it is achieved. The benefit of use cases is that they show a simple process how the user will use the system to achieve their goals (Usability.gov, n.d.). For this product the use case scenario I is keeping the users in an optimal level when performing a task. This can be utilized, for instance, by employees, students, drivers, or surgeons in various situations. Sleep monitoring and quality of sleep can be use case scenario II. The modular design allows users to attach the EEG sensors to sleeping masks. Sleep quality has been proven to be important and allowing monitoring in comfortable and natural settings can be beneficial to users. Use case scenario III can be stress, anxiety, or panic attack monitoring. These can be seen if the person is overly aroused. Both under arousal and overarousal can adversely affect performance levels and wellbeing. If they can be altered and users can take helpful actions, this may increase their quality of life. The user chart in Figure 20 is an example of how the user can utilize the product. It shows the path user will take in an application to complete a task; the design should allow users to reach and complete desired tasks in as few steps as possible (Product Plan, 2022)

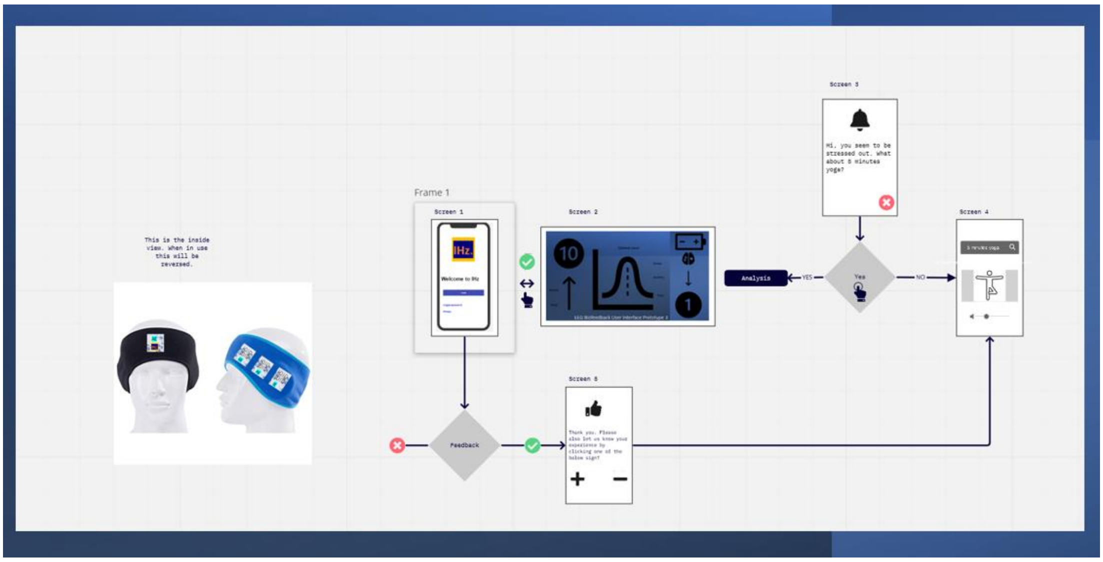


Figure 20. User flow chart

The user as shown in the user flow chart can put on the ear warmers and place the electrodes. The electrodes need to be in touch with the skin, so the view is inside out. The mobile or web application opens the IHz prototype. When the user logs into the system the bio feedback will indicate whether the user is in an optimal range or have diminishing arousal or increasing arousal levels. For example, if the analysis is showing increase in arousal status the system will send an alarm and offer 5 minutes of yoga time. The user has an opportunity to close the screen or continue. If they continue, after the yoga session the software asks for feedback. The same can be applicable for the low arousal levels – the system alerts the user and offers five minutes game time to increase the arousal level to the optimal range.

Action 1. User places the ear warmers. Figure 21 shows the inside view – when the product is in use this will be reversed so that the electrodes will be in touch with the skin. In this case, the electrodes are attached to the ear warmers.

Figure 21. New product. Inside view, needs to be reversed when in use.

Action 2. The user logs in to the system as in Figure 22. The system will show the real time bio feedback on arousal levels. On the left-hand side are sleep, apathy and the optimal level is in the middle. On the right-hand of the UI are stress, anxiety, and panic.

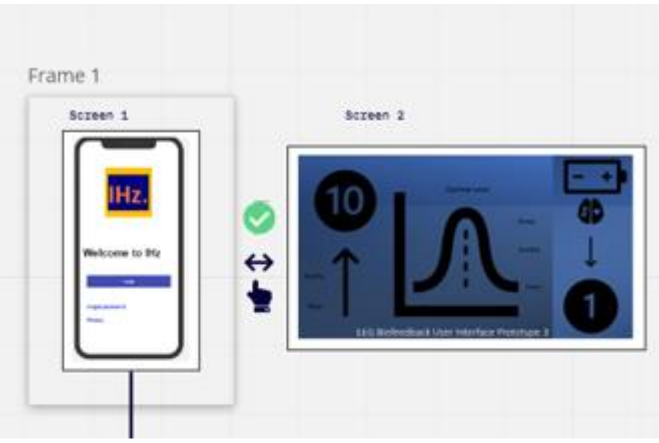


Figure 22. New Login page and the software design

Action 3: As in Figure 23 the system provides an alarm showing that the person is stressed out (over aroused) and offers a 5-minute yoga break. The system gives an option to continue or close the screen.

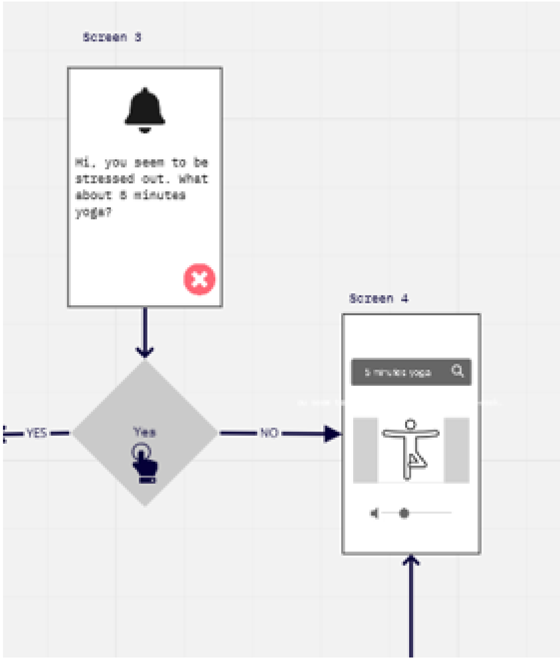


Figure 23. Yoga suggestion and the yoga session

Action 4: In Figure 24, if the person chooses to do yoga, the guided yoga screen will open. This can provide affiliation opportunities with the game developers to increase the income for the business.

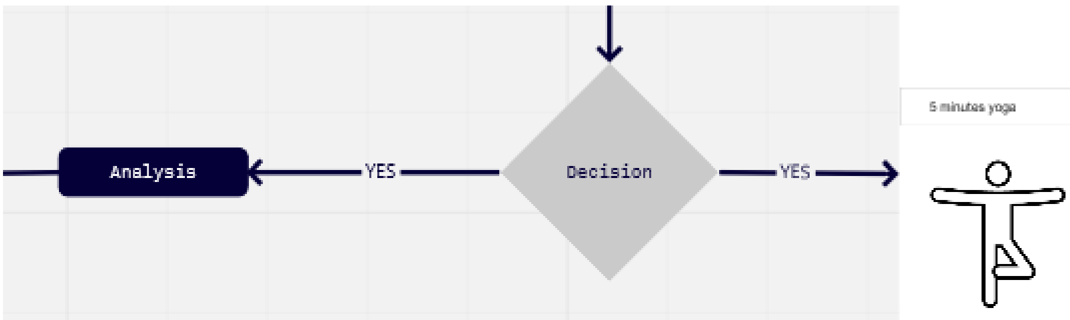


Figure 24. Analysis and user's decision to continue.

Action 5: In Figure 25, in this screen the user is asked for feedback, whether they were happy with the service and whether the experience was positive or negative. As mentioned before, the same can be applied to low arousal level, so if the person feels lethargic, the system will send a warning sign and offer a 5-minute online gaming session to bring them back to an optimal level.

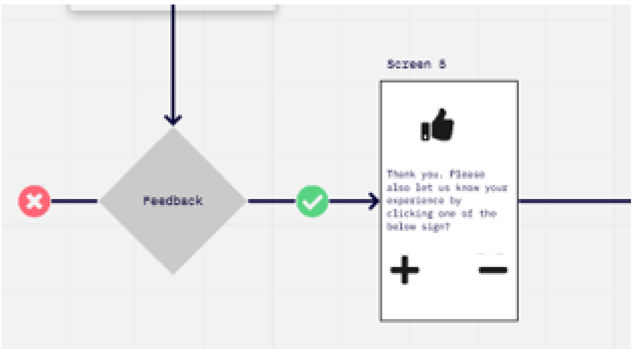


Figure 25. User Feedback + or – after the yoga session or gaming

Q3. Which characteristics are important for the headpiece design and the data for user interface in the most promising use cases and why?

The workshops and further analysis revealed that people value small and discrete items when it comes to EEG monitoring, especially if it is going to be used in a work environment or in other outside activities and circumstances. Users prefer continuous bio monitoring 24x7x365 and a simple software design. In this case, a curve shape design was preferred. The system shows the arousal status and sends an alarm to users when they are not in the desired range so that they can adjust back to an optimal level quickly.

Based on the findings three active electrodes need to be placed on the forehead. These are electrode location numbers Fp1, Fpz, Fp2. In addition, two inactive electrodes need to be placed on the ears for referencing. The modular concept design is discreet and small. It can be used with household products such as baseball caps or ear warmers. The curve shaped software was also designed showing diminishing arousal levels, increasing arousal levels and the optimal level. Analysis and alarm also show when the person is not in an optimal range and offers suggestions such as yoga or gaming to bring them back to an optimal level. The product and the software concepts are simple and user friendly and can be used by people with different abilities. The focus group discussions also revealed sustainability is important when developing a new product. Participants of the group liked the idea of developing the new product from natural materials such as recycled or organic cotton whilst minimizing harm to the health and the environment. In summary, it can be said that UX, UI, and Universal design principles are important characteristics of the product. The product is marketable to people with diverse abilities, it provides flexibility in use, the product design is simple and easily understandable by diverse range of consumers. Using natural products and being environmentally cautious is valued by consumers and it can also provide competitive advantage in the consumer market.

Some of the key players in the EEG consumer market are Muse, open BCI, NeuroSky, Emotiv, Mendi, CGX and Bitbrain. All these products are predominantly made from a single piece plastic as can be seen in Figure 26. The thesis writer reviewed the competitors' products and developed a new modular concept. For the prototype branding purposes IHz. was used. The product's unique selling point (USP) is that it is made from recycled or organic cotton whilst minimising plastic usage as much as possible. Another differentiator is that it is made from a modular piece instead of a singular piece allowing flexibility. The product can be used or integrated with household products such as hats, beanies, or eye masks for 24x7 EEG monitoring purposes. The price point is also improved compared to some of these competitors. The average price ranges from 200-400 euros per commercial headsets whereas the new product could be around 100 euros with the economies of scale. This makes the product competitive, affordable, and accessible. The product and the software are user friendly in line with global design suggestions. Therefore, it can be said that affordability, accessibility, modularity, and usability have been integrated and enhanced in the concept design. The ecological impact and sustainability were integrated into the product development process. In Figure 26 the product designs from Muse, emotive, open BCI and Bitbrain can be seen. IHz. is different from the main competitors in the sense of modularity and minimalist environmentally friendly design. The EEG electrodes developed by the project engineers are also made from natural products such as silver and copper and they did not compromise the quality of the signals. In fact, it can be said that the signal quality has improved, however, further tests are required to represent all the findings from the lab environment.

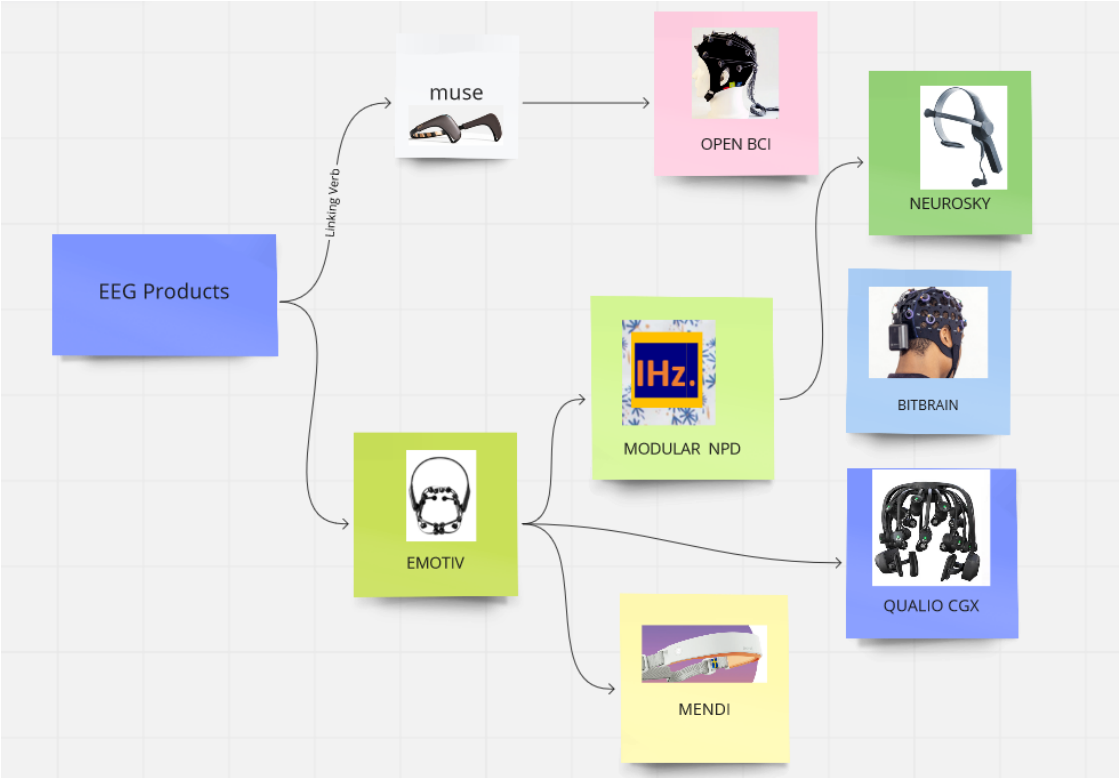


Figure 26. Competitors and IHz. EEG solutions

4.3.2 SWOT analysis

Swot analysis is a true and tested method for strategic analysis. SWOT analysis can be applied to any organization, product, or service due to its flexibility. Strengths include the characteristics of the product which give competitive advantage and weaknesses are the disadvantages. Opportunities are external factors which one does not have control over but can take advantage of, and threats are the elements that may cause harm to the product (Productfolio, n.d.). Table 8 shows the SWOT analysis of the new product concept developed.

Table 8. SWOT analysis of the new product (IHz).

Strengths (Internal +) (S)	**Weaknesses (Internal -) (W)**
Not a similar product in the market which measures arousal status 24x7. The unique selling point (USP) of the product are environmental & ethical, modular, and competitively priced. New electrodes are made from silver and copper and can transfer high quality signals.	Untested market and untested product might result in unforeseeable problems. Marketing might need a strong budget to promote the new product.
Opportunities (External +) (O)	**Threats (External (-) (T)**
Low competition, early entrance to market might result in high revenue. Product can collaborate with other medical devices and be part of the IoT and digital health ecosystem.	Competition might catch up quickly and copy the product features & benefits.

The electrodes are created from natural products such as silver and copper and they provide good quality signals. EEG electrode market size is to grow 35.11USD million dollars due to increase in neurological disorders. North America held the largest EEG market share in 2021. The market growth in America is attributed to the growing number of EEG procedures performed, the rising numbers of elderly population and rising expenditure on neurological diseases. Government and non-profit organizations are raising awareness of early diagnosis of neurological diseases, and it shows that the growth in the market size will continue. It is expected that China, Germany, Japan, and France emerge as predominant markets to grow for EEG electrode markets as well as North America (Cision, 2022).

4.3.3 Validity, reliability, and ethics

Validity refers to accuracy and checks whether the results represent what they are supposed to measure (Scribbr, 2022). Validity of the study can be confirmed by validating the methods and results. Methodological validity will demonstrate if the people in the workshop meetings were the right choices, and if they were asked the right questions. The result validity checks whether the results are real, or somehow misleading (Scribber, 2022). Reliability refers to consistency and checks whether the results can be replicated under the same conditions (Scribbr, 2022). Reliability can be evaluated from methodological, or results' perspective and aims to ensure that the results are not random or just one-time results. This can be reviewed by someone else doing the same assessment and checking whether they get the same findings (The Balance Small Business, 2021). The results should be reliable as people from a variety of backgrounds have contributed including subject area experts. Throughout the research people also had the opportunity to view the meeting outcomes and comment further via open platform, if there were any misinterpretation of the findings.

It was highlighted in the meetings that there might be problems with the reliability of the EEG data, but this needs to be investigated further in a lab environment. The potential problems with EEG data mentioned in the meeting were that the information received could be unspecific, additional information might be needed, such as eye movement, behaviour, or autonomic system response for data to be more accurate. In addition, the EEG data can be difficult and complex to analyse. Nowadays, it is possible to save the charts as a csv-file and analyse further in programming languages such as Python, but the participants mentioned that it was not a common practice yet.

Primary research was conducted via workshop and focus group discussions and different methods such as brainstorming and observations were used. For the first workshop a group of people from diverse background were invited. The voluntary participants signed a consent form to participate in the project. The meeting plan and presentations were prepared and checked with the thesis supervisor. The meeting was recorded. The meeting outcome was written down and shared via Microsoft Teams to give visibility. The meeting outcomes were sent to participants and key stakeholders via email to check and comment further if necessary to increase the validity and reliability. For the focus group discussions, a similar process was applied. The process was transparent and allowed diversity and inclusion. It allowed open platform for knowledge sharing and feedbacks. It allowed reflection as participants could read the meeting outcomes and think further and reflect on the solutions. Overall, the thesis process was satisfactory and can be considered as ethically conducted.

Ethics in general looks at the things from right and wrong perspective and is divided as metaethics, normative ethics, and applied ethics. The lines between different types of ethics are not clear and overlap (IEP, n.d.). In this project one of the ethical concerns was based on the material choices and after reviewing some alternatives it was decided that using organic or recycled cotton seems to be a more ethical and environmental choice. Another ethical concern could be that in the workshop and focus group discussions not everyone was at the same knowledge level. The variation between skillset, expectations and knowledge gap across different areas was high. As a result, it seemed that participants were likely to follow the dominant person, and this may have affected the validity of the research. Another area was that although it was a multidisciplinary project the participants' willingness to innovate, participate or create new things were limited. So, the skillset, time, resources, budget, and commitment required for such a complex project was not excellent.

NSPE code of ethics for engineers are to make highest standards of honesty and integrity. They should be independent and truthful, serve public interest and prevent misleading the public (NSPE Code of Ethics for Engineers, n.d.). Overall, in the project ethics, reliability, validity, and transparency were considered and applied throughout the thesis and the writer tried to manage ethical challenges throughout the project. The thesis writer represented the data and findings objectively and transparently to avoid any ethical misconducts.

The ethics of using EEG by consumers can be another area of ethical concern. If the signal quality is not good the data might not be reliable. If they are receiving wrong set of data, they might feel that they are alright. The security and privacy of the EEG data might be another area for ethical interest. The data should be protected with according to the law and set best practices to give protection to users. These are areas which can be checked further in lab environment and pilot settings before releasing the product into the consumer market. The product guidelines should also notify the users that the product is not built for self-diagnosis purposes and if any doubt they should consult a medical professional.

5 KEY FINDINGS AND SUGGESTIONS

5.1 Potential applications for arousal measurement

Arousal theory suggests that when doing a task, for individuals to perform well they should be in an optimal level. Too much arousal may cause anxiety and stress and low arousal levels can cause boredom and sluggishness (Cherry, 2022). The Yerkes-Dodson arousal level theory correlates with the brain's electrical activity. For example, when sleeping the frequency of human EEG wave is below 5 Hz. However, when an individual engages in a task and is focused, the EEG recording is between 12-30 Hz. (NeuroSky, 2015). Based on this theory, when doing a task users can be monitored if they are over or under aroused. If they are over aroused, for example, feeling stressed, the system can alarm the users to have a break to bring them back to an optimal level.

This theory can be checked further in a laboratory environment or real work settings, for example, if a surgeon is required to operate nine hours, how well can he perform and stay focused during that surgery? Stress levels of the employees can be monitored and managed, as employee absence and lack of productivity can be costly for global economies (CIPD, n.d.). Logistics companies can also monitor and alarm drivers when they lose focus, and effectiveness of the system can be checked via reduction on accidents or penalty tickets. Other alternatives can be for healthcare workers or care givers to test the product and receive an alarm for autistic tantrums or any other health problems such as panic attacks or anxiety. With the product it can be also checked how showing personalized old movies and photographs to Alzheimer's patients affects their arousal levels; this allows to determine whether their wellbeing can be monitored and improved via personalized digital pills.

In this case, the set objectives were achieved by using the design thinking method. The modular biosensors will collect the EEG data in real time and transmit the data to the user interface curve. The curve will show the status of user's brain activity to help them maintain optimal arousal levels. The product is in line with the wearable technology trend. Projected size of the wearable technology market by 2025 is expected to reach 70 billion US dollars (Das et al., n.d.). The findings revealed that there is an increasing trend on the EEG market due to increase in neurological and psychological problems (Cision, 2022). There is a genuine need for EEG monitoring device and growing market demand for the wearable technologies.

Arousal monitoring biosensors and the software can be used for multiple purposes and different use cases including sleep, stress, and anxiety monitoring as well as helping users maintain optimal arousal levels. The product can be utilized as part of the digital health ecosystem to reduce the burden on the healthcare organizations. Empowering consumers with 24x7 real time EEG monitoring options can improve quality of healthcare service. This can increase effectiveness, efficiency, and convenience whilst decreasing cost for hospital visits and time off work. Users can also share the EEG data with their health care providers. Distant monitoring can minimize hospital appointments (Hernandez, et al. 2021). The product can be utilized in workplaces to monitor stress levels to reduce the long-term absence. Mental health and stress are adversely affecting the workforce causing long term absenteeism (CIPD, n.d.). EEG is a safe way of collecting brain data and can be utilized in many areas such as the quality of the sleep can be monitored at home to detect problems like sleep apnea. The areas for EEG brain monitoring are growing and starting to open new doors. For example, brain mapping can reveal what is causing impulsive behaviour or some people having difficulties controlling emotions such as anger.

EEG products are already used in hospital environments for diagnostic purposes, and they have become fashionable in the consumer market, especially in the areas of meditation and aiding to fall asleep. There are multiple players in the market such as Muse EEG powered Meditation & Sleep headband for sleep monitoring, Brain Bit for meditation and sleep, and for brain training and improving attention capacity. Open BCI can also be used for neuromarketing, gaming, as well as in medical settings. The open BCI headset also requires Ganglion to collect physiological data unlike other consumer devices. The common features that the existing EEG consumer products have are that they are mainly produced from a single piece plastic, and mainly used for sleep monitoring and meditation purposes, although, also other areas are included such as for education, business, or gaming. It seems that there is no other 24x7 EEG arousal monitoring solution offered to the consumers. In that sense, the solution developed in this project can be said to be unique, innovative, and experimental.

The growing market in the wearable technologies area, neurological problems and the increased burden on healthcare systems led this new product development opportunity to be pursued further. Users buy products or services for safety, affordability, or prestige but most importantly to solve a problem or meet a need (Marion Kauffman Foundation, 2007). The workshop revealed that there is a need and demand for the 24x7 EEG arousal monitoring device. As a result, the multidisciplinary team worked on the project and brought different perspectives and expertise onboard to bring the project to fruition. Usability, accessibility, and universal design aspects of the product were considered and applied when developing the new design concept, for instance, designing the concept of the product and software in a simple, consistent, and safe way. Universal design aims to build a useful product that people with diverse abilities can use (University of Buffalo, n.d.). The product was designed in a modular fashion allowing flexibility to users. People with diverse backgrounds can use the product with minimal aid from others allowing product to be used by people with different capabilities.

The product can be used for research purposes at universities as well as in care homes or for consumer use. For example, it could be turned into personalized digital pill for Alzheimer's patients, the system could play their favourite music, show old movies or some pictures from the past when they feel stressed out. If the product was to be commercialized it could help monitor wellbeing 24x7 remotely and data could also be shared with the healthcare providers allowing better control and management on some health problems. The solution can also be integrated with other IoT devices such as smart homes with the support of telecom providers like Cisco, which already has unified communication infrastructure and capabilities (Cisco, 2022). Turning frequency into binary coding or vice versa should allow further collaboration between human to machine interactions. The engineering project team developed a small electrode from silver and copper, but the electrode is not wireless. The engineering project team is likely to continue working on this project to materialize and test the prototype and various possibilities as a future product development.

5.2 New product development

The initial product was developed as a one-piece tube style, which could be used as a bandana. However, after the last meeting the design was reviewed and altered to a modular style to give more flexibility to users. The arousal theory and the new EEG biosensor prototype work in a way that the small biosensors will collect the data from the frontal lobe of the brain and report back to the users, for example, via iPhone. It was concluded that five small modular EEG biosensors should collect sufficient data if attached or integrated into a fabric. The software collects the data and presents it in a simple UI design in the shape of a curve. This will allow users to monitor their brain activity in a simple and effective way as was shown in Figure 20. The solution demonstrates an end-to-end arousal monitoring system including product design and UI design.

In this case the main aim of the product was to monitor the optimal arousal levels. The optimal arousal level can be monitored via Beta waves in a range between 12-30 Hz. Of course, the product can be used for monitoring a different arousal status. For example, if the users want to monitor their sleep, modular biosensors can be attached to a sleeping eye mask and users can set the range to monitor the activity below 5 Hz. If users wish to monitor their anxiety or panic attack the range can be set to above 30 Hz (NeuroSky, 2015). Users will receive an alarm if they are not in required range or alternatively healthcare workers could give individuals a range that they should be monitoring, and data could also be shared with the healthcare workers when required.

For further development, the small EEG electrodes can be attached, integrated, or printed on a fabric or any other environmentally friendly material. The fabric or material size will be adjusted based on the electrode sizes. The product design is relatively simple but functional, allowing flexibility and freedom. Further testing is required to check, for example, if the signal quality is sufficient, whether the EEG biosensors are washable, and whether the modular biosensors stay in place when people use the product for various activities such as playing tennis. In addition, if engineers were able to integrate all five small electrode requirements into a single tiny electrode, this could also be integrated into earbuds or other daily used products such as glasses. This was the original request from the workshop but requirement analysis with the experts suggested that it would not be possible without compromising the signal quality. As a result, for the time being, the intermediate solution of a modular product prototype was developed.

Ethical and environmental aspects were considered whilst developing the product. Most new fabrics are produced from plastic materials like polyester, nylon, acrylic and polyamide; in fact, it is around 64%. These materials shed millions of microplastics every time they are washed. The microplastics are below 5mm in size and not visible to human eye; they are so small that they are easily passed-through wastewater treatment plants into the sea. Some brands advertise these fabrics as recycled to make them look environmentally friendly, but it is misleading. Worryingly, sea creatures are eating these toxic fibres, passing them up the food chain. “One washing load of clothes could be shedding up to 17 million tiny plastic fibres” (Byrne, 2018). It is estimated that 1.4 trillion plastic fibres go to the ocean from clothing. “Laundry alone causes half a million tons of plastic microfibers into the ocean every year, the equivalent of three billion polyester shirts”. These plastic fibres have been found all around the world in everyday food such as beer, honey, sugar, and salt (UN Environment Program, 2019).

The product concept was designed on a modular basis from organic or recycled cotton. The aim was to minimize the waste whilst making the product more environmentally friendly. As mentioned earlier, plastic fibres from clothing can mix with food causing health and wellbeing problems globally (UN Environment Program, 2019). When developing a new product, it is important to consider ethical aspects from the beginning to the end to avoid any damage to environment or health.

5.3 Reflection of the development method

The objective of this thesis was to create an EEG-based monitoring solution concept for consumers for everyday environments. The design thinking method was followed, which was found to be suitable for the purpose but not without its limitations. As a human-centred approach focused on understanding user’s needs and pain points, through collaboration between participants, and with flexible and iterative nature of the process, the design thinking method allowed a complex problem to be turned into an innovative solution. On the other hand, perceived lack of structure, limited resources including time, and participants’ lack of motivation and accountability in a thesis setting were identified as the main drawbacks when using the method. However, it was concluded that with appropriate resource allocation, including a relevant budget, and support from management these issues could be addressed, and the design thinking method can be a beneficial approach for problem-solving by allowing creativity and flexibility to innovate new solutions.

Key lessons learned for this type of product development from the thesis writer's perspective are that the innovation should start with the problem statement and gap analysis in the market. To do this, key stakeholders could get together and talk about potential problems and gaps in the market. Then they could concentrate on a solution and a plan, which should include the key resources and budget allocation. When the right solution is found, the team could ideate about the design and develop a product prototype and user interface design and perform adjustments to improve the product as an ongoing project.

On reflection, using a different model could have been more beneficial, such as a method called generic innovation process, which fulfils some of the shortcomings of the design thinking process. The process starts with the ideation phase, followed by concept design, prototyping, detailed design, implementation and adjustment, and diversification. This model was created to close the gap between design thinking process and sustainable business model innovation. Sustainable business model aims to enhance environmental and social effectiveness of the business and give competitive advantage (Geissdoerfer et al., 2016). The product prototype developed was also environmental, ethical, and sustainable. The generic innovation process could have been a better fit for this project. In addition, the method starts the process with ideation phase, which is also important, because it might speed up the whole process, save time and give a better structure compared to the design thinking method.

6 CONCLUSIONS

The objective of this thesis was to create an EEG-based monitoring solution concept for consumers for everyday environments. The thesis followed the Design Thinking method as a roadmap. The solution was a smart head piece, which has a personal monitoring and alarm system that can be utilized with wired or wireless sensor technology. The study consisted of one workshop and three focus group discussions to get user centred information and feasibility of the desired product. Based on the findings the thesis writer concludes the following:

- The design thinking process is a customer centric approach. It focuses on complex problems and aims to create beneficial solutions for consumers. On the positive points design thinking allows flexibility, iteration, innovation, collaboration and learning opportunities from each other. The drawback of the process can be that it lacks structure, and is repetitive, time consuming and challenging. Despite the drawbacks the process fulfilled its function, and a relatively complex problem was turned into an innovative solution and a prototype concept.
- The main use case for this project is monitoring the arousal levels and keeping the users in an optimal range and alarming them when users are over or under aroused. The product could guide employees, students, surgeons, or drivers to stay in an optimal level when they are working on an important task. Arousal monitoring system can be utilized in many other areas such as for sleep quality monitoring, panic attack, stress, and anxiety monitoring.
- Small EEG electrodes produced from silver and copper can be integrated or attached to modular organic cotton fabrics. High signal quality, reliability, using natural and environmental products, utilizing small and discreet electrodes, and accessible pricing point were found to be important design characteristics and requirements.

- The product can be used as part of collaboration systems and infrastructure. This will give opportunities to deploy the product in many areas such as part of smart homes or health ecosystems.
- The product requires three active electrodes on the forehead and two inactive electrodes on the ear for referencing but this can be reduced, and the sizes of the electrodes can also be minimised.

In summary it can be said that the neurological health problems are on the rise. There is a need and demand for this type of product. The product can be part of the IoT system and be utilized for multiple purposes. Further research, development and testing are required before it can be released to the consumer market.

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