Tampere University of Applied Sciences

Collecting Biosignals

Data Experiments with EDA and EEG

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ABSTRACT

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Collecting Biosignals – Data Experiments with EDA and EEG

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This practice-oriented study collected biosignals and conducted technical experiments to convert the biosignal data into feedback signals receivable by human senses.

The exploratory experiments utilised EDA and EEG biosignal detection devices combined with software. The software was created during the process in order to receive data from the devices, and then create auditory and visual feedback loops from the data. The technical result was a number of new software + device prototypes for biosignal sonification and visualisation, and one for brain wave-based communication.

In addition to the primary focus of technical experimentation, models of analysis were adapted from the fields of semiotics and phenomenology. This was done in order to explore and elaborate upon self-reported textual narratives of the technical exploration and the user experience. This analysis helped create a structure of the experience and understand signals as semiotic signs.

Research tasks and questions provided structure for the thesis. The main ones were the exploratory biosignal conversion, brain wave-based communication, the narrative analysis and the semiotic sign analysis. The study concluded with an inventory of prototypes that had been created and a discussion of the lessons learned.

The final research question was how the results of this practice oriented experimental study relate to existing fields of science: could one find domains of research that are relevant to the findings of the experiments? A preliminary charting of existing research and domains of inquiry was done.

Further review of existing research can expand the scope of this inquiry and guide the next steps.

Keywords: biosignal, EDA, EEG, XR, DIY, audiovisual, feedback loop, perception

CONTENTS

ABBREVIATIONS AND TERMS

3D scanning	A method to remotely collect data about an object, such as the shape, dimensions, texture etc.
API	Application programming interface. A way for programs or components to communicate with each other.
BCI	Brain-computer interface.
Biosignal	Any signal originating from a biological structure. In this study: electrical signals measured from a human.
BLE	Bluetooth Low Energy, a wireless personal area network technology.
Bricoleur	Someone who uses the means at hand, instruments he finds around him...tries by trial and error to adapt them, not hesitating to change them whenever necessary, or to try several at once (paraphrasing Derrida 1967).
C++	A programming language.
DIY	Do It Yourself. A way or making things by yourself, including an ethos of self-reliance and creativity.
Dongle	A small connection device, e.g. for a computer.
EDA	Electrodermal activity. Variation in the electrical characteristics of the skin. Also called GSR.
EEG	Electroencephalography. The detecting of electrical activity in the brain, aka. brain waves.
GSR	Galvanic skin response. Variation in the electrical characteristics of the skin. Also called EDA.
GUI	Graphical user interface.
LiDAR	Light Detection and Ranging, a method that uses laser light to measure distance, used in e.g. 3D scanning.
Python	A programming language.
SDK	Software Development Kit.
UUID	Universally Unique Identifier (for data devices).
Web Bluetooth	A technology which lets web applications (e.g. browsers) communicate with devices using BLE.
XR	Extended reality.

1 INTRODUCTION

According to the guidelines of Tampere University of Applied Sciences, courage, creativity and originality are emphasised in the choice of a thesis topic. The thesis has to follow the needs of working life, and the development of professional practices, knowledge and skills are important (Thesis at TAMK 2024).

To ensure a connection to working life and professional practices, the thesis project involves a contract. This thesis was performed under the format of a thesis contract which set the general goal of achieving technical results through experimentation. In the plan, no exact deliverables were specified, but the main task was defined to be about collecting different biosignals and then conducting experiments to convert the data into an experience. Taking heed of the University's guidelines and the contract, the thesis plan (study plan) accordingly envisions an experimental process. The starting point is primarily technical, to produce concrete results from experiments. Another important aim is developing personal technical and professional knowledge and skills. The accumulated knowledge and skills will have practical working life applications later.

The thesis plan includes collection and integration of real-time biosignals from detection devices onto a data platform, solving technical problems of the hardware, software, interfaces and the operating methods, and then designing prototypes based on the findings. The reader is advised to read the definitions of Abbreviations and Terms on the preceding page carefully first, in order to get to know the technical vocabulary. It is also useful to have a look at Appendix 1 to see the list of equipment, with EDA detection rings and EEG headsets playing the main role.

In addition to the primary technical focus, a number of models are adapted from humanities / social science in order to explore and further elaborate upon narratives of the technical explorations. While the technical prototypes and experiments form the core result of this thesis, the analytical models help create a structure of the human experience and understand signals as semiotic signs. The bulk of technical details, diagrams, results and narrative tables can be found in the concluding chapter and in Appendices 2, 3 and 4. The main text concentrates on describing and analysing the process and experience textually.

The technical and analytical parts of the study are motivated by the need and desire for concrete results and skill development, which is in accordance with this type of study: a thesis with a connection to working life and technical professional skills. This University of Applied Sciences course and thesis format have provided a framework for learning about diverse subjects in an exploratory combination. The desire to learn and to explore is also the answer to why this thesis combines such a diverse set of topics and frameworks.

On a practical level, the thesis contains a number of exploratory experiments utilising electrodermal detection devices (EDA rings worn on a finger) and brain wave signal detection devices (EEG headsets), combined with software. The software programs were created during the thesis work to create biosignal data feedback loops utilising visual and audio sensory signals. On a more general level, the study is in the domain of digital information and communication technology, and its interfaces with humans. On a higher level of abstraction, the study is about the human relationship to technology in general. There is an interplay between machine and human, as the machine detects human biosignals and then plays them back to the human user in various forms.

The experimentation is described, and the technical results and the subjective user experiences are discussed. Methods and concepts are adapted from the fields of project and quality management (the PDCA cycle), phenomenology and semiotics. They are used in experimentation and analysis and are introduced in the following sections.

A biosignal:

- Refers to any signal originating from a biological structure.
- Can be measured over time.
- Can vary in nature and contain information about the system, organ, and process that generated them.
- Can be used to assess health status and cognitive processes.

- Can have different origins (electrical, pressure, chemical) and are measured using sensors, transducers, and actuators.

(List adapted from Bolpagni, Pardini, Dianti & Gabrielli 2024, 11)

This study solves practical technical challenges and creates prototypes that actually work, and can have practical uses. But it also contains elements of speculative design (Dunne & Raby 2013), as it experiments with a feedback loop of biosignals, also touching upon virtual reality, and has the potential to expand the user's perception beyond any immediate practical uses. Dunne and Raby state that design speculations can act as a catalyst for collectively redefining our relationship to reality; speculative design thrives on imagination, and aims to open perspectives on wicked problems, to create spaces for discussion about alternative ways of being and to inspire imaginative flow. Auger (2013, 12) says ”speculative design is not only to encourage contemplation on the technological future but can also provide a system for analysing, critiquing and re-thinking contemporary technology”. Auger further points out that speculative futures can extrapolate from the present and imagine near-future products and services. The combinations of biosignals, software, various audiovisual channels and technologies open up possibilities for interesting technical design implementations, and for design fiction (e.g. Sterling 2005, 30). While this study does not include extrapolation into the future, Bleecker (2009, 8) notes that both science fiction and design fiction create imaginative conversations about possible future worlds.

Inspiring the thinking of the author during this study has also been the concept of “a metaverse”, written in lowercase on purpose. There are many alternative ways to describe different sides of the concept: mixed reality world, virtual universe, cyberspace, immersive digital reality, augmented sensory extension, digitally extended perception etc. This kind of “a metaverse” is not a single thing or place. Rather, it can be thought of as an agglomeration / collection / variety / palette / pattern / constellation of technologies, tools, capabilities and possibilities for expanding the human experience, combined with maker ethos and “ethical hacking”, i.e. making things better by challenging them. The science fiction novel Snow Crash, where the term Metaverse (in capital letters) is first introduced (Stephenson 1992, 29), describes it as a computer-generated universe, visually created inside the user's goggles and pumped into their earphones. The protagonist of the book, called Hiro Protagonist, lives in a small and sparsely furnished storage unit with a roommate. But he experiences another reality via the goggles: the Metaverse. As an example of a much more recent description, Ritterbusch and Teichmann (2023) offer: "A three-dimensional online environment in which users represented by avatars interact with each other in virtual spaces decoupled from the real physical world" and "the Metaverse will be a single three-dimensional online environment with many Metaverse platforms, in which each Metaverse platform is embodied in the form of virtual spaces."

The common denominator from the perspective of this study is that technology brings the user into new spaces or new dimensions, into a new kind of existence enabled by technology. An immersive virtual reality scenery, and a non-visual digital device which helps to augment the user's senses in the "real" world, can both belong to "a metaverse". Computing, optics, artificial intelligence (AI) and various other technologies can be combined in different ways that can expand and enhance human experience and perception. Biohacking and biopunk (see Gefter 2011), human augmentation and even transhumanism (Huxley 1957; More & Vita-More 2013) have things in common with this thought. The author would like to think of "a metaverse" as something relaxed, benign and fun-loving, an exploration of new frontiers and perspectives. In this sense, technical exploration, introspection, novel communication technology and expanding human perception with the help of biosignal detection devices are all an exploration of "a metaverse". By making those technologies usable one is creating a tiny corner of a kind of metaverse.

As technologies and programming become ever more accessible, possibilities for creative experimentation increase. One does not need expensive scientific laboratories with staff, real estate and heavy infrastructure in order to experiment and do citizen science. A few second-hand devices and free software can go a long way, as this study demonstrates. With the exception of two new EEG devices, all other equipment used in this study is quite old, and either borrowed or bought second-hand (for the equipment list, see Appendix 1). This thesis describes a technical experimentation process, and the fun had while connecting and using different technologies and devices in an improvised setting.

Some notes on the choices of text style and formatting: To facilitate readability, especially in sections that concern semiotic analyses and terminology, the choice is made to highlight some key terms in *italics* or **bold** type, in order to make the key concepts stand out from the rest of the text. For a similar reason of visibility, in some cases numbers have been written as numerals instead of written out as text (e.g., 10 instead of ten). The text concerns topics both in the past and the present, for example analysis of past experiments happening in the present. Therefore both past and present tense are used in the text, often within the same chapter or paragraph.

1.1 Personal background and motivation

From a personal perspective, this study has been a journey of inspiration and learning. When choosing a study path years ago, one attractive alternative was the study of consciousness. For practical reasons, a different path called: engineering, business and culture. So the present thesis represents a return to an old favourite: exploring interfaces between technology and consciousness. Writing this thesis has been a very useful framework for learning about and catching up with several technologies and topics, such as programming, biosignals and brain science. On the work front, generating innovative projects is inspiring, the curiosity of combining different technologies being a driving force. This thesis represents the joy and curiosity of experimental combinations.

The author's own reading and personal interpretation of technological and social scientific texts over the years is an underlying, not easily documented basis from which the writing of this thesis proceeds. Preconceptions are a potential source of bias. An attempt is made in the next chapter to list a few domains of inquiry which aren't explicitly used in this study, but which do lurk in the conceptual background of the mind.

1.2 General conceptual background and the "mood" of the study

Below are some frameworks that underpin the thinking of the author. While most of them are not mentioned later in the text, they can give the reader starting points from which to understand the context of the whole study and the perspective of the author. It's also an inventory and toolbox of various alternative vantage points from which it is possible examine the subject matter. A background perspective for this study was provided by the author's past and newer experiences of semiotics, philosophy, brain physiology, science fiction, signal processing, human-computer interaction (HCI), grounded theory (e.g. Glaser and Strauss 1967), and computer programming. Also present are concepts like DIY thinking (Do It Yourself), a spirit of citizen science, and learning by doing.

DIY ethos (Do It Yourself) explains why this study aims to create new experiences and perspectives with relatively easily available and relatively simple equipment. One idea is to show that a personal expansion of perception and the senses is already within reach, and can be realised even by an amateur DIY "techno-bricoleur". Bricoleur is a concept put forward by the anthropologist Lévi-Strauss and as described by Derrida (1967, 418). The Oxford English Dictionary defines a bricoleur as ”A person (esp. an artist, writer, etc.) who appropriates and improvises with a diverse range of existing materials or sources to create a new artwork, theory, etc.; the creator of a bricolage." Words like tinkerer or ethical hacker perhaps also capture something of the essence. Wolf and McQuitty (2011) define DIY as "activities in which individuals engage raw and semi-raw materials and component parts to produce, transform, or reconstruct material possessions, including those drawn from the natural environment (e.g., landscaping)." They also discuss topics such as sense of accomplishment, enjoyment and control. This is also connected with the concept of the prosumer (as opposed to consumer). Toffler (1980, 283–284) noted that humans went from an agricultural society based on production for use (prosumer economy) to an industrial society based on production for exchange, but that "we see a progressive blurring of the line that separates producer from consumer": a rising significance of the prosumer. Kotler (1986) commented on Toffler and developed on the idea of the prosumer (and by extension the DIY) movement as an opportunity for business.

Serendipity is a concept of stumbling upon unexpected results, of accidental discoveries. The "serendipity pattern" refers to observing unanticipated, anomalous and strategic data, leading to the development of a new theory or to the extension of an existing theory (Merton & Barber 2004, Introduction XXI). Throughout their book, Merton and Barber discuss various aspects and perspectives on serendipity and discovery, starting all the way from the 18th century. The discovery of penicillin (Fleming 1929) is one striking example of serendipity. In this biosignal study, the qualitative data (human observations) and quantitative data (biodata obtained from devices) are generated through experiments. These experiments are guided by intuition about “what might work”. The point is not to guarantee a preconceived result. The inductive process allows new things to emerge without dictating a rigid perspective from the start. There is a possibility, not certainty, for serendipitous discoveries.

Mihaly Csikszentmihalyi (2014, 537–541) discusses a **systems model of creativity**. In simplified terms, one must have first acquired knowledge of some domain of human endeavour to be able to contribute novelty, new inputs and innovation. The gatekeepers of society and science will then accept or reject this novelty to be included into the domains of existing knowledge. New people will then learn from the increasing pool of knowledge. In the case of combining biosignal detection (or perception and introspection) related technologies, this loop of creativity can be strengthened as technology becomes more easily available and approachable. More people are able to create innovation.

Technical methods and resources are becoming easier and easier to access. If a choice is available, people (hopefully) don’t want to be ushered into digital walled gardens. Personal or shared and overlapping metaverses could be places for free experimentation and reflection – akin to the early optimistic times of the internet. A helpful and accessible dimension, which extends beyond immediate human senses and bodies, and which can help us understand ourselves and our own neurological and psychological reactions, instead of becoming a platform for others to exploit those same reactions. This is why it makes sense to *do it yourself (DIY).* Even the process of creating experiences in “a metaverse” is itself a part of the experience. Both the process of creation and the result can provide opportunities of learning, self-reflection and discovery. This way one can understand, create and participate, instead of buying, passively receiving and consuming, and ending up being controlled in the process. By participating in creation, one can hope to evade, or at least make an effort to resist, ending up as a recipient of socially or technologically engineered impulses and social control. Another way is to think along the lines of "The unexamined life is not worthy of a human" (Plato 399-387 BCE): great tools have now become available. One can use them to ask questions about ourselves and the human condition. This study is taken as an opportunity to use new technologies for exploring perspectives, limits, and boundaries of self and others. XR technologies (which are enabling “a metaverse”) can be an interface of science, technology and subjective experience. **Contrasts between ”A and B type design”** as juxtaposed by Dunne and Raby (2013, preface VII) are also useful for setting the mood for this study.

TABLE 1. Juxtaposing design types A/B, adapted from Dunne and Raby (2013)

Type A	Type B
Problem solving	<u>Problem finding</u>
Provides answers	<u>Asks questions</u>
Design for production	<u>Design for debate</u>
Design as solution	<u>Design as medium</u>
For how the world is	<u>For how the world could be</u>
<u>Science fiction</u>	<u>Social fiction</u>
<u>Futures</u>	<u>Parallel worlds</u>
<u>Applications</u>	<u>Implications</u>
<u>Innovation</u>	<u>Provocation</u>

The list has been shortened here, for the purpose of showing just those items which match the mood of this biosignal study at the beginning. They are <u>underlined.</u> Dunne and Raby say B type design is not intended to replace A type, but there could also be C, D, E and so on: types of design can complement each other. The list is also instructive of this complementarity of design types, because the attributes which are not currently in focus (e.g. ”design as solution”) could well move into focus in the next steps after this study.

2 DESIGNING THE EXPERIMENTAL RESEARCH

In simplified form, the structure of this thesis is fourfold:

- Introduction to the conceptual background and methodology.
- Technical experimentation: electrodermal and brain wave signals.
- Analysis of signs and narratives gathered from the experimentation.
- A list of results and concluding discussion.

The introductory part sets the mood and research methodologies, and poses questions for the experimentation. The concluding part applies the methodologies and attempts to give answers. This study takes the general experimental approach of ”what could one achieve with the technical equipment available?” The right focus is found because one doesn’t assume to know the focus from the start. Observations can point the direction.

2.1 Research questions

Experimenting and informal discussions with people generated ideas and helped articulate the research questions. The answers to these questions are of various types: some are clearly defined practical results of a technical nature, some are analyses of texts and signs with multiple possible interpretations, and some answers consist of generating new topics and new questions. The first three questions are technically oriented, the next two contemplate the results with methods adapted from humanities / social science, specifically phenomenology and semiotics, and the last question guides the thesis to a conclusion.

Question 1) Produce practical results in accordance with the contract thesis format: collect different biosignals, and experiment to convert the data into a human experience. What signals will the experiments be able to handle, and what kinds of use cases and prototypes can be created? The use cases, prototypes and their signals are discussed in the main text and the concluding chapter of this thesis. A fuller technical description can be found in Appendix 2.

Question 2) One technical use case is chosen for special attention: can this study achieve a rudimentary communication, a simulacrum of “telepathy” with the available equipment, while starting from a non-expert technical skill level? What kind of a system could be created for the task? Specifically: without extensive mental training (e.g. of controlling one’s brain waves), or without extensive hardware or software development, can this equipment enable a situation where it can be said with certainty that at least a simple human language message was sent from one person to another by using brain waves, and received in some understandable form? The answer is a qualified yes, as will be shown.

Question 3) Overall, how feasible and easy is it to actually perform electrodermal activity (EDA) and electroencephalogram (EEG) experiments without a laboratory, i.e. when the main resources are relatively old, cheap, borrowed or second-hand equipment, free software and online advice from programmers and an artificial intelligence language model?

Question 4) What is the nature of the main signals used in these experiments, in terms of being signs: to which categories or classes of signs do they belong? As described in later sections, this study interprets and categorises signs using frameworks adapted from semiotics, forming a simple taxonomy: a list of signs.

Question 5) How do these experiments feel from the maker’s and user’s perspective? Describe the perception, feeling and thoughts during the experimentation process, and those that arise when one detects live, real time biosignals. A phenomenological method is adapted to help find answers: reading samples of self-reported narrative texts and breaking them into meaning units. Self-reporting by the author is chosen for convenience, speed and simplicity, instead of collecting extensive user feedback. The reader of this study can experience a part of the experimental process by reading the provided excerpts, or the fuller narratives. The author also acquires insight by taking the time to analyse the experience. The structure emerging from the narratives is discussed in the concluding chapter. All the narrative tables can be found in Appendix 3.

Question 6) This leads to the conclusion of the study. The study starts “from the ground up” with technical experimentation (from question 1 onward), then moves on to analysis (from question 4 onward). All of this produces a body of results: multiple technical ones, and analyses, ideas and hypotheses. The question is: where does this body of results as a whole fit in the academic world, i.e. which existing fields of research and science are a good match? Can a naturally fitting “home” be found for this body of results in some existing field(s) of science? Finding such a home would be a good conclusion for the thesis. It will help in moving forward with the inquiries that have been started.

2.2 Theoretical framework and practical research design

The previous sections introduced the background and some fields of inquiry which weave a general conceptual backdrop, and the research questions. This section describes the actual structure and expected results of this study.

The study adopts multiple perspectives, technical and analytical. The general methodological approach can be called multi-method qualitative research: using multiple qualitative methods in the same study, with different types of data to address a research objective (Roller & Lavrakas 2015, 288). While quantities are also being processed in the technical part, qualitative aspects play the key role in the experience and the analysis. The chosen analytical methods are adapted from the fields of phenomenology and semiotics. See Table 2 for a summary of what happens in this study.

TABLE 2. Structure of what happens in this study

<table>
<tr><td colspan="2">The main work: experimental development with
biosignal devices and software. It produces outputs:</td></tr>
<tr><td colspan="2">Output 1: immediate practical results</td></tr>
<tr><td>Technical results:
prototypes, software programs</td><td>Learning results (for the author):
technical & humanities / social science</td></tr>
<tr><td colspan="2">Output 2: A developer/user’s self-reported narratives of the
experimental development work and user experience</td></tr>
<tr><td>They are analysed using one framework
adapted from phenomenology</td><td>They are analysed using two
semiotic concepts of “sign”</td></tr>
<tr><td colspan="2">Results for the research questions, discussion and conclusion</td></tr>
</table>

Results for questions 1–3: technical experiments, protoypes, related results and technical skill development	Results for questions 4–5: understanding of the initially unstructured experiences and signs	Results for question 6: navigating existing fields of research, to locate a “home” where this study’s results conceptually belong

2.2.1 Structure of the technical experiment process

This section gives an overview of the key theoretical contexts and frameworks directly used in the study.

The Plan-Do-Check-Act (PDCA) cycle. This cycle is roughly the logical order in which the technical experimentations proceed. PDCA includes planning (problem or objective definition), doing (implementing), checking (evaluating results) and action (back to plan if results are unsatisfactory). The cycle originated from W. Edwards Deming’s lecture in 1950, and has later evolved into many versions and uses (Moen & Norman 2009; Roche & Delamotte 2024).

FIGURE 1. PDCA cycle (from Moen & Norman 2009)

Each stage of the technical experiments in this study centers upon one or more devices. Then follows the initial planning of how to extract the biosignal data from the device and how to process it, then doing the experiments, then checking the functioning (or non-functioning) of the system and the produced effects, and finally a reflection and subsequent action on the technical results and the user experience. This is iterated until the prototype works well, and the attention moves on to the next device and use case. There is also a similar concept in social sciences: action research (Lewin 1946; Coghlan 2019). The cycle of action research is a term coined originally by Lewin, who spoke of “a spiral of steps each of which is composed of a circle of planning, action, and fact-finding about the result of the action”. While this thesis does not examine social groups, these kinds of steps do apply here as well. Coghlan (2019) defines the action research cycle as 1. constructing, 2. planning action, 3. taking action and 4. evaluating action. Also, a spiral shaped development methodology with stages is well known in technology, especially software development (Boehm 1988; Newcombe 2020). The origin and exact genealogy of all these methods is not crucial for this study, but it is good to note that the technical experimentation here follows an iterative cycle or spiral.

The practical starting point of the experiments is simply the devices: their capabilities define the path of possibilities. The devices can measure human biosignals and produce data, such as electroencephalography (EEG), electrodermal activity data (EDA), and also some data from movement. The devices are used in an experimental and playful way, to see what data they can produce, what various implications these results can have, and in which ways one could use the collected data in biosignal feedback loops to a user. Then the experiment setup is changed, and the process is repeated. A simple example of a biosignal feedback loop could be listening to your heartbeat or seeing it as a wave on a screen. This is a single signal with 1-2 simple representations in real time. The representations / feedback are the sound and the image on the screen. There are in principle many other possible biosignals that can be detected, and multiple ways to represent the data (i.e. feedback). With suitable detection devices, signals can be for example EEG, EDA, respiration, perspiration, body temperature, movement and so on. The data could in principle be represented in visual, auditory, haptic or other ways, depending on the feedback devices' capabilities.

2.2.2 The user experience from phenomenological perspective

Since Husserl founded phenomenology (e.g. 1922), it has developed and branched in many directions. Stanford Encyclopedia of Philosophy (2013) says:

> The discipline of phenomenology may be defined initially as the study of structures of experience, or consciousness. Literally, phenomenology is the study of "phenomena": appearances of things, or things as they appear in our experience, or the ways we experience things, thus the meanings things have in our experience. Phenomenology studies conscious experience as experienced from the subjective or first person point of view.

Audi (1999, 664) notes that as a wide and branching field of inquiry, phenomenology “means different things to different people”. For the purposes of this study and for answering research questions, a suitable tool is needed to examine the subjective, conscious experience of the user of a biosignal feedback system.

Meaning units and their transformation

Giorgi’s method for meaning unit transformation is potentially suitable for this task (see Giorgi 1997, 2009; Giorgi, Giorgi & Morley 2017). It is a phenomenological approach, and applicable for analysing user experiences. The experiences reported in this thesis are autoethnographical, self-reported by the author. Autoethnography is an approach to describe and systematically analyze personal experience in order to understand cultural experience; it is “both a process and a product” (Ellis, Adams & Bochner 2011, abstract). Here the original textual narratives of conducting the experiments and using the prototypes are divided into meaning units, which are then analysed for their content. In practice this means that user experiences from the various biosignal feedback experiments are first written down as self-reported narratives by the author of this study, and the narratives then go through a transformation process. A flowchart of the analysis process where meaning units are transformed is depicted in Figure 2.

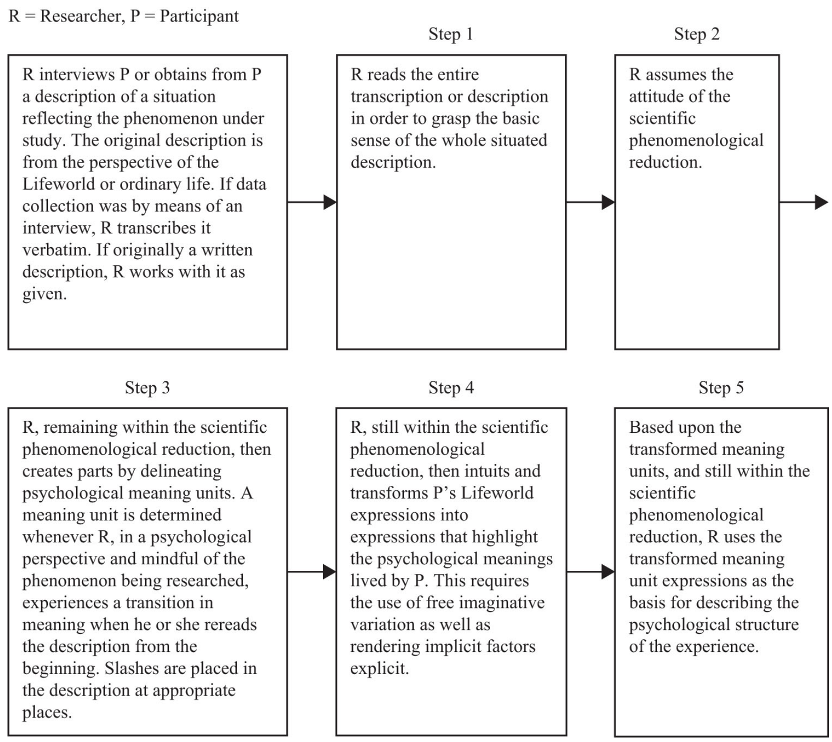


FIGURE 2. Data analysis process flowchart (Giorgi, Giorgi & Morley 2017)

This type of methodology has been used previously by others to examine various topics ranging from professional learning, experiences of medical patients, to experiences of people in virtual environments (Webster-Wright 2010; Malterud 2012; Teräs 2017).

Using Giorgi's meaning unit transformation method to the full would involve an in-depth analysis of the narrative meaning unit transformations, to ”try to determine the most invariant constituents of the experience” by seeing ”whether the structure would collapse if a potential constituent were removed” (Giorgi 2009, 199). By removing those potential constituents of the experience that would not collapse the structure if removed, one could identify the final, most essential constituents. This study adapts Giorgi's framework to help make sense of the narratives, and also uses it as a platform on which to run an experiment of automated text processing with an AI language model (described below). The analysis culminates in identifying a number of ”invariant constituents”, or crucial words and concepts, of the narrated experience, and a structure of the experience.

In phenomenological research, and of course in science in general as well, “bracketing” is an important consideration (e.g. Creswell 2018; Giorgi 2009; Moustakas 1994). It means that the researcher should set aside their preconceived notions or prejudices and take a fresh look at the material being studied. This creates a challenge for self-reporting which is used in this study. Can one put aside one's preconceived notions of one's own narratives? This concern is addressed in the following way: all of the experiences being described took place during the technical experimentation process, before the later analytical framework had been fully set in place. Care was taken to write the full version of the narratives as remembered at the time, without purposefully shaping them to fit a framework. Another way to look at the concern of bracketing is that full insulation from the author's subjective preconceptions is not even necessary in this case. The methodology is used here to delve deeper into the narrative texts, in order to identify new topics and perspectives which are not immediately obvious on the surface. The results are going to be qualitative, not exact or quantitative. If the method helps find new topics and perspectives, it does not matter so much whether full bracketing (or objectivity) was achieved or not.

This thesis adapts the above described meaning unit analysis process in the following way: two manual (human) transformation stages are performed, and an experimental AI-assisted (language model) analysis stage is added as an extra step. A Python script is made to experiment with language model iteration loops, to see how the meaning unit identification and transformation process could be automated. Or failing full automation, to see if the language model can still suggest some interesting perspectives. The initial hypothesis is that the current language model is unlikely to be able to discern many implicit nuances and meanings in the text, but to what extent, remains to be seen. AI has the advantage of producing results very quickly and iterating ad infinitum. Giorgi (2009, 130) says that the process of establishing meaning units has a degree of arbitrariness to it, and different researchers may come up with different units: there are different places where transitions in meaning can occur. Based on this, one may consider the language model loop to be a “different researcher”. If it comes up with unorthodox or peculiar meaning units, different from a human analyst, they can still be evaluated for their usefulness. See Figure 3 for a diagram of how this language model experiment works.

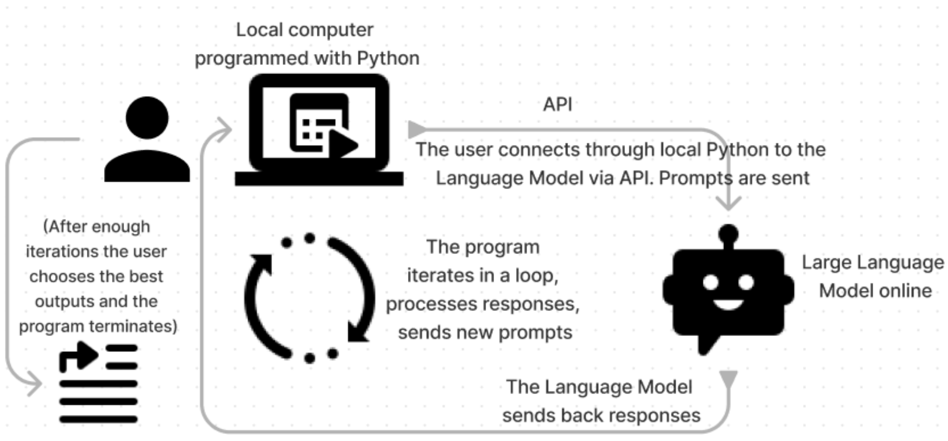


FIGURE 3. The experimental language model loop

2.2.3 The signals seen from a semiotic perspective

Semiotics is a science and technique for studying meaning in human systems of representation, generally defined as the science of signs (Danesi 2000). This study takes two authors of semiotics, Charles Sanders Peirce and Louis Hjelmslev, and applies their frameworks of sign analysis to the results of the technical experimentation which is done in this study. Peirce was “one of the most original minds of the later nineteenth century, and certainly the greatest American thinker ever" (according to Bertrand Russell 1959, 276). Hjelmslev was a co-founder of the Linguistic Circle of Copenhagen and a major figure in linguistic structuralism, creating a system he called glossematics (Thomas 2011, 201– 206; Fischer-Jørgensen n.d.) While there are many approaches and schools of semiotics and linguistics, the systems of these two are among the most well known. Both provide a structure or classification of signs. This study will experiment with the signals (signs) found in the technical experiments, and see how they fit into these systems. While there are other semiotic frameworks and perspectives that one could also use for the sign analysis, for example later and extended versions Peirce's and Hjelmslev's models, the author of this study has interest in exploring specifically Peirce's and Hjelmslev's systems in terms of simple application, and also in learning more about them in the process. The aim is to use the systems to classify a number of signs, and to learn.

Using the semiotics of Peirce

Peirce's taxonomy of signs (Peirce Edition Project 1998, 291) provides an interesting classification through which one can try to make sense of a signal from semiotic perspective. In order to understand Peirce's large sign system an explanation will be useful. The famous linguist and semiotician Ferdinand de Saussure (1916) defined sign as being dyadic, consisting of two elements: a signifier, and that which is being signified. In contrast, Peirce's sign is triadic, consisting of three elements. The interplay of the three elements produces (or is) **semiosis**, an instance or process of meaning creation.

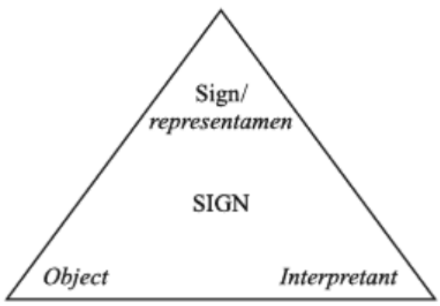


FIGURE 4. Relationship between elements of the SIGN (Johansen 2002, 27)

Semiosis is a "cooperation of sign, object, and interpretant whose tri-relative in-fluence is not resolvable into actions between pairs" (Peirce Edition Project

1998, 411). Put in another way: ”A sign, or representamen, is something which stands to somebody for something in some respect or capacity” (Peirce et al. 1994, paragraph 228). Johansen (2002, 26–27) summarises:

> In Peirce’s system, the SIGN, in the broad sense, consists of three interconnected elements: (1) the sign in the narrow sense, also referred to as the representamen, i.e. that which represents something else; (2) the object, i.e. that which the sign stands for, that which is represented by it; and finally (3) the (possible or potential) meaning the sign allows for, which may materialize as its translation into a new sign. Peirce refers to this as the interpretant.

Each of the three elements has three subtypes, creating a triple trichotomy. Below is a summary of the trichotomies along with some examples. For a reader who may not be familiar with this topic, a word of encouragement: Peirce’s system is complex, and the definitions and terms in the writings are sometimes ambiguous and confusing even to experts. A number of the words have different meanings than in common language use, and Peirce himself kept changing the terms he used. Elements of Peirce’s system can be found in different parts of his large corpus of texts, many analysed posthumously. Consequently it is no wonder that it is challenging to form a cohesive understanding of the whole system and the terminology. In Peirce’s system:

Sign (aka. Representamen) has three subtypes:

- **Qualisign**: A quality which is a sign, for example ”a feeling of red” (Peirce et al. 1994, vol.2, paragraph 254).
- **Sinsign**: A specific spatio-temporal thing or event that functions like a sign (Everaert-Desmedt 2011), for example a powerful blow of a note on a trumpet (da Costa e Silva 2018, 280), or the blink of a light.
- **Legisign**: A sign through law or convention, for example passwords, insignias, tickets for a show, traffic signals, and the words of a language (Hebert 2019, 243).

Object has three subtypes:

- **Icon**: A sign that resembles or imitates its object. Peirce et al. (1994, vol.2, paragraphs 90 and 92) reads: ”Originality is the most primitive, simple, and original of the categories”, and icon is an ”Orignalian” Sign. For example a portrait of a person is an icon, leading the viewer to form an idea of the person it represents.

- **Index**: A sign that is directly connected to its object. Here are some examples of index, collected from Peirce et al. (1994, vol.2, paragraphs 285 and 286): A sundial or clock *indicates* the time of day. A rap on the door. Anything which focuses the attention. Anything which startles us, in so far as it marks the junction between two portions of experience. A low barometer with moist air is an index of rain. A weathervane for the direction of the wind. The pole star is an index, or pointing finger, to show which way is north. A spirit level is an index, indicating the vertical direction.
- **Symbol**: ”A symbol fulfills its function regardless of any similarity or analogy with its object or any factual connection with it. Examples of such symbols are any general word, sentence, or book” (Peirce et al. 1994, vol.5, paragraph 73). ”A *symbol* is something to which a certain character is *imputed*, that is which stands for whatever object may have that character” (Peirce 1984, 296). Sebeok (2001, 103) explains that the icon and the index embody sign relations which are in the ”natural mode”, meaning likeness (icon) and existential connection (index), as contrasted against the symbol, which is in the ”conventional” mode. In Peirce et al. (1994, paragraph 292), it is stated that the word ”man”, as a symbol, is a succession of three sounds, becoming a sign only in the fact that a habit will cause replicas of the sound effect to be interpreted as meaning a man or men.

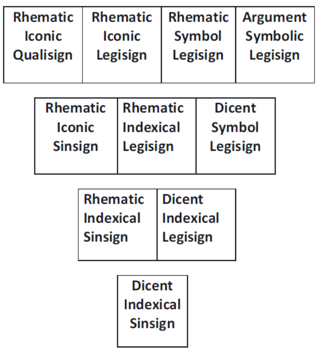
Interpretant: the understanding or meaning derived from a sign. Short (2007, 30) says: ”The significance of a sign is to be found in the interpretant. The sign signifies its object only via being so interpreted”. Fiske (2011, 40) states: ”We must realize that the interpretant is not the user of the sign, but what Peirce calls elsewhere ‘the proper significate effect’: that is, it is a mental concept produced both by the sign and by the user’s experience of the object”. The subtypes of interpretant are:

- **Rheme** (or rhematic): representing its object in terms of a quality.
- **Dicisign** (or dicent): representing its object in terms of actual existence.
- **Argument**: representing its object in terms of a law or habit.

Stjernfelt (2007, 430) summarises: ”Rhemes are signs making explicit their information, dicisigns are signs making explicit their object, and arguments are signs making explicit their interpretant.”

The definitions and explanations are quite abstract, but the sign types will become clearer later in this study when the system is applied to the subject matter. In Peirce's system the sign types do not stand alone, and they don't make full sense (or fulfill their potential) unless combined with others. For example, a blinking yellow traffic light could be *sinsign*, because there is an event (blinking) that functions like a sign. But it is not merely that. A more comprehensive description would be a *dicent indexical sinsign*. Dicent because the sign conveys information which urges to actual action (to being cautious and paying attention), indexical because it indicates a place and/or situation where care needs to be taken, and sinsign, because, as stated above, the blinking is a concrete event. But it could be assigned *dicent symbolic legisign* status as well. Dicent for the same reason as above, symbolic because the yellow light has been assigned this symbolic meaning in traffic, and legisign because the sign's meaning is interpreted through traffic regulations.

Peirce's signs and classifications can be understood as constantly rearranged elements in an ongoing process of semiosis, rather than fixed unique labels for a fixed object or phenomenon.



Interpretant	Object	Sign-Vehicle	
Rheme	Icon	Qualisign	A feeling of red
Rheme	Icon	Sinsign	An individual diagram
Rheme	Index	Sinsign	A spontaneous cry
Dicent	Index	Sinsign	A weathervane
Rheme	Icon	Legisign	A [type of] diagram
Rheme	Index	Legisign	A demonstrative pronoun
Dicent	Index	Legisign	A street cry
Rheme	Symbol	Legisign	A common noun
Dicent	Symbol	Legisign	Ordinary proposition
Argument	Symbol	Legisign	An argument

FIGURE 5: The ten sign types (Clemmer 2021, 268, image simplified from the original in Peirce Edition Project 1998, 296), and the sign types together with examples (modified from Stanford Encyclopedia of Philosophy 2022, the originals being from Peirce et al. 1994)

Figure 5 shows the sign types of Peirce's simple version of the sign system (here called "simple" because it only has 10 sign types). The three trichotomies described above result mathematically in 27 different possible combinations: 3

(qualisign, sinsign, legisign) times 3 (icon, index, symbol) times 3 (rheme, dicisign, argument) = 27. But Peirce ruled out many of these as not making logical sense, and came up with this list of 10 possible combinations, i.e. sign types. A thing may have several of these attributes at once, or different combinations in different contexts.

These 10 *combinations* are the end product of just three trichotomies. Later Peirce found seven more trichotomies, increasing the total number of *trichotomies* to 10. As can be expected, this results mathematically in many more possible combinations, and a very complex and nuanced system of signs. One version of the system has 66 sign types, and going even further, Peirce noted there is a potential sign space with 59,049 classification questions to be considered (Peirce Edition Project 1998, 482). Cobley and Jansz (1998) jokingly called the large number ”troublesome”. In this thesis it is enough to use the system of three trichotomies and the resulting 10 combinations, i.e. sign types. This 10 sign classification system is used in order to help this study identify a rudimentary taxonomy of the signals handled by the technical prototypes.

Using the semiotics of Hjelmslev

While Peirce’s sign system has a big role in this study, it is useful to also take another framework from a different tradition of semiotics, that of Hjelmslev.

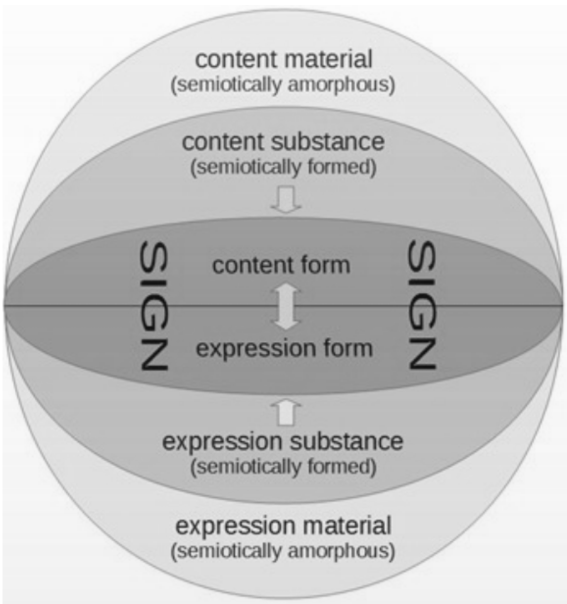


FIGURE 6. Hjelmslev’s sign model (from Nöth by Fricke & Siefkes 2015)

Hjelmslev’s sign model could be considered an extension of de Saussure’s (1916) work on signs: Hjelmslev added more dimensions. Figure 6 shows Hjelmslev’s structure of a sign, this image being modeled after Nöth (1985, 70).

In this exploratory study, in order to facilitate the analysis, a more compact version of this sign model is used: expression plane substance and form, and content plane substance and form, while omitting the material level. What this kind of sign structure can mean in a practical context, in this case a game, is interpreted by Isigan (2012) in Figure 7.

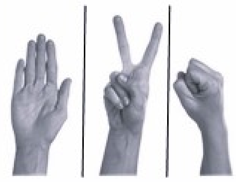
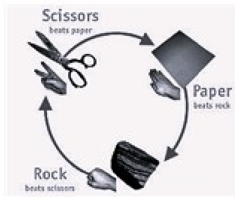
Rock - Paper - Scissors	Substance	Form
Expression Plane		
Content Plane	“Rock” “Paper” “Scissors”	

FIGURE 7. Rock Paper Scissors: A Linguistic Approach (Isigan 2012)

In this example, the game Rock-Paper-Scissors is divided into how it is **expressed**: the expressed **substance** is the physical existence of the hand, which then takes a **form,** expressed in the three hand signals of the game.

In terms of **content**, the substance is provided by the three concepts of rock, paper and scissors, and the form is provided by the game rules, which govern the game on an abstract level.

This kind of table will be used here as a tool in the analysis of signs from Hjelmslevian perspective. The meaning of the terms expression, content, substance and form become clearer when they are applied to different situations in the chapters below.

2.2.4 Participants, ethics, data collection and privacy

The Research Integrity and Ethics guidelines of Tampere Universities, the guidelines of Finnish National Board on Research Integrity TENK and the Ethical Recommendations for Thesis Writing at Universities of Applied Sciences were consulted.

In addition to the author, one person participated in the actual experiment process. Participation in the research was based on informed consent, and withdrawal from participation was available at all times. A consent form to participate was signed by the participant. The form is kept private and secured.

To preserve anonymity, the participant's signal data was not saved, and no other participation records of any kind were kept. No identification, such as names or pseudonyms of the participant, was recorded at any time in connection to any experiment or data.

The nature of the tests was mostly technical: to see how well the equipment + software setup works and how to improve it step by step. Consequently, there was no need for data storage. In practice, the participation included wearing a non-invasive EDA ring for a number of times, and also hearing different audio clips that played as a reaction to EDA readings of the person themselves, and as a reaction to EDA and EEG readings of the author. The author was the only person to wear the EEG equipment.

The biosignal measurement data which was obtained was used for technical testing of the equipment and software, and for audiovisual feedback loops. All of the biosignal data in the testing sessions was streaming from the devices, and was used only once at that instant. Any residual experiment data, such as in a memory cache or computer folder, has been erased by the author, according to the best technical knowledge of the author. Even if any residual data were to remain in any device, it is fully anonymous and cannot be connected to a person. The only exception to this are two graphs which are shown in this thesis: one EDA graph snapshot and one partial EEG graph snapshot, included in the thesis for illustration purposes.

As for the data in the form of textual narratives of the user experiences: they are all those of the author.

The author is the one who did most of the testing and experimenting, estimated over 99 % of the total time spent using EDA rings. Also, the author was the sole user of the EEG and VR equipment during this study, although the other person did participate in the EEG communication experiment by being a passive listener of audio signals from a loudspeaker.

While data was not recorded, some spontaneous reactions and verbal feedback from the participant informed various stages of the experiments. For example a test situation could produce observations such as (fictional quote): “this seems to be working well”, or “this audio file sounds more pleasant than the other one”. These comments informed and helped the experiment process. To preserve anonymity also at this stage, the comments themselves were not recorded nor written down.

3 THE EXPERIMENTS: EXAMPLES OF SONIFICATION, VISUALISATION AND BRAIN WAVE COMMUNICATION

This chapter describes two chosen samples of the many technical experiments that were done. The chosen samples are biosignal sonification and visualisation, and brain wave-based communication. A more complete description of the stages of the experiments, prototypes and a number of technical diagrams can be found in Appendix 2.

3.1 EDA and brain wave detection, sonification and visualisation

The technical experimental process with EDA and EEG data visualisation and sonification went through at least nine identifiable stages, and produced as a result a number of new prototypes and software programs. The experiments originally started in a state of uncertainty of whether any biosignal data could actually be accessed and processed at all, and used as sensory feedback to the user. It was unknown if any actual prototypes could be created. The work concluded, a little surprisingly considering the level of uncertainty at start, with several working prototypes and even too many (well over 70) live data channels opened, so that it was difficult to choose which ones of the many to actually use for the audio and visual feedback.

3.1.1 Example: wearing most of the equipment at the same time and seeing the data pulsate in an immersive 3D world

Here the final stage of the EDA and EEG sonification and visualisation experiments is chosen to be presented as an example, as it shows most of the equipment and programs in action (see Appendix 2 for the rest of the experiments).

The technical experiments progressed from creating the first simple Bluetooth connections to the biosignal detection devices, to experimenting with simple sonifications and programming, to finally going ”all in” by wearing almost all the gear and playing almost all the programs, sonifications and a visualisation simultaneously. Here is the description of the final stage:

The user wore all the four EDA rings, one EEG headset and also the VR headset simultaneously. The participation of more persons and more devices in this kind of a setup is possible but optional, for example by wearing and operating all of the three EEG headsets simultaneously. Figure 8 shows the setup.

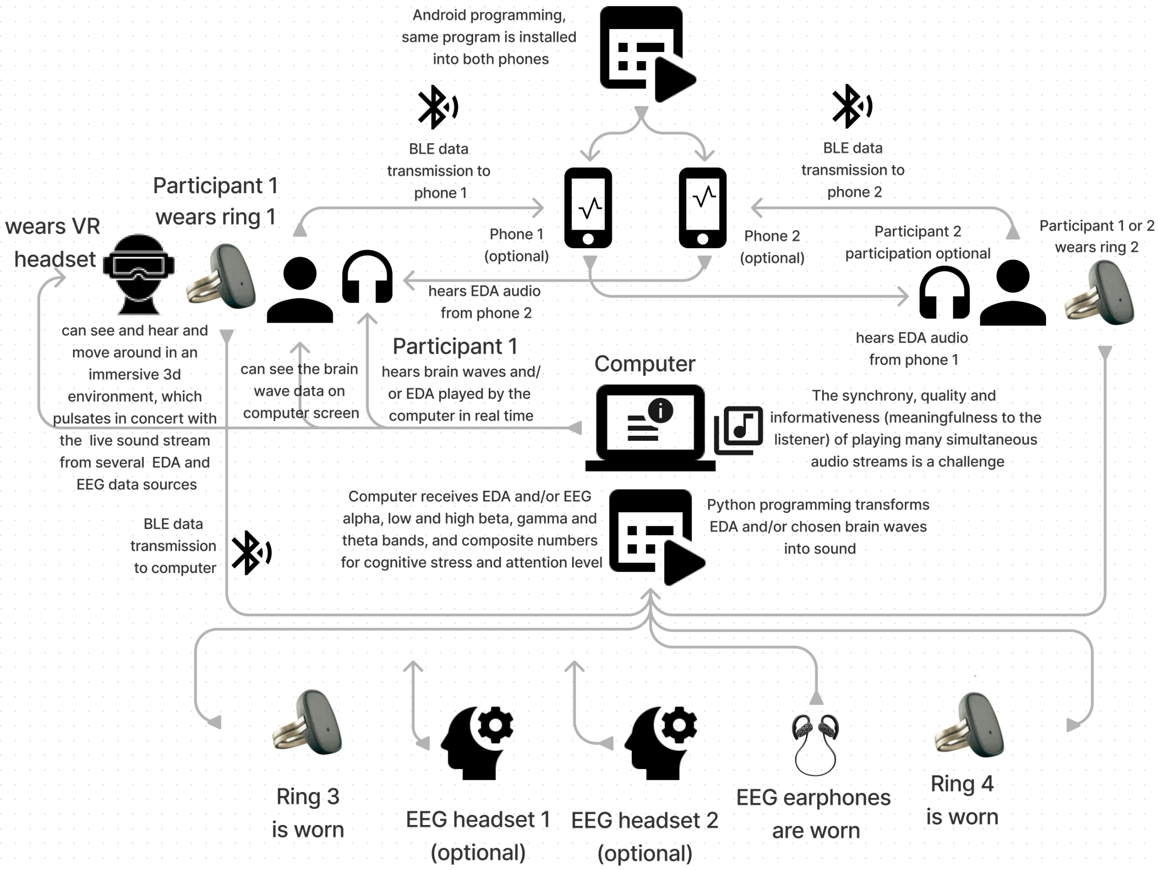


FIGURE 8. Almost all equipment worn, with live audiovisuals played inside VR

While the setup depicted in Figure 8 can work both with or without Android phones or extra participants, those elements are still shown in the picture, in order to point out that the system is malleable: new phones, devices and other participants could be connected at any time, and the loops of data and audiovisual effects can be connected and disconnected into various combinations at will.

Participant 1 or any other person can be the wearer of any of the EDA rings, or of all the rings. From the system standpoint this means that no matter who are wearing the rings 1–4, all the data from all the rings can wirelessly and simultaneously be transmitted to a data processing device. Inside the device (computer), four instances of the same Python program sonify the data of all the rings and unify it into one audio stream, which can then be heard in the ringwearer's headphones, or in any other channel of choice (e.g. loudspeakers, or another person's headphones). Also the EEG data is sonified at the same time.

This one audio stream, which represents real-time biodata readings of all the people wearing all the ring(s) combined, and also the data from the EEG headset(s), then modifies visual effects inside a 3D environment which has been prepared and uploaded into the Virtual Reality (VR) headset which is being worn. For example the sound stream created by sonifying EDA and EEG can make lights inside the 3D world pulsate with the rhythm of the sound, viewable as an immersive experience with the VR headset.

This particular 3D world was created by loading a 3D digital model of a room into the computer, then by connecting the VR headset to an instance of a Tilt Brush VR painting program (available for download at VR application stores), then loading the 3D room model into the headset, and using Tilt Brush to paint sound-reactive points and lines on the virtual surfaces (such as walls) inside the virtual room. These sound-reactive digital paints are a feature of the Tilt Brush program. Here they provided a convenient way to demonstrate the visual feedback of biosignals inside an immersive VR environment.

The variations in the sound effect result in visual effects, such as flickering lights in the sound-reactive virtual paint, which is visible inside the virtual world. In this setup the person wearing all the devices and the VR headset can be standing, sitting or lying down inside an immersive VR world, which in this case is the virtual room. The room's walls or objects that have been painted with the sound reactive virtual paint pulsate with light and colour in rhythm with the person's own brain waves and EDA readings. While wearing the headset and earphones, the user is immersed inside this virtual world, and the outside world is not seen or heard.

The above is the description of the actual experience which was created in this study. But the potential alternatives for the shape and nature of such a VR world are many: the virtual space could be a sky with the stars pulsating with the rhythm of the biosignals, or a mountain scene, a meadow, a city, anything that can be scanned or designed into a digital 3D space. It would be possible to have every single data stream (for example alpha and beta brain waves separately, or even each of the tens of EDA, EEG and movement data sources separately) to modify details inside the 3D world. The power bands of brain waves (gamma, beta, alpha, theta, delta) and acceleration readings could modify different unique aspects and even movements of objects inside the 3D virtual space. As an imagined example, each of the well over 70 biodata channels which were accessed in this study could be programmed to control the live behaviour of individual phenomena inside a virtual scenery, such as wind in the trees, rain and snow, clouds, celestial bodies such as stars, and events like the northern lights.

The 3D model inside the VR headset could also be superimposed on top of the space where the user is actually physically located. This means that if the model is fictional (e.g. a futuristic spaceship control room, or some other kind of location) then the dimensions of its walls will be modified so that they correspond to the space where the user is actually physically located. In this way the user can walk around the VR space without running into walls or other obstacles, and preserve the illusion of being on the spaceship. The actual space where the user is located can also be 3D scanned with a suitable scanner (e.g. with a LiDAR equipped iPhone) and then this scanned 3D model of the room could be fitted on top of the same actual room space. Any sound-reactive surfaces, points or objects can be painted on top of this 3D space where the user is virtually and actually located. With the sound-reactive functionality offered by a suitable VR program, the user could see and hear their own (or another person’s) brain waves and other biosignals, seeing the data as pulsating light at chosen spots inside the immersive 3D space.

For simplicity, and to demonstrate the overall concept, in this experiment one unified sonification channel was used instead of making separate audiovisual presentations of the potentially available multiple real-time data sources. This means that in this particular setup the VR 3D environment gets one audio feed where all the biosignal-derived sounds have been combined into one, and the VR application receives the signal and makes visuals inside the VR world pulsate.

It is important to note that this setup was particularly visually oriented and integrated many elements together, “with all the spices” and VR added. As can be seen in Appendix 2, each of the elements in the technical system can also be separated, and can function independently of each other in a simpler and more understated manner. For example, only sonification, only visualisation, or only one mobile or stationary device at a time, or in any combination of these. No VR workspace is necessary for these separate functions.

3.2 Experiment for communication with EEG

While the other experiments, of which the above is one example, took place with an open-ended task of collecting different biosignals and conducting experiments to convert the data into feedback loops, the EEG communication task had a specific goal: send a human language message from one person to another by using brain waves, so that it is received in some understandable form.

There are already many applications and research for reading signals from brains, such as controlling systems for games, research on brain-to-brain communication (e.g. Jiang et al. 2019) or high performance brain-to-text communication (Willett et al. 2021). This section describes an experiment in DIY mode, from the bottom up. With the help of the available technical equipment and resources, the task is to see if it is possible to demonstrate communication at a distance, using brain waves only, and what kind of original system could be created. Some examples using similar EEG headset hardware as in this study, but with different solutions, can be seen in e.g. the online video Communiquer et écrire par la pensée malgré la maladie (2018), which shows a writing system using brain waves (with additional information on the particular software solution in the video Brain Computer Interface 2017), in the documentation on how to control drone flying by brain (OpenBCI 2023), and in projects such as restoring communication to people with aphasia and subvocal phoneme recognition (OpenBCI 2022, community project list).

While the detailed technical setup was not known at the start of this experiment, it will help the reader to first have a look at Figure 9 to see how the final communication arrangement came to be.

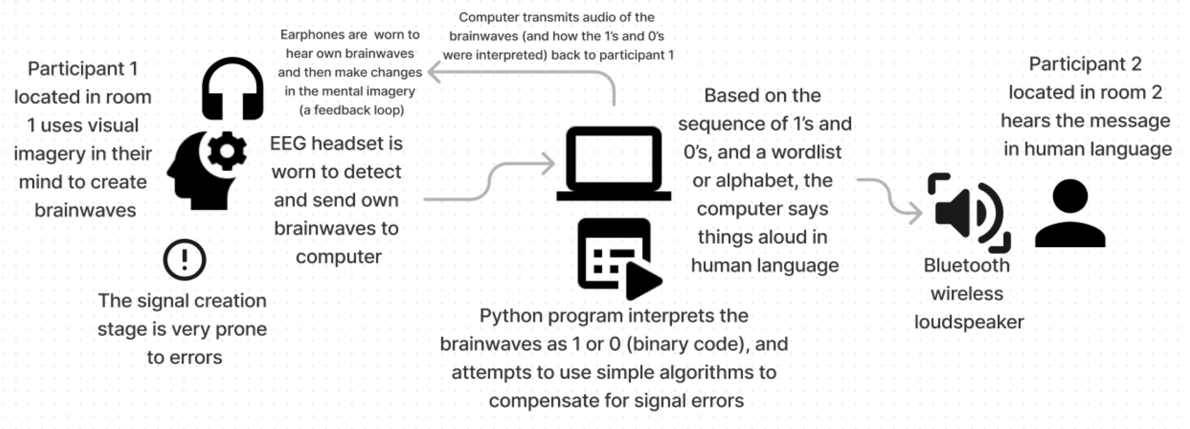


FIGURE 9. EEG communication experiment

After some programming challenges in the beginning, the EEG devices were found responsive to Python API commands. The challenge then was how to quickly identify a brain wave signal or several brain waves (channels), which could be controlled by conscious mental activity. The signal should be clear enough and stable enough so that a simple computing algorithm could identify it reliably. At minimum, there should be something like one “basic” state and one “different” state. This means that when the program understands the brain to be in a “basic” state, it will assign it one status, and when the program detects the change into “different” state, it will assign another status, and these are interpreted as digital data. It means that the two states can be interpreted as zeroes and ones, opening the possibility for digital communication. If one can add more than two states which the program could reliably identify, then the information content could become even richer.

One key question was which type of brain wave to choose, also depending which ones were available from the EEG devices, and how easy it was to emit at least two distinct types of signal. For this study, two ways to do this were to 1) look for earlier studies on the topic, and 2) just to wear the headsets and experiment to see which kind of mental activity seemed to change which types of waves. It was quickly found out that a similar case had been described in a local study, using brain waves as a game controller (Pukkila 2019). In that study, alpha and beta brain waves were experimented on. A concentration-relaxation cycle of a game player was the signal which was controlling the game. This task turned out to be difficult, as players could not easily switch between mental modes, and therefore this study didn't give conclusive advice. After this brief look at the previous local study, it was thought that it would be quicker and more interesting (and actually more exciting) to just experiment directly, instead of looking for existing solutions. Also the experience from the earlier experiments during this thesis encouraged the author to take the DIY route: advancing with trial and error in a PDCA cycle had proven to be a hard but effective way to learn quickly.

Now the task was to find out what data could be useful. The Emotiv EPOC X EEG headset and the free API was used in this particular research task. The OpenBCI EEG set could have been used as well, but since it had already been used in other experiments described in Appendix 2, it was decided to try the EPOC X. Each one of the headset's sensors can detect five brain wave frequency bands, called theta, alpha, low beta, high beta and gamma. Without going into technical details, activity (or power) detected in each of the frequencies typically indicates certain distinct brain states. For instance, high power in alpha frequency range may indicate a relaxed state. The EEG headset's 14 channels each gets its data from an electrode, and each electrode could detect the five brain wave frequency bands. 14 times 5 means 70 live data readings altogether. The hypothesis was that among these 70 readings one could probably quickly identify a few that are both 1) easily controlled by the user and 2) can give a clear, strong enough signal which can be reliably identified. A Python program was put together to test this. These 70 brain wave readings were detected and shown as a moving bar graph, updated by the computer (the highest bars extended beyond the top limit of this image, Figure 10).

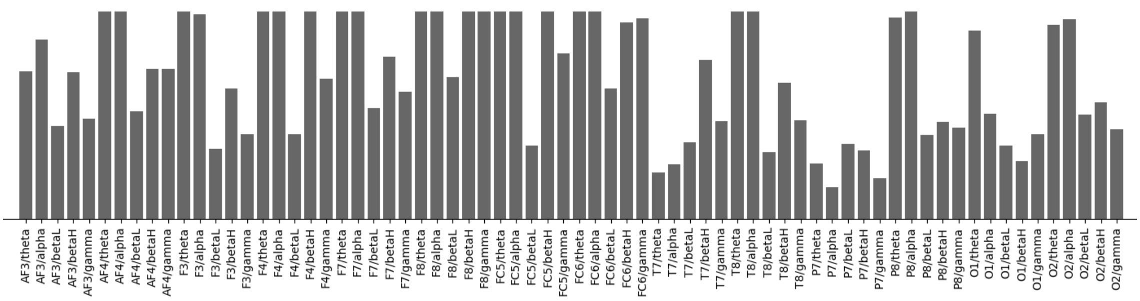


FIGURE 10. Multiple EEG channels, real-time data

This was a lot of moving data at one glance. It was difficult to get a coherent understanding what was happening. How to identify which readings could be controlled easily? Various online comments and technical websites pointed to using motor imagery for BCI control, meaning for example imagining one's hand moving, which an EEG device can then receive as a brain wave signal. This kind of technique is used in mind controlled gaming. Speech was also mentioned as a potential way to create identifiable brain waves, here meaning imagining oneself speaking. Subsequently several iterations of Python programs were made and tried, in order to identify a clear and easily controllable signal from the 14 EEG headset channels available, with the sensors (electrodes) being placed near locations where movement or speech related signals are emitted by the brain. The signal was supposed to come from imagining right and left hand movement, or from imagined speaking, but for reasons that did not become clear, this did not work well. Real-time data flowed in, and different mental efforts and imagined movements did change the readings, but a coherent way to create identifiable results remained elusive.

Visual signals were another possibility. Signals from the brain's visual cortex could be detected in channels o1 and o2 in the Emotiv headset. Letter o stands for occipital, back of the head (see Learning EEG 2020). When the eyes are closed, the visual system is in a "low power mode" and alpha brain waves, which indicate a resting state, become stronger. When the eyes are open and there are visual stimuli, the alpha brain waves are reduced. It might be possible to trick the brain's visual system into thinking that there was a visual image, while in fact the eyes were closed and it would only be an imaginary picture. This in turn would reduce the alpha waves, and the reduction could be detected as a signal by the EEG device. Because alpha waves are so strong when the eyes are closed, and become so dramatically reduced when there are visual stimuli, they seemed like a good candidate for a clearly identifiable signal.

After trying out different settings for a Python script, and variations of mental images, it was indeed possible to achieve some results. The program was set to emit a sound when the alpha waves from the brain wave channel were reduced under a certain threshold value, and to be quiet when the alpha waves were strong. This sound effect was meant to help train the user to send the right kind of signal. When the user was sitting calmly and eyes closed in a kind of meditative position, the program detected strong alpha waves and silently showed the readings as a graph on screen (the user could of course not see the readings). A beep from the computer notified the user when the alpha waves decreased below a set limit, meaning that the computer had received a signal of “one”. Thus, when the user was thinking about flashing lights and rotating geometrical shapes, alpha waves decreased, the computer sensed this signal and immediately gave this audio feedback, signifying “one”.

But problems remained: there were many erroneous beeps. Sometimes, for unknown reasons, the detected alpha waves fluctuated, even though there was no consciously imagined visual stimulus and the eyes stayed closed. How could one make this setup more reliable? There were options such as calibrating the threshold value of the computer program to just the right level, so the conscious mental images would be detected, but the other sudden fluctuations in the alpha wave values would be ignored by the system. Or finding some certain mental images which would always work by creating the desired signal at will. In any case, even though the signal was still unreliable, the computer’s readings and sounds showed that ones and zeroes could be signalled this way.

The brain-computer interfacing to send a recurring and clear signal of one or zero proved to be the most arduous task of this whole thesis. Training oneself with the help of a brain wave level audio signal and a threshold level correction loop was tiresome. But finally it worked. The details of the working prototype are closely connected with the linguistic coding of the system. This coding and the prototype are discussed briefly in the chapter below, and described in more detail in Appendix 4.

3.2.1 Designing a language to fit the technical constraints

What is the code to communicate in, if the signal can only be binary ones and zeroes? The communication system would need to be compact, simple and reliable, but also fast enough so that the amount of data is enough for meaningful communication. Such a system was devised in this study, comprising of one way to send the signal and another to interpret it.

Three sets of coding were chosen. One set is for the mental image: a vivid mental visual image vs. a visual blank, to be sent as ones and zeroes. When sending, the coding happens either with a three or a four bit system. For example, if the user keeps their mental visual image blank, then imagines a vivid moving image, and then a blank again, it is the binary number 010. If it is agreed that a four bit system is being used, the sending happens in the same way, but with one more bit added. For example the sequence blank-blank-blank-image is 0001 in binary numbers.

Two alternative sets are for interpreting the message. The received bits of data can be interpreted either as meaning the letters of a simplified 14 letter alphabet, or they can be interpreted from a chosen set of phrases (see Appendix 4 for details on the alphabet and the phrases). Using the alphabet system, the sender can send words and whole sentences, and the communication is slower, but the topics are not limited. Using a set of predetermined phrases is quicker, but the scope of topics is very narrow.

This is illustrated by a simplified example. The sentence “come here” reads “kome here” in the shortened alphabet (some letters like c and k need to be substituted to save space). The user would need to send eight letters to convey this simple message; several bits of data per letter. But if the user is using a limited set of predetermined phrases, one of which is “come here”, then just a few bits of data is enough to indicate which phrase they want. Sending is much faster.

Designing the simplified communication system was an interesting task, necessary to make the communication happen successfully. While the system could benefit from a more developed error correction system and user training, it worked: successful audio communication of letters and phrases from one person to another took place by detecting and transmitting a brain signal.

This concludes the chapter on technical experimentation examples. The next part analyses the user experience and signs of the prototypes which were created.

4 EXPERIENCES OF THE EXPERIMENTS

The chosen analysis methodologies have already been briefly introduced in the beginning chapters of this study. Here their detailed application is presented.

4.1 Perspectives from phenomenology and semiotics: meaning unit transformations and sign classification

This section offers two main types of analysis: the first one is adapted from phenomenology, and the second one from semiotics. Both approaches are specifically *adapted* and not directly *adopted*: the study is borrowing some elements and concepts, but not conducting a full scale phenomenological or semiotic research procedure. This is a compact way to examine the subject matter from several different perspectives, and enriches the picture. But while saying that this is a compact way of analysing, there is still a lot to digest. There are many narrative tables with meaning units, followed by an analysis of signals (signs) adapted from Peircean and Hjelmslevian perspectives.

Key issues of the narrative analysis are discussed in this section, with excerpts from the narratives providing an introductory step into the analysis. The bulk of the complete narrative tables with transformations can be found in Appendix 3.

Firstly, a number of narratives about creating the technical prototypes and the subjective user experience were written down for analysis. The author of this study is the narrator and the main user, so these narratives are self-reported. Self-reporting was chosen for convenience, speed and simplicity, instead of collecting large samples of user feedback. The task given to the author-narrator was: “Describe your subjective experience during the experimentation, and talk also about the signal.” The narratives are in text form, a collection of thoughts and feelings accumulated during this study. They were partly noted down during the experiments, partly remembered later and from there expanded into a set of continuous narratives. Each narrative is a snapshot of various stages of the technical experiments. They tell a story of what happened, and they also introduce the reader to the signals that the semiotic analysis will look into.

Each narrative goes through meaning unit transformations along the lines of Giorgi’s methodology (1997, 2009; Giorgi et al. 2017). Additionally, a different round of analysis is done by feeding the narratives into a Python program and then via API to a language model, creating a recurring loop. The AI (language model) driven analysis needs supervision from a human: the quality of individual results is uneven. But it soon becomes clear that it also is a usable tool. By providing endless variations of its own versions of meaning unit transformations, while requiring human curation, the AI produced texts can provide the human analyst with additional perspectives. The language model’s outputs are written in the same tables together with the transformations made by human. There are limitations: while the study borrows aspects from and follows the general process of Giorgi’s methodology, the exploratory transformation steps are here not following a strictly defined full protocol. The transformations are aiming to identify key issues from the narratives, step by step, and then ”try to determine the most invariant constituents of the experience” (Giorgi 2009, 199). Finally, based on analysing the narratives this way, a general structure is written to describe the whole process, consisting of the experiments and the user experiences. The structure is written in the concluding chapter of this study.

Concerning the question of how to identify the invariant constituents: is one word enough as a constituent, or are lengthy explanations needed? For simplicity of analysis and of presentation, the author has made a choice here: individual keywords are accepted as the essential element unless it’s clear that more words are needed. As the borders of meaning units can have a degree of arbitrariness (Giorgi 2009, 130) this study will also take the approach that there is some arbitrariness to where to draw the line of what is an absolutely essential constituent part, and what is the linguistic vehicle (word, sentence or paragraph) needed to convey that essence.

In the structure of this study, semiotic signal analysis happens after introducing each excerpt from the narratives. In the semiotic part of the analysis, the main topics are the biosignals used in each part of the experimentation, specifically the audio feedback signal which the user receives, as well as the visual mental image which is used to create a brain wave signal. The signals are scrutinised and their classification is attempted from the perspective of Peirce’s model of signs, and from that of Hjelmslev's structure of sign. These were introduced at the beginning of this study, and their concrete application is presented here.

This study uses Peirce's 10 sign system, labeling the technical system's signals accordingly (but if an extended version were to be used, it would be also possible to expand this analysis to Peirce's ten trichotomy, 66 sign types). Due to the nature of the technical system and the whole experimental setup, *dicentic indexical sinsign* was judged to be the most common type of sign identified. Such a sign conveys information about a specific state of affairs and is a singular instance or event, for example an instance of sound (a beep) whose pitch tells the level of the biosignal data reading. Other types of signs are also encountered and explored.

The narratives, together with the technical experiment descriptions, form the object of analysis in this section. For easy readability, only the first narrative table is shown here in full. The table includes the narrative text, meaning unit transformations, the AI language model input and the author's comments. It is followed by a summary of essential elements found in the narrative, and then the semiotic analysis. The rest of the complete narrative tables can be found in Appendix 3, and the technical details of every experiment stage are in Appendix 2.

4.1.1 Beginning: EDA and acceleration with beeping sounds

Table 3. First narrative: EDA and acceleration sonified by beeping sounds

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
This is mad! This is great! First it seemed that all is lost in some labyrinth of Bluetooth signal transfer protocols and this whole thing will take ages. But now suddenly the live data came in from the ring, and it was printed on the screen. And after getting the data in, turning it programmatically into sound (sonification) was quite simple. Beep, boop, bleep, bloop, it sounds a bit like R2-D2! While wearing the EDA ring, my EDA level and hand movement give a combined immediate sound. Hand goes up: bleep, bloob, biip biip. Feels somehow rewarding. Hand goes sideways and palm up: beep,	1: -The person expressed worry that the work would be complex and take a long time, then pleasure in that initial results were achieved, and that some parts of the programming (sonification) were less challenging. -They referred to science fiction (a Star Wars robot sound) and described a rewarding feeling while recounting different movements producing different sounds. Hearing one sound is "neutral" but a sequence is "funny, crazy retro scifi". For this experience to happen, it is important to be involved in creating the sound.	Frustration - Bluetooth signal transfer protocols Success - Live data transfer, visual representation Simplicity - Data sonification Association: R2-D2 sounds, Star Wars, familiarity Interaction - EDA ring, auditory feedback, hand-raising Emotional reaction - Joy, accomplishment, unique sounds	One observation which was not subjectively obvious when doing the experiments, but emerges from the narrative: The system and its signal becomes *engaging* if you are *involved* in creating it. Movement was more interesting and fun for the user than the official main topic of EDA data.

boop, bleep. It's amazing and so cool! Palm down: another set of movement sounds emanate, until it stabilises to the new position. Hearing one beep is a neutral experience, I know it's just a simple waveform by computer. But hearing different sequences is suddenly like a funny, crazy retro scifi situation. I think the fact I'm so involved in creating it makes it fun too. Creating both the system and the biosignal. If it was a random program downloaded from somewhere and playing random beep sounds, I wouldn't care much.	2: -Worrying about complexity and feeling relief about achieving successes. EDA and EEG data are the main stated interests in this study. -But while EDA is mentioned, the excitement expressed here is not much about EDA, but about interactive sounds from movement data. -A sound becomes engaging and "non-neutral", when one is involved in creating the system to make the sound and/or creating the biosignal itself.	Description - Movements, sounds, positive impression Transition - Computer-generated sound, sci-fi experience, sound patterns Pleasure - Personal participation, system creation, bio-signal production Introspection - Personal significance, impersonal vs. personal encounter.	The AI language model manages to capture some keywords and feelings, and connect them to events in the narrative. The topic of involvement is also noticed by the model: "personal participation and significance, impersonal versus personal encounter".

In this case a number or individual words, instead of sentences, summarise most of the essential things that cannot be removed without collapsing the essence of the narrative. These are: person, (bio)data, programming, EDA, movement, beep, worry, pleasure, challenge, care/engagement. It suffices to simply list these elements here. The overall analysis will be summarised into a structure in the concluding chapter of this study.

Sign classification: Peirce. Both the EDA signal sound and the acceleration signal sound could be classified as a *dicentic indexical sinsign* under Peirce's system. *Dicentic*, because the signal (beep) is claiming that a particular status or situation is present, in this case the status reading of EDA, or the acceleration of the device at the moment of measurement. *Indexical*, because the beep *indicates* a specific measurement and a specific value having been measured. *Sinsign*, because the beep is an actual occurrence of an event, i.e. the sound emission event.

It is interesting that it is possible to also interpret the sign in other ways, which adds dimensions to the analysis. For example, the fact that a high pitched sound corresponds to a high data value reading and vice versa, although seemingly intuitive and natural (the high reading corresponds to a high sound), it is an agreed convention. Therefore one could claim the beep to be a dicentic indexical *legisign*, i.e. a sign through law or convention. Another example of different perspectives is, if the beep signal corresponded to heart rate instead of an EDA reading. In this case, the beep could also well be thought of as *iconic*: a sign that resembles or imitates its object, i.e. a heartbeat. While a heartbeat sounds very different from a beep, both are short sounds, and a kind of resemblance exists especially if the beep happens simultaneously with the heartbeat. Then there is also the direct experience, the ”feeling” of a sound and its pitch as a sensory experience, which leads one to think about *qualisign*. As a result, at least at this level of analysis, using the Peircean system does not give an absolute and rigid classification of each sign. Rather, it gives a way to see a sign from different perspectives, with a potential of having various attributes, and being part of an ongoing process of semiosis.

Sign classification: Hjelmslev.

TABLE 4. EDA and acceleration sonified by beeping sounds

	Substance	Form
Expression plane	The sequence of actual physical sound waves causing the beep effect, being produced by a loudspeaker or earphone.	The pitch of the beep sound. Also possible changes in attributes like duration and intervals between beeps could be part of form.
Content plane	The substance of what the system measures and then sonifies: the electrodermal activity (EDA) and movement (acceleration) of the user's hand, particularly the ring finger.	Conceptual structure and interpretation of what it means: EDA readings signify excited or stressed states of the user, and acceleration readings possibly imply various movements such as walking, dancing, gesturing, or being immobile.

4.1.2 Stage of diverse sounds, EDA sonified with a sound clip

The second narrative is about EDA reading sonified with a sound clip. For reference, the full narrative text with meaning transformations can be found in Appendix 3, and the technical details of each experiment stage are in Appendix 2. Here is an excerpt from the full narrative, leading then to signal (sign) analysis:

> *This is better than expected! Data transfer from one device and sound effects to another work just fine... But I was too optimistic about weaving a responsive program loop, which could adjust sound pitch smoothly and immediately in response to the live biosignal data... So now I have an unending variety of sound effects. Downloaded a few free: didgeridoo, wind chime, throat singing, heavy metal vocals, a heartbeat… For reasons like pitch, rhythm, sample quality and others, some sounds feel good, others sound strange, unpleasant or unnatural. Despite programming glitches, the didgeridoo sound clip was kind of meditative from the start. A low, almost languid blaring.*

Some wordings of the full narrative replicate the first narrative and are essential for the structure, but they are omitted here, because they are already on the previous list, and will thus be included already. New concepts that appear in the full narrative are: complexity, celebration, loops, elegant/not elegant, didgeridoo, help, choices, Python.

Sign classification: Peirce. Similarly to the previous section about the beep sound, the didgeridoo sound clip can also be classified as a *dicentic indexical sinsign.* Factual information about data is conveyed (= dicentic), indicating a specific EDA reading (= index) through the event of the sound clip playing (= sinsign). The *legisign* aspect is to be considered, because the correspondence of high vs. low reading to high vs. low sound pitch is an agreed convention, not immutable.

However, the nature of this sound clip itself makes things more nuanced. A several seconds long sound of a human musical instrument playing is more complex than a short computer beep. The droning sound of the didgeridoo has a kind of immediacy to it, evoking a direct feeling of the sound, which is an attribute of a *qualisign*. While being used specifically as an *index* of biosignal data in this study, in another context the unique sound of this instrument may also have philosophical, mythical, cultural or other indications. It could also be perceived as a *symbol*, for example of culture. And if removed from the context of the specific biosignal reading, the sound could be experienced as a *rheme*, suggesting unspecified potential. *Rhematic indexical sinsign* is a possible classification.

Sign classification: Hjelmslev.

TABLE 5. EDA reading sonified with sound clip

	Substance	Form
Expression plane	The sequence of actual physical sound waves causing the sound effect, being produced by a loudspeaker or earphone.	The general pitch of the didgeridoo sound clip (changing according to measurement). Also the relative changes and undulations in the recorded clip (unchanging, if the same clip is used for every iteration of the sound).
Content plane	The substance of what the system measures and then sonifies: the electrodermal activity (EDA). Also the notes, rhythms and other musical aspects of the particular sound clip, the didgeridoo.	Conceptual structure and interpretation of what it means: EDA readings standing for excited or stressed states of the user. Also any conceptual aspects of the didgeridoo music.

4.1.3 Stage of sound loops: EDA readings sonified further

Excerpt from the third narrative:

> *...audio clips sound strange or jittery when the pitch is adjusted. They are supposed to give me a feeling of my EDA level, but instead they annoy. I long for something simple, and it feels the "computer beep" was nicer compared to these richer sounds… The audio clips sound unnatural, something in the experience breaks when the sound pitch is changed. A heartbeat turns into a little annoying noise, the wind chimes sound nervous or depressing then the pitch goes high or low. For some reason, the audio clips of a didgeridoo and throat singing are still able to produce an effect that is mesmerising and relaxing, when played in a loop: the same clip over and over again, but with the pitch adjusted each time…*

Key elements from the full narrative: disappointment, longing, strangeness, simplicity seems better, complexity jams the system, contradictions.

Sign classification: Peirce. *Dicentic indexical sinsign* is still the primary sign type identified here if one looks at the signal strictly from the perspective of measuring biosignals. If one doesn't limit the consideration to this particular use case, then *qualisign*, *legisign*, *symbol* and *rheme* become possible vantage points, as in the previous example. But since the sound clips are played in a continuous, overlapping loop, it becomes hard or impossible for the listener to hear when one clip finished playing and the new play starts. It becomes harder to assign *sinsign* status to any particular sound clip in an overlapping loop, sinsign being "a specific spatio-temporal thing or event" (Everaert-Desmedt 2011). The *qualisign* aspect (the feeling of the sound's pitch) demands more attention. But in Peirce's 10 sign system, the only allowed qualisign is a *rhematic iconic qualisign*, a pure quality. In order to stay within Peirce's 10 sign system, one could consider that the sinsign is not necessarily each sound clip separately, but one can switch the onus to the listener. It would make sense to assign *sinsign* status to each separate stretch of sound which the listener notices to contain information. For example this could occur at the moment the listener notices a change in pitch, not necessarily at the exact end or start of sound clips (subsequent clips may also have the same pitch, or the listener may be unable to hear very small pitch changes).

Throat singing (a form of singing practiced in e.g. Mongolia) becomes an interesting corollary to didgeridoo. Both have a looping, hypnotic sound that has a kind of immediate impact, and both carry various cultural connotations, although different ones. The instrument is different: a tube for didgeridoo, vox humana for throat singing.

Sign classification: Hjelmslev.

TABLE 6. EDA readings sonified with sound loops

	Substance	Form
Expression plane	The sequence of actual physical sound waves causing the sound effect, being produced by a loudspeaker or earphone.	The general pitch of the didgeridoo sound clips (changing according to measurement). Also the relative changes and undulations in the recorded clips (unchanging, if the same clip is used for every iteration of the sound). Here the form is different from the previous example: then the sounds were discrete occasions with silences in between. Here the loop is continuous, with no silences.
Content plane	The substance of what the system measures and then sonifies: the electrodermal activity (EDA). Also the notes, rhythms and other musical aspects of the particular sound clip. The structure of the sound loops is a continuous overlapping chain.	Conceptual structure and interpretation of what it means: EDA readings standing for excited or stressed states of the user. Also any conceptual aspects of the didgeridoo music.

4.1.4 Stage of brain wave sonification: EEG with sound loops

Excerpt from the fourth narrative:

> *I forget now which audio clip it was that first worked with the EEG sonification. Could have been the didgeridoo, the throat singing, or a computer generated noise sound clip. They all have a murmuring, rumbling quality to them. It's an overwhelming, exhilarating, almost mystical effect, you sit there with the EEG headset on, press play, and all of a sudden a strange and powerful symphony of your own brain waves floods the earphones. Goosebumps. At this stage the simple computer beep was not used. The low key "roaring" sounds somehow seemed more appropriate to represent the stream of brain waves (and by imagined extension, that of consciousness). It might have been less thrilling if the sound was just a clean "beep".*

Elements that emerge from the full narrative: hunch/intuition, going astray, breaking a barrier/bottleneck, flow, EEG, symphony, murmur/rumble, preference for a type of sound, the "mystical", and interpreting (i.e. imagining on purpose) the EEG sound as representing a "life force". The latter interpretation conceptually exists somewhere on the border between pattern recognition i.e. detecting an actual pattern, and apophenia (alternatively spelled apophanie) i.e. perceiving a connection or meaningful pattern between unrelated or random things (e.g. Fyfe, Williams, Mason & Pickup 2008). Kazemzadeh (2012, 117–118) talks of apophenoesis / apophenoetics, a concept related to apophenia. It is a process and study of how the mind decodes patterns, and could function as a model and tool to activate creativity and innovative thought. The process uses content ”out of context that can be processed and reprocessed in the mind forming new patterns of significance”. Kazemzadeh (2020, 7) illustrates the use of apophenoesis for creative practice with an example of Leonardo da Vinci, who used to look at a stone wall with stains in order to stimulate imagination.

Sign classification: Peirce. These brain wave measurements sonified can be considered *dicent indexical sinsigns*, similar to the EDA measurements in the previous examples. But there is also a case to be made for *rhematic iconic qualisign*: while the brain wave measurement yields exact data indicating the detection of actual brain activity, the measurement is not done with an exact brain wave band or brain function chosen as the source. The measurement locations (of the detecting electrodes) are here also relatively arbitrary and not calibrated very carefully, since the goal is to get data for sonification rather than to record exact data for a focused purpose. So for the user these sounds can represent a (rhematic) possibility or a quality, not definite and exact facts. The sudden ebbs and flows can be thought of as resembling the brain waves (iconic) and the murmur of the sound is a kind of quality in itself, which the user may or may not associate with the nature of brain waves (qualisign). The quick changes in the sound pitch also create an effect which makes the brain wave sonification feel more immediate than the slower reacting EDA readings.

One could even decide to experience the imprecise brain data sonification as an artwork. A collection of devices put together to produce an experience with unknown (rhematic) potential. The user may not know exactly how and from where the signal comes from, and what exactly it signifies. But it is an audible experience that has potential for signification, if one only could know the origins and decipher the message. In 1916, Marcel Duchamp (2013, 251) created a ready-made-aided[1] art object called With Hidden Noise[2]. A ready-made artwork is an everyday object that the artist recontextualises, and designates as art. Duchamp (2013, 209) gives an example of a ready-made: a bicycle wheel he

[1] Ready-made aidé.
[2] À bruit secret.

attached vertically on a kitchen stool and then watched spin. According to Schwarz (1969, 44) a ready-made-aided, aka. a semi-ready-made work “is obtained when the author elaborates an assemblage, which is a combination of more or less modified ready-mades”. The artwork With Hidden Noise can be held in hand like a large rattle (a percussion instrument that makes a rattling sound). It consists of a ball of twine between two plates, with an object inside that makes a noise if you move it. The object, with text on top, can be seen in Picture 1.

PICTURE 1. À bruit secret, With Hidden Noise. Photo credit: photograph by: Michael Cavanagh and Kevin Montague © Artist: Fair Use (Section 107, Copyright Act 1976) frenchsculpture.org

A key factor is that someone else than the artist put the object inside, so the artist himself does not even know what the object making the sound is. On the top and bottom plates, there are cryptic lines of text with some letters missing, like on a neon sign where some of the letters are not illuminated (Duchamp, 251). The artist Holland Hobson created an electrical buzzing sound version of With Hidden Noise in 2000 (Fijalkowski 2020). Were a digital and interactive version of this artwork made, with the cryptic texts changing on the surface according to the mystery object’s sound signal, it could be an artist’s analogy of what is happening in the EEG data experiments of this study. There is similarly a mystery: the user does not precisely know the origin of the signal and the significance of the sound. The origin of the signal is metaphorically hidden “inside the ball of twine”, and its exact nature is not known to the listener. Furthermore, the cryptic, incomplete texts on the surface of the plates of the artwork could be imagined to be signals partly deciphered from the sound (and deciphering signals happens to be a theme which will be explored in this study). In this sense, experimenting with an EEG prototype here is analogous to making a high tech DIY version of a “Hidden Noise Maker” (e.g. Hirshhorn Museum 2024).

Sign classification: Hjelmslev.

TABLE 7. EEG readings sonified with sound clip loops

	Substance	Form
Expression plane	The sequence of actual physical sound waves causing the sound effect, being produced by a loudspeaker or earphone.	The general pitch of the sound clip (changing according to measurement). Also the relative changes and undulations in the recorded clip (unchanging, if the same clip is used for every iteration of the sound).
Content plane	The substance of what the system measures and then sonifies: brain wave bands (EEG). Also the notes, rhythms and other musical aspects of the particular sound clip.	Conceptual structure and interpretation of what it means: the implications of the brain wave readings, for example the level of the alpha wave band can stand for restful vs. active state. Also any conceptual aspects of the chosen music clip(s).

4.1.5 Stage of many sounds and visuals: EDA and EEG

Excerpt from the fifth narrative:

> *Putting on six devices at the same time felt quite interesting. Four EDA rings, an EEG device and a VR headset. The exact readings of all EDA and EEG data merged into a quietly roaring stream of sound, from which it was impossible to identify single data sources. It was quiet if the sound volume was turned down, and loud if turned up. But even with the quieter version, you can hear the stream of data, and you know it’s the multitude of information your own body is transmitting. It felt overwhelming even with lower sound volume. It’s not about the growling river of sound: you could listen to any artificial sound track of the same. The effect comes from when you think that these are the actual signals of your body transformed to sound in real time. A promise of great introspection, a deeper connection to yourself. Like holding a magnifying glass over yourself and seeing streams of data normally invisible to the eye. And an actual visual effect also happens inside the VR space, a virtual room.*

The elements from the narrative are: extreme, multichannel, multisensory, overwhelming, creative solution (virtual paint), but in this case one failed promise of introspection.

Sign classification: Peirce. Now the data sources are multiple, with four EDA sources and one EEG source combining into a symphony (if not cacophony) of sounds. A roaring stream. For the user, it is difficult or impossible to discern individual data sources and sound pitches, even when they still do accord with the actual data readings from the devices. Each device is also calibrated a little differently, and the rings are worn in different fingers, so even though they measure EDA, each individual reading is different enough so that their sonified sound is not in unison. Instead of *dicentic* indexical sinsign, as in previous examples, the sound effect could be a *rhematic* indexical sinsign. The sign still *indicates* biosignal data values, and each sound is more or less an individual occurrence, or the ebbs and flows of the total sound could be taken as individual occurrences (i.e. *sinsign*). But the whole of the sound stream is no longer telling the user about a certain high or low value of the data. The EDA and EEG readings now cancel out or resonate so that the sound still says *signals are being detected*, but the exact nature of the signals is not discernible. They remain a potential, a possibility, without taking on this or that exact meaning.

Alternatively, there is a case for the sound being a rhematic *iconic* sinsign or rhematic *iconic qualisign*. If the user forgets about trying to read the signals, and instead takes them as a representation of life, imagining "a sound of a life force flowing", it turns *iconic.* If one imagines that the sound heard resembles a stream or vibration a life force generates, then it is an icon for it, in terms of Peirce's terminology.

Categorising the visual effect as a sign becomes a multilayered case. On the one hand it represents device data readings, in the same way as the brain wave and EDA sonifications do. But it represents data only in aggregate, not each data stream individually: all of the brain wave and EDA data has been unified into one sound stream, and the visual effect reacts to this sound stream, not to individual data readings directly. On the one hand, one could say the visual effect "inherits" the status of *rhematic indexical sinsign* from the sound stream. On the other hand, one could say that by directly indicating the sound itself, unrelated to what is causing the sound, the visual signal becomes a *dicentic* indexical sinsign.

Sign classification: Hjelmslev.

TABLE 8. Multiple EDA and EEG readings sonified

	Substance	Form
Expression plane	The sequence of actual physical sound waves causing the sound effect, being produced by a loudspeaker or earphone. Also the physical rays of light producing the whole immersive space and the visual light effects.	The roaring ebb and flow of the multiple data sources' sonification. Also the visual light effects, rhythmically following the sounds produced from the data (not following the data directly).
Content plane	The substance of what the system measures and sonifies: EDA and brain wave bands (EEG). Also the notes, rhythms and other musical aspects of the sound clip(s) being used, and their resonance or mutual cancelling out.	Conceptual structure from where the sound emanates (multiple data sources), how it is sonified, and interpretation of what it all means to the listener. Similarly for structure and interpretation of the visual effect.

4.1.6 Stage of brain wave messages

Excerpt from the sixth and final narrative:

> *...But in this one I should try actively create biosignals (brain waves), so that they could be detected by the EEG device... Emitting the right kind of EEG signal had to do with visuals. One tried to modify one type of brain wave simply by imagining that one was seeing something, but eyes closed and not moving. It was mentally a really strenuous exercise. I tried seeing scenes of multiple suns suddenly exploding from darkness, massive whales suddenly jumping from a calm ocean surface and then crashing in massive waves, and different kinds of geometrical shapes moving and rotating. The EEG signal reacted and was often detected correctly, but errors kept coming… Finally I settled for a kind of 3D pyramid-like frame, rotating it with increasing velocity in the visual mind. I had read somewhere that the complexity of the 3D movement could create a good identifiable signal… Finally, finally came some feelings of accomplishment! I could control the mental visuals just enough, so that the EEG device and software could identify short strings of data which I intended to send… And the machine was saying aloud a number of selected phrases I told it to say, just by modulating my biosignal… And about the signal… This was probably as simple as it could get. Using brain alpha waves strong-weak to send a signal meaning zero-one. ...there was a feeling like I was developing a new unusual skill. I mean, trying to precisely trick your alpha wave by mental images was something new.*

Listing the constituent elements of the narrative at this stage demands more explanation and text than the previous stages. The elements are: ”Very different experience”. "Telepathy". Sending instead or receiving. Very strenuous. Errors. Unique skill, first time learning. New communication protocol (new alphabet).

Creating strong, vivid visual geometrical effects in the mind. Low information density signals. Binary code.

Sign classification: Peirce. This system has many signs. A recap: trying to modulate one's own brain alpha waves: sitting eyes closed, thinking about nothing, alpha waves go up. This is a "zero". Thinking about visuals like a geometrical shape rotating: brain visual activity goes up and alpha wave goes down. This is a "one". This is a way of communicating in binary, zeroes and ones, with three bit sentences.

To which category of signs does the created mental image belong, according to Peirce's 10 sign system? This is a different case from the previous ones. In the cases presented earlier, the human user is sending signals involuntarily (or mostly involuntarily) from their body, and receiving an audio and/or visual signal feedback signifying their bodily state. But in this case, the user is actively attempting to imagine things in their mind (rotating geometrical structures), and in doing so manipulating their own brain waves in order to send a coded signal to a machine.

One may add another interesting question here: what is the signal’s (and sign’s) nature not only from human perspective, but as seen from the machine’s perspective? How could one classify the signal sent by the human to the machine in terms of a machine or computer semiotics? One question is the technical, machine learning perspective of handling EEG signals (e.g. Saeidi et al. 2021), another is the semiotics of machines (Andersen 1997; Nadin 2007).

About the visual image: let’s just see what happens if one tries to use Peirce’s system for classification here. It is found that the mental visual signal or sign could match many of the 10 sign categories, one by one, depending on the perspective taken. This highlights a characteristic of Peirce’s system: categorising a sign does not mean it cannot also belong to another category. The category may change depending on the perspective, context and emphasis.

To reiterate: qualisign, sinsign and legisign relate to qualities, individual events, or general rules respectively. Icon, index and symbol to resemblance, causal relation and convention. Rheme, dicent and argument point to potential, factual, or logical. Here are two hypothetical examples. These are deliberately ”forced” into the structure of 10 signs, to see how they do or don’t make sense:

- The case for *rhematic iconic qualisign* with a hypothetical explanation: ”The image itself (a moving geometrical shape in the mind’s eye) does not assert or state something specific, like a dicisign would. At least in the absence or further information, it just rotates there. So, rhematic. Because the image resembles something, like similar geometrical structure in real life, it is iconic. The image has certain qualities, like the imagined shape, colour, velocity or acceleration etc, or it can be seen as just representing the motion. Qualisign.”
- The case for *argument symbolic legisign* with a hypothetical explanation: ”The geometrical shape itself and its movement and changes in perspectives follow spatial reasoning: if one wants to seeing another side of the object, then the argument is that the object needs to be rotated to reach that perspective. Also, the visual stimulus from the movement is argued to create a signal that the computer can detect. Symbolic rules of movement are used in creating the movement of the object in the mental image, and the object’s movement itself symbolises a lowered level of alpha brain waves. The visual imagination of geometrical shapes progresses according to rules of geometry (even if they were invented fantastical rules). This rule system makes it a legisign.”

The reader may think that these examples require some mental gymnastics to be accepted (the author does think so). The above examples show that it is possible to assign sign categories to many different kinds of signs, but some feel more relevant and appropriate than others. However, doing such an exercise can still help in revealing things about a sign that may not be obvious at first glance. For example the rules of imaginary visual geometry were not a topic that the author had thought about during this EEG experiment, before doing this semiotic exercise. But posing this question suddenly results in a new hypothesis: “Who can say using an imaginary visual geometry isn’t a potential tool for making one’s brain wave signal clearer, if it causes identifiable changes in a brain wave?”

After the above examples, *dicent indexical sinsign* is still a strong candidate in this case, same as with the EDA signals. Sinsign, because the mental image is a specific instance. Indexical because it directly causes a change in brain waves. Dicent because it asserts a specific piece of information (e.g., "1" or "0"). But there is a key difference: the intention to send. In the case of receiving EDA feedback signals, the receiver relatively passively observes the signal coming in. In the case of trying to send a signal with brain waves, there is a strong intention and exertion to create the mental image in the first place, and then to have the receiving machinery interpret (or ”understand”) it as the correct sign which was meant to be sent.

Does it make a difference to the category of a sign, whether it is actively sent or passively received? Superficially it would seem that one can say it is a *dicent indexical sinsign* in either case. But one can consider a quote which was already shown in an earlier part of this thesis: ”A sign, or representamen, is something which stands to somebody for something in some respect or capacity” (Peirce et al. 1994, paragraph 228). Peirce continues in the same paragraph by saying that the sign or representamen creates in the mind of that person “an equivalent sign, or perhaps a more developed sign”: the created sign is the interpretant of the first sign. This is a description of semiosis. When creating a visual image in one’s own mind in order to send a message, one is involved in the creation of the representamen, which in turn is a crucial element in semiosis (see Figure 4 in chapter 2.2.3 The signals seen from a semiotic perspective). It would seem that the intent or active effort in creating the sign is in fact important, and whether the sign then belongs to this or that category is a less relevant question. Simple categorisation of signs misses the crucial nuance that this is a process of ongoing semiosis. Subtle differences in the created sign (aka. the representamen) may change the resulting interpretant, making it into “an equivalent sign, or perhaps a more developed sign”. And if considered from the perspective of interpretant (or interpretation), the passive recipient is not so passive after all. While the sender is involved in creating the representamen, the recipient participates in making the interpretant (interpretation) happen. In this way, the sign categories are certainly not immutable truths or unchangeable definitions of things. They are more like changeable labels in an ongoing process of semiosis.

From the perspective of the computer receiving the signal, what is this signal's category? At least two categorisations seem to have a good fit:

- *Dicent indexical legisign*: There is a factual true or false statement connected to reality, dicentic: the signal reading is low or high, signifying 1 or 0. This indicates certain states and is interpreted according to certain rules by a program (*index, legisign*).
- *Dicent symbolic legisign*: Similar to the case above, but since the connection of a low alpha wave reading and its interpretation (number 1) is according to convention, the relation is symbolic.

Then there is the result for the final recipient of the message: the computer speaks the transmitted words or preset phrases to the listener. These messages are in human language, and can be interpreted as signs that way. Their particular classification as signs is not crucial for this study, but what is interesting is the interplay of the many different signs inside the system *before* one can arrive at this result.

Sign classification: Hjelmslev. With eyes closed, one is imagining mental visual images, like a geometrical shape rotating. The aim of this imagining is to temporarily reduce alpha brain wave activity, which the computer will then interpret as one bit of information (a "1"). What are the elements of this visual image that is used to send a signal, in terms of Hjelmslev's structure of the sign? There are at least two sides to the question: the physical neurological processes, and the subjective conscious experience of creating and then “seeing” the visual image inside one's mind. Here is the mind-body problem, or that of mental causation: how does consciousness make things happen in the physical world, and also vice versa, how do external stimuli cross the “gap” between physical and mental, and become experiences in the mind (Chalmers 1996; Levine 1983; Stanford Encyclopedia of Philosophy 2023). In terms of Hjelmslev's sign structure, it is less problematic to categorise attributes of physiological and neurological signals as signs. But excluding the physical part, what is the “substance” and “form” of a deliberately created visual image inside a subjective consciousness, “inside the mind”? While this topic easily generates more questions than answers, and it could be a whole research project on its own, the following table contains some thoughts.

TABLE 9. Sending messages with brain waves: the subjective mental image

	Substance	Form
Expression plane	Perhaps here are the mental elements or “building blocks” of concepts, shapes and dynamics of consciousness. Analogous to a canvas with brushes and tubes of paint ready to be applied by a painter, or a box of Lego pieces ready to be put together. But this is a challenging topic. How can one define the existence of such building blocks in the first place? Instead, perhaps the “essence”, or the very existence of consciousness is the substance of the expression plane?	In this case the form of the expression would be the chosen and actively created image of the moving geometrical object in the person’s mind.
Content plane	While it is debatable which parts belong to substance and which to form, one could define the content plane substance as the different states or stages of the mental image. First, there is no image, then it is created and visually refined by mental effort, and then there are different kinds of movements, rotation and points of view one can imagine having to the object. At some point the image changes into another one, or disappears and is replaced with no specific mental visual image.	Here are the rules of the whole use case: the user generates the images with the knowledge that it can be interpreted as “1”, i.e, a bit of information by the computer. If the imagining fails to trigger a “1”, then it has failed its task and needs to be tried again according to the computer’s programming, and so on. Under these rules, the absence of the mental visual object is also a signal, a “0”.

Table 9 is looking at the sign from a subjective “inside the consciousness” perspective. Table 10 has an analysis of the signal which the computer detects. It is the physically (electronically) mediated end result of the mental activity. Depending on how one decides to define the boundaries of the planes, the different elements could be moved into different boxes, but this is one interpretation:

TABLE 10. The signal received by the computer

	Substance	Form
Expression plane	While the actual electrical signals from the brain are the origin, they are mediated to the computer by the EEG device as digital data. So the substance on the expression plane from the computer’s perspective are the device electronics and electricity which carry the signals.	The form on the expression plane is the different and constantly changing states of electricity in the circuits. One might also consider some layers of the technical signalling architecture to be part of the expression plane form (e.g. physical, transport and protocol layers).
Content plane	Layers of the technical signalling architecture could also be considered to belong to the content plane, but from the perspective of the computer program looking to receive ones and zeroes, the technical structure is less relevant. From that perspective, the substance of the content plane is simpler. There are a few states only: the program is running or not running, connection to EEG device is established or not established, either a 1 or a 0 is received, and finally there is or there isn’t a system error which prevents normal operation.	Here is a connection to the content plane form of the user’s case (shown in the previous table). The computer and the user are in the same “game”, playing with the same rules but in different roles. While the user (the one imagining the visual image to send a signal) is an analog human, the computer just follows its digital programming and reacts to signals accordingly.

This concludes the analysis of narratives and signs. The findings are discussed in the concluding chapter.

5 CONCLUDING CHAPTER: ANSWERS TO THE RESEARCH QUESTIONS

This section unpacks the work done during the study by answering research questions posed in Chapter 2, one by one. The study started as a kind of multi-method qualitative research (see Roller & Lavrakas 2015, 288), and it also concludes with answers from multiple perspectives. Some of the research questions demand discussion, which is done here, and therefore there is no separate chapter reserved for discussion. Other questions can be answered more compactly. The questions were:

Question 1) This is the primary task of this study. Collect different biosignals, convert the data into a human experience. What signals will the experiments be able to handle, and what kinds of experiences and prototypes will be created?

At the start it was unknown if this study could create one working biosignal prototype. Considering that five functioning prototypes have now been created, plus an extra experimental one for analysing text, the result of the primary task can be considered very successful.

Below is a list of the signals dealt with in this study, and the Table shows the results of the experiments:

- Signals for detection by devices: EDA readings, EEG brain channel readings, acceleration, mental motor imagery, imagined speech, mental visual images, mental visual resting state.
- The incoming feedback signals to human users: audio beeps, audio sound clips, signal data visualised as numbers and as moving graphs, the lights pulsating in an immersive VR space, a computer's speech saying words and phrases chosen according to the incoming data.
- Additionally, movement and visual related signals were present in the VR immersion session, but these were handled by the VR headset.

TABLE 11: Prototypes and programs created during this study

The following prototype systems were created during this study. The process is described in chapters 3 and 4, and in Appendix 2. The technical results consist of various devices connected with newly created software in various permutations. All were successfully demonstrated. 1. A sonification prototype for EDA signals which can work either separately or simultaneously and on multiple devices (single or multiple users, computer, phone). 2. A sonification prototype for EEG signals which can work either separately or simultaneously and on multiple devices (single or multiple users, computer, phone). 3. A simple visualisation for EEG signals, 1–70 channels. 4. A hybrid of devices and software: an immersive biosignal feedback experience in VR space. 5. A simple language model (AI) feedback loop with Python via API, for experimenting with narrative meaning units and transformations. 6. A simple one-way communication system using brain waves, three and four bit binary numbers, a simplified alphabet, phrases and computer-generated speech. The following programs were created using the programming language mentioned: 1. EDA data reading, visualisation and sonification software (Python. Several program versions.) 2. EDA data reading, visualisation and sonification software (Android.) 3. EEG data reading, visualisation and sonification software (Python. Several program versions.) 4. Using an EEG detector, a “Yes/No” answering system, based on eyelash movement (Python). 5. A textual analysis program loop, sending prompts via API to AI language model, processing the feedback locally and resending processed results as new prompts (Python and ChatGPT 4.o) 6. An EEG data communication program which includes the following functionalities: reading the EEG brain channel data, giving the user audio feedback training signals, calibrating the signal detection threshold level, interpreting the read data, and speaking the received message aloud to another person via loudspeakers or headphones (Python).

While the chosen experimental and testing method involved iteration through trial and error, it would also be possible to study what happened and also codify the process from a production perspective. One example could be a software engineering case study, e.g. the publication by Runeson et al. (2012).

Answering about the experiences that were created: The experiences are discussed under question 5) below, so the topic is not duplicated here. Descriptions of the experiences have also been given in the chapters on technical experiments and experiences, