

The influence of age on the ability to use Brain-Computer-Interfaces

Use-case: TV remote control

Masters Thesis

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Abstract

In recent years, Brain Computer Interfaces - BCI in short - evolved to a level of maturity which allows for these devices to be produced cheaply and thus being available to consumers. The newest example with extensive media coverage was the video published by Elon Musks *Neuralink* where an monkey learned to play pong. The study in this thesis uses a device from a manufacturer called *Nextmind* to examine wheter age has an effect on the ability to use such a device. A study was carried out with a number of XXX participants from different age groups. They were confronted with a task to use a Graphical User Interface to select elements by looking at them. not finished

1 Introduction

In recent years significant progress has been made on the development of interfaces which relies on direct interaction with the brain itself. The latest popular example is Elon Musks *Neuralink* with their monkey learning to play the game *Pong* only by using its brain ([Neuralink \(2021\)](#)). Apart from a solid scientific methodology, this study also presented a good media coverage including a showcase video which went viral. However there are more examples of a working interfacem, which will be discussed in section 1.4, since this vast area of resarch is an intersection between several areas of research: medical engineering, neuroscience, computer science and HCI¹. These interfaces are generally called *Brain-Computer-Interface* or *BCI* in short. [Microsoft Research \(23/10/2020\)](#) has a very precise definition of the scope:

Brain-Computer Interface (BCI) is a system that measures central nervous system (CNS) activity and converts it into artificial output that replaces, restores, enhances, supplements, or improves the natural CNS output and thereby changes the ongoing interactions between the CNS and its external or internal environment. BCI is direct communication pathway between an enhanced or wired brain and an external device.

As of Q2 2021 there are already devices available for consumers to buy, which fall into this category. This opens up possibilities for a widespread application of these kind of interfaces. Nevertheless, new ways of interacting with computers require some degree of resarch to define useful and user-friendly ways to interact with such technology. This study aims to provide insight into one aspect of this process.

After a thorough disussion about the state of research in this field, the research hypothesis will be defined based on considerations about future use cases. Subsequently a user survey will be designed, carried out and conclusively evaluated to put the results into context.

¹Human Computer Interaction

1.1 Management Summary

In the 2018 Gartner Hype Cycle report (Gartner (24/05/2021)), which is shown in figure 1.1, BCIs are denoted as to be on the brink of the peak of inflated expectations:

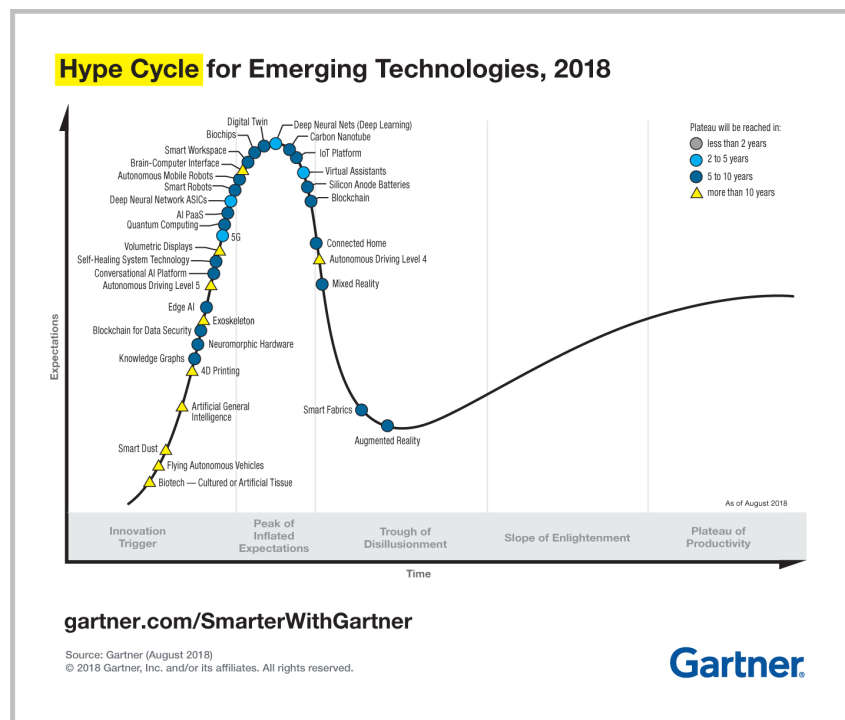


Figure 1.1: Gartner report of emerging technologies 2018

It is important to note though that as of 2018, it'll still take more than 10 years to reach a plateau of productivity. Although there is no mention about this technology in subsequent reports in the following year, two market revenue forecasts from 2015 until 2022 and 2018 until 2022 show a similar pattern in figure 1.2.

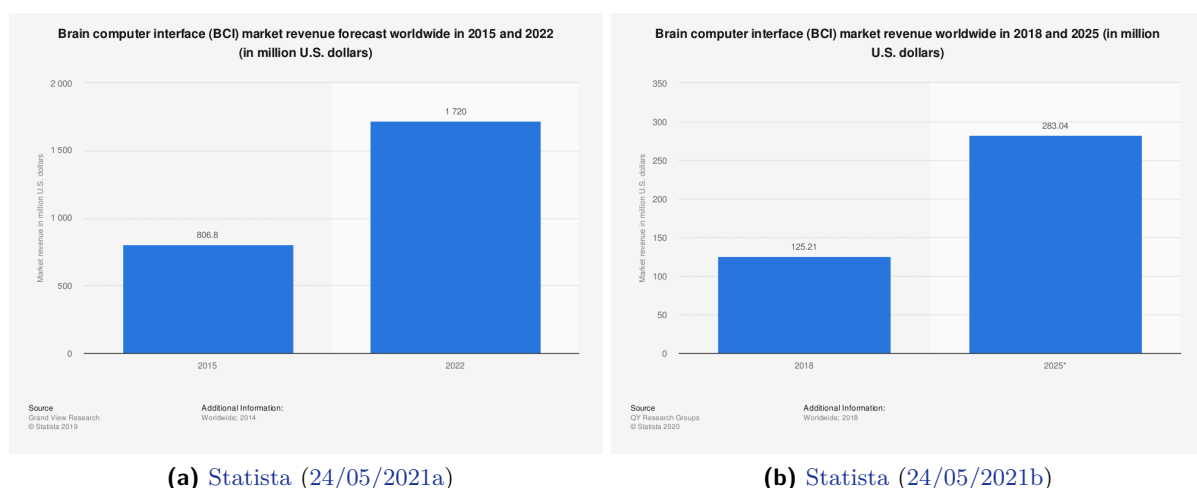


Figure 1.2: Statista revenue forecast as of 2015 and 2018

Essentially the market revenue expectation has been very inflated from 2015 on so that it was corrected downwards in 2018. But although the absolute growth was projected to only a small fraction, the relative growth potential stayed about the same of doubling within the next seven

1 Introduction

years. This is very indicative for the technology being overhyped, as Gartner explains: ([Gartner \(24/05/2021\)](#))

A wave of “buzz” builds and the expectations for this innovation rise above the current reality of its capabilities. In some cases, an investment bubble forms, as happened with the web and social media

Nevertheless, what this technology sets apart from other featured technologies is the fact that it has been around for a few decades and has been continuously researched upon. A strong indicator is the amount of organizations and conferences held about this entire discipline, as can be seen in section 1.4. The fact that it has only been on the radar of early adopters and tech-enthusiasts in conjunction with market revenue projections is a strong indicator that this technology has reached a level of maturity which makes a widespread application outside of laboratories somewhat feasible.

The latest *2020 Gartner Hype Cycle* report shows already the enhanced version of bidirectional BCIs (titled “2-Way Brain Machine Interface”) on the slope of innovation:

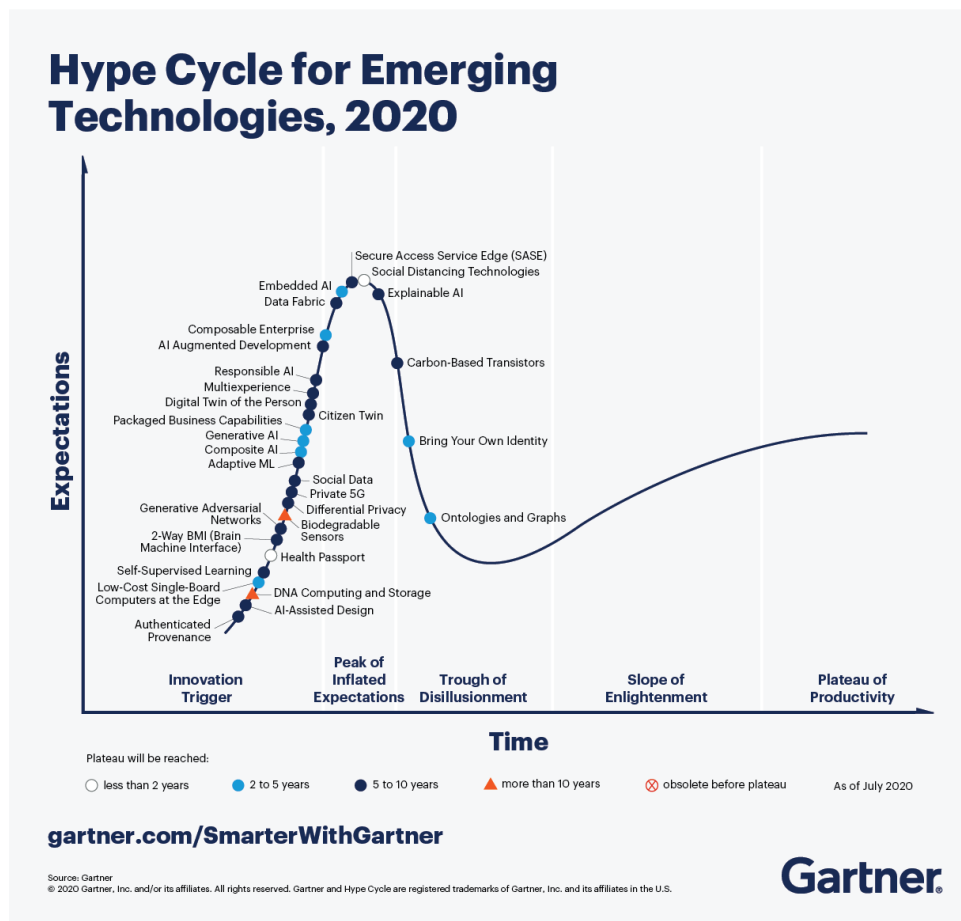


Figure 1.3: Gartner report of emerging technologies 2020

All in all, there are strong indicators that the technology gained traction over the last few years and could be considered a worthwhile investment if approached with care.

1.2 Brain-Computer-Interfaces

In this section a general overview of the working principle of these interfaces will be provided. Since this study is aimed at computer science and HCI², the neuroscience and medical domain will be only covered very briefly.

First studies began by [Vidal \(1973\)](#), who investigated the possibility to use EEG³ waves, which were first recorded by [Berger \(1929\)](#), as a way to create a direct interaction between a machine and a human brain.

There are three types of BCIs: invasive, partially invasive and non invasive. This depicts the degree of intrusion into the skull and brain tissue. *Invasive* BCIs are electrodes, which are implanted directly into or onto the grey matter of the brain. This can cause long term issues like scars and also degraded signal strength according to [Abdulkader et al. \(2015\)](#). Partially invasive BCI however are although located within the skull not in direct contact with the grey matter. Non-Invasive BCI are only placed on the head without intrusion of any tissue. Due to the direct contact, invasive BCI provide the best resolution of the measured signals. Non-invasive BCI in comparison suffer from signal degradation and deformation of the cranial bone tissue. Therefore partially invasive BCI are a compromise between good signal strength and the risk of medical conditions. Another potential advantage of non-invasive BCIs is that these Interfaces could be easier mass-produced and become affordable to consumers. Also they don't require specialized medical knowledge and equipment to operate.

The way these interfaces work is based on the same principle: A human brain emits electrical signals, which can be picked up. According to [Vidal \(1973\)](#), they can be described as follows:

"Embedded in this sustained "spontaneous" or "ongoing" electrical activity, short, distinctive (0.5-2 sec) waveforms can be found that are evoked, for instance, when a brief sensory message (stimulus) such as a brief illumination of the visual field or a tap on the forearm is received by the subject."

Based on the origin within the brain, these can be correlated to certain stimuli, mental and emotional states ([Jardim-Gongalves \(2018\)](#)) and according to [Waldert \(2016\)](#) been used to drive *an external effector or affecting internal body parts and functions*. The external effector is the use case which is being examined in this study.

Without a BCI, interaction with a computer requires some physical interaction with devices such as keyboards, mice or gestures on a touch screen. There are mainly two different reasons, why these devices are a constraint to speed and efficiency of HCI. The first reason is a limitation on interaction speed: Although there is no definitive consensus about the speed of thinking, alone being able to type along the spoken word is unattainable for non-professional typists. A professional typist has to be able to type at 180 - 220 WPM⁴ according to [NCRA \(25/05/2021\)](#). [ScienceDaily \(25/05/2021\)](#) made a survey with 168.000 volunteers, where the fastest typists weren't even able to come close to this mark with 120 WPM. Therefore it is safe to assume that typing in the same speed as thinking is impossible except for rare individuals who devoted a significant time practicing. Secondly: in applications such as games, where reaction time and accuracy is the fundamental element for success or failure, an interaction based on motoric interaction with a physical pointing device has some significant drawbacks like limited accuracy, if the whole chain of wrist movement in conjunction with a mouse is under scrutiny.

If a BCI was to replace these types interaction, these constraints could potentially be alleviated and interaction based on physical interaction rendered obsolete.

²Human Computer Interaction

³Electroencephalogram

⁴Words Per Minute

1.3 Working principle

Before any deeper considerations in regard to the general scope of this study can be made, it is important to understand the working principle of the BCI, which will be used. Although the vendor of the BCI in question does not disclose any details of the inner workings itself, it is safe to assume that the underlying technique used is the so called *Steady State Visually Evoked Potential* - SSVEP in short. Sokol (1976) provides detailed inside into the topic from a neuroscientific point of view. The general principle however is that any visual stimuli cause a certain pattern of waves within the visual cortex of the brain. These patterns can be used to evaluate if a certain pattern is being seen *and* in fokus of the person.



Figure 1.4: How VEP works in principle citation?

This is being done by subsequently feeding the sensor data through a trained neural network. The objects, which are being seen by the person, have been labeled *neurotags* (NextMind (23/11/2020)) from the vendor of the BCI. These neurotags can provide two different readouts: If it is triggered (i.E. *seen*) and the confidence, which depicts the level of *focus* of the user on the neurotag (NextMind (18/11/2020)).

The physical layout of the sensor is show at figure 1.5. It has 18 eletrodes, which are arragend in pairs to cover the area, where the visual cortex is located at on the back of the cranium. It is battery driven and communicates via the Bluetooth LowEnergy protocol.

1.4 Related work

As previously mentioned in section 1, research on BCIs is partitioned between four different domains: *medical engineering*, *neuroscience*, *computer science* and *HCI*. Apart from commercial entities such as *Microsoft* or *IBM* and scientific journals, the majority of the research community is clustered in three organizations:

- ICBCI (*International Conference of Brain Computer Interfaces*), which is a department of the WASET (*World Academy of Science Engineering and Technology*)
- EMBS (*Engineering in Medicine and Biology Society*), which is a department of the IEEE
- BCI Society, which is an entity of its own



Figure 1.5: Physical layout of the sensor

There are also research efforts in the east-asian region, according to corresponding tech-sites such as *Global Times* (20/04/2021) and *Techwire Asia* (24/05/2021) but due to a language barrier, these sources cannot be considered.

To narrow the scope, where this research paper is located at, the considerations from section 1.5.4 are taken into account. As already established in section 1.3, the sensor used in this study uses SSVEP and is non-invasive in nature. Therefore the general scope of this research is located in the realm of *non-invasive BCI based on SSVEP used for HCI*.

Oralhan and Tokmakçi (2016) and Resalat et al. (2011) investigated the effects of different twinkle frequencies and duty cycles on the efficiency on precision of SSVEP BCI. They found that a certain combination of these parameters on fact could improve the ITR⁵. Lee et al. (2016) used a similar approach and found the ideal combination in conjunction with Korean characters. S. M. Abdullah (2014) used a consumer ready BCI by *EMOTIV* to create a *Matrix-Speller* in the Bengali-Language to allow people who have lost the ability to communicate to express themselves again. Chen et al. (2020) also used a SSVEP BCI to implement a BCI-speller and scrutinized the tradeoff between responsiveness and accuracy. Chen et al. (2020) designed an interface which is operated by a SSVEP BCI to control a robot arm, which could administer food to disabled people. Soroush and Shamsollahi (2018) developed a SSVEP BCI which overcomes the necessity for training the sensor to the user who wears it. The prototype reached a similar precision as *trained* interfaces. Gergondet and Kheddar (2015) investigated and selected certain visual stimuli which work best with certain use cases. Meriño et al. (2017) made a study, where participants controlled a UAV by using a SSVEP. Peters et al. (2018) used simulated impairments to examine if usage of a SSVEP is still possible with medical conditions which affects speech and ocular impairments.

Although not strictly within the SSVEP domain, the study by Beveridge et al. (2017) showed very promising results by not using visual stimuli but mechanical ones, where he had teenagers playing a racing videogame with the aid of mechanical stimuli.

There is a massive ongoing research effort to make the life of people who are suffering under ALS⁶ better and improve their ability to communicate normally, by using SSVEP, a hybrid

⁵Information Transfer Rate

⁶Amyotrophic lateral sclerosis

between an SSVEP and P300⁷ or purely P300 based BCI. A significant number of relevant studies has been published in the BCI Society Journal: [Sugata et al. \(2016\)](#), [Holz et al. \(2015\)](#), [Speier et al. \(2017\)](#), [Geronimo and Simmons \(2017\)](#), [Speier et al. \(2018\)](#), [Mowla et al. \(2017\)](#), [Huggins et al. \(2016\)](#). All these studies aimed to provide a better understanding and performance of using BCI on people with medical conditions, which cause serious physical impairments.

1.5 Establishing a use-case

Establishing a use-case in the context of this study is a pivotal point hence this section will be split up into several sections:

1. General considerations
2. Deduction of the core points of this study
3. Evaluating the constraints of a participatory study
4. Deduction of use-case
5. Conclusion into hypothesis and use-case

1.5.1 General considerations

The first step in conceiving any potential way of using such a device is to evaluate the way any user could interact with a BCI with a computer. According to ([Buxton 2010:4.13](#)) the way users interact with a device require an agent of control i.e. a hand, what is being sensed by the device (position, motion or pressure) and the number of dimensions being sensed (1, 2, 3). This results in a different input taxonomy for any given device. However, a BCI does not have either of these parameters, since the interaction does not require physical interaction. Hence a classification by means of using a taxonomy cannot be achieved. Where the interactions of BCIs can be compared to those classified by taxonomies is by the way they function they apply in relation to a user interface.

The API⁸ endpoints of the NextMind sensor offers two different modes of interaction. These are explained in the SDK⁹ of the sensor in detail: [NextMind \(18/11/2020\)](#). They are depicted as *tracking results* with a *hit* property and a *confidence* metric. Where hit is a two state interaction: the neurotag is being seen by the user and subsequently recognized by the sensor and its backend or it is not. The confidence property depicts the attention which the user is paying to the *neurotag*. This is a continuous decimal value between 0 and 1. The fact that these types of interaction are based on neural activity raises the question if a pure mapping of continuous and discrete input modalities to established interfaces would be beneficial to the user experience. Under the reasonable assumption that without any training the metric *focus* can only be deliberately controlled on a very coarse level, the necessary sensitiveness required for modern GUIs¹⁰ can not be achieved with this particular sensor. The remaining two state property, which can be utilized to select or deselect certain objects also only allows for limited interaction. However, these neurotags can be placed in arbitrary places. Although a *toggle*-like behavior is not mentioned explicitly, it might be possible to de-select any activated neurotag when the *focus* property falls under a certain value.

⁷An Event Related Potential (ERP) BCI

⁸Application Programming Interface

⁹Software Development Kit

¹⁰Graphical User Interface

1.5.2 Corepoints of this study

Based on the previous reasoning, the following questions can be raised in regard to the feasibility of any interface which could potentially be conceived with this technology:

1. How fast is the perceived and measured reaction time of these neurotags?
2. What is the minimum size the neurotags have to have in order to be recognizable?
3. Is the interface usable for brains of all ages or do gerontological effects have an effect on usability?
4. Do certain medical conditions (i.e. attentiveness disorder) have an impact on the usability?
5. How fast can a user switch between neurotags?
6. Is a BCI controlled GUI intuitive to use?
7. Does a personal affinity to technology have an influence on the perceived difficulty of interaction?

These questions can be clustered into two groups: *neurological* and *interaction*. But all these considerations open up a vast space of potential cases, hence the priority is to examine whether these interfaces are generally usable by the majority of users and if these interfaces are intuitive to use. Out of this list only the points 1, 2, 3, 5, 6 and 7 can be applied to a general audience. Considered the possible interactions with the *Nextmind* sensor, a study which focusses on the neurological domain makes more sense in the context. **Revisit reasoning**. This leaves the points 3 and 5. Although these are two different topics, the setup of the experiment itself will show that in fact number 5 can be examined along the way as well, which will be discussed in section **Add ref + revisit argumentation**.

1.5.3 Constraints of a participatory study

Although this study won't use the *AttrakDiff* survey, which was designed by Prof. Dr. Marc Hassenzahl (30/09/2020), it is still worth considering how a potential use-case might perform in the context of an *AttrakDiff*. The reasoning is that a survey, which is entirely constructed to serve the purpose of producing results in favour of the study, might be harder to grasp for the participants in the experiment. The reason being that an interaction purely for the sake of interacting with something does not provide an incentive for the user to do so. As a consequence, the results which are produced by the participants, might be skewed due to a lacking frame of reference.

Figure 1.6 shows two axes which depict the hedonistic quality of an interaction, which is a metric of pleasure and the pragmatic quality which depicts a metric of *ease of use* or *technical quality*. Even without any deeper knowledge it is safe to assume that it is preferential for the interaction to be located in the upper right corner, since this makes it "*desireable*" instead of "*unnecessary*". Given that, it is certain that any interaction needs a way to facilitate pleasure in the user.

1.5.4 Deduction of use-case

Concluding the two parameters *frame of reference* and *facilitation of pleasure* into a coherent picture, it can be inferred that the experiment has to be set up in way that gives the participants a familiar use case which facilitates positive feedback.

As already established, this study will examine gerontological effects in the context of an interaction. Therefore the age of participants will very likely vary to a wide degree, what

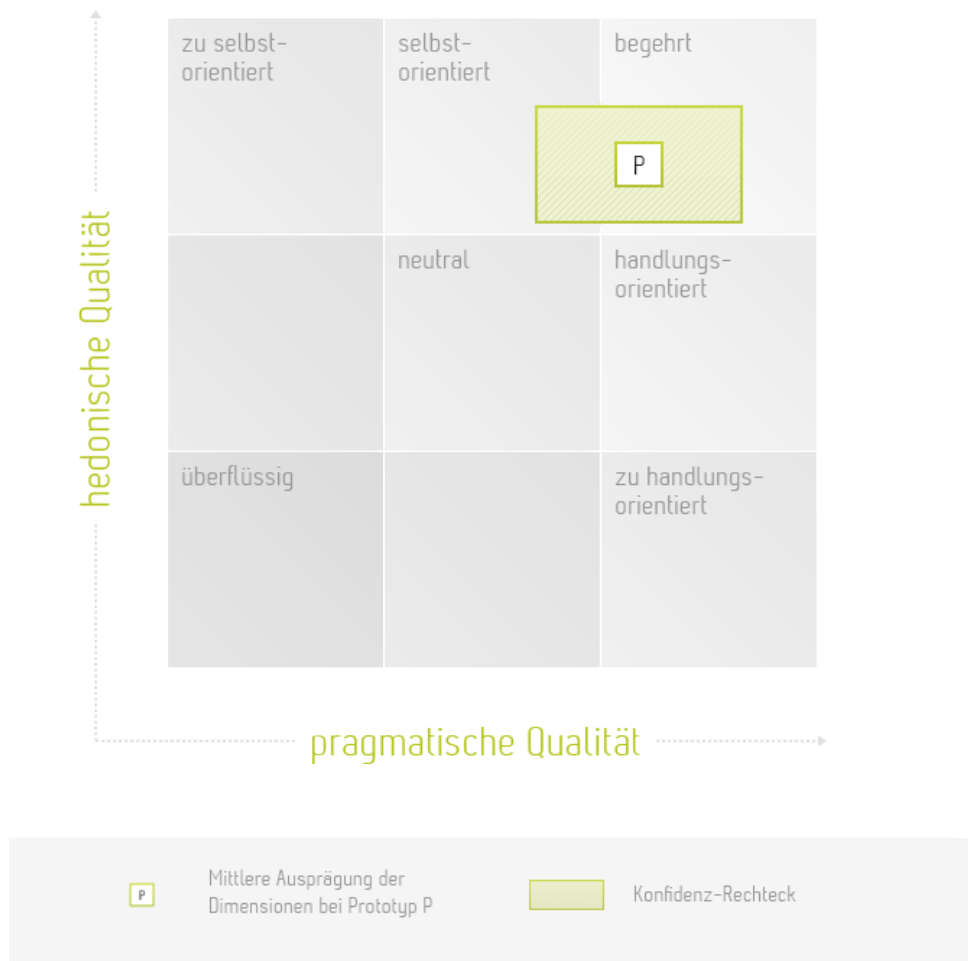


Figure 1.6: MAKE ENGLISH AttrakDiff results for a given interaction model, Source: Prof. Dr. Marc Hassenzahl (30/09/2020)

necessitates a use case which is common to all age groups alike. Because people above a certain age did not grow up with computers, an experiment which relies heavily on the usage of computer as main point of interaction is very likely not a good choice due to the difference in proficiency. One example where both these criteria are met is a remote control for a television. Although nowadays there are computers involved, the interaction hasn't really changed in the last decades on a general level.

Nevertheless the working principle of the BCI is a visible flashing pattern, as established in section 1.3. Therefore the representation of some kind of GUI on a display is still necessary. Since VR goggles provide better isolation from external visual stimuli, the representation within a VR application was chosen.

1.5.5 Concluding hypothesis and use-case

Section 1.5.2 established that age is the first parameter to examine in this context, therefore the fundamental research hypothesis can be defined as follows:

"Age does not have a detrimental effect on the ability to use a non-invasive BCI based on VEP technology."

In Section 1.5.4 the fundamental reasoning behind the use case, which provides the necessary framework for this study was established:

1 Introduction

A GUI which represents a tv remote control will be presented to the participants within a VR environment.

2 Technological challenges

Due to being non-invasive there must exist certain drawbacks with this technology. I want to examine the shortcomings and possible ways to overcome these. A valuable resource of information might be nextminds homepage.

2.1 Resolution of the Interface

- definition of the resolution parameter
- ITR
- accuracy
- input taxonomy diagram
- how to examine with survey

2.2 Constraints

As far as I understood, the interface allows for two different interaction goals. It would be interesting to see, which kinds of interaction are possible.

- Interaction objects
- interaction types in regard to input taxonomy
- evaluation in user survey

3 Survey Structure and layout

Before any survey can be designed, certain considerations like sample size, population ... [ref to döring/bortz for details](#) have to be taken into account. Also depending on the desired outcome of the survey, the questionnaire has to be defined.

3.1 Considerations

The primary goal of the survey is to find empirical evidence that age does not affect the ability to use a BCI. In order to exclude certain parameters, which might cause an unwanted effect, potential disturbance parameters have to be identified and discussed:

- Age
- Gender
- Quality of the sensor readings
- Motion Sickness
- User wears glasses

Apart from the demographic parameters of age and gender, the other factors have to be considered to prevent potential malformed data. Firstly, a condition which causes a detrimental effect on the ability to see and identify patterns might have a dampening effect for the visual cortex to create the required brain waves. However, the physical layout of the VR goggles used allow for prescription glasses to be worn. Hence this is not a concern in the context of this study. Secondly, when working with VR goggles, there is always the possibility of motion sickness involved. On the other side: this will unlikely have a negative effect since the experiments will be static. There won't be any movement from either the user itself within the environment nor the GUI involved, which removes the prevalent reason for motion sickness according to [Golding \(2006\)](#). Lastly the readings of the sensor will very likely be different for each experiment. Since the sensor provides quality readings, these will be considered in the data evaluation. Nevertheless, there will be a questionnaire provided which will ask the user after experiment if he experienced any of these effects to have a possible explanation for potential outliers.

Under the assumption that gender has no effect on the study, because the brain of men and women is at least structurally identical. Therefore age is the only parameter which is the variable in this study. To put the results into context, the survey participants will be clustered by age into different groups.

3.2 Design of experiment

The solid proof that the hypothesis holds true or not can not be made based on looking at diagrams and educated guesses. Hence the need for design of experiment to provide a numerical framework which defines thresholds and quantities to make results reproducible. This section is based on the theoretical framework which is described in ([Siebertz et al. 2017: 87ff](#)) under

the considerations in the previous section. There are two main parameters to consider, when it comes to the DoE¹:

- How many samples are necessary to reliably prove that the hypothesis holds true?
- Where is the threshold which determines whether an effect is significant or not?

In the context of DoE the former is often depicted as β and the latter as α .

Parameter alpha - α : Alpha is the governing parameter, which decides how big the risk in a given sample size is that the hypothesis is wrong and therefore falsified. Since the hypothesis can be either true or false, the probability that it is wrong decreases with the number of samples taken in a binomial fashion (Siebertz et al. 2017: 103). That means in this case that the likelihood p of a participant to be above or below the threshold, which is discussed in section 3.3, is not determined by age. According to (Siebertz et al. 2017: 110) common values for alpha tend to be chosen such that the probability of a falsified hypothesis is at 1%, 5% and 10%. Where a smaller value means a more strict threshold. To account for the explorative character of this study the value of 5% is chosen. Therefore the susceptibility for unaccounted side-effects is reduced and the total number of participants is still not unfeasibly large.

Parameter beta - β : This parameter depicts how effective a potential effect is in a given sample size. The likelihood of a significant effect not being recognized decreases with an increasing number of samples, since it becomes increasingly unlikely that a systematic effect affects the samples always in a way which makes it undiscoverable. Table [ref table](#) shows that with an increasing number of samples, given the determined alpha value, the likelihood decreases rapidly:

[Create table here](#)

3.3 Operationalization

Chapter 3.2 provided the necessary framework to decide whether the hypothesis holds true or not. However there is another factor to consider, which has not been discussed so far: Which way does the data have to be interpreted in context of the DoE to be effective.

[No definitive answer yet. Idea: The likelihood of having an average timing outside the stddev of all users.](#)

3.4 Survey

Section 3.1-3.3 established the theoretical framework of the survey. This chapter aims to define the experiment which will be used to gather the data. To do so, the following considerations have to be made:

1. What tools will be used?
2. What data will be collected?
3. How are the age groups structured?
4. How is the data collected?
5. What is the structure of the questionnaire?

¹Design of Experiment

3.4.1 What tools will be used

- Quest2
- Nextmind BCI
- iPad for questions

3.4.2 What data will be collected

- demographics
- considerations from section 3.1
- Speed of the neurotag activation
- confidence score of active neurotag
- quality readings from each electrode

3.4.3 How are the age groups structured

t.b.d.

3.4.4 How is the data collected

- questionnaire
- logfiles from vr-application

3.4.5 What is the structure of the questionnaire

see 3.1 for details

4 Survey results

Once the study has been structured and carried out, I can write down the results.

5 Findings

This section also depends on the outcomes in context to the research question.

6 Conclusion

6.1 Results

Summarizing the results and findings of the study briefly.

6.2 Future Work

Based on the findings and new devices on the horizon, this should give a brief outlook on how to continue this research.

7 Acknowledgements

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A Material

A.1 Surveys, Protocols, etc.

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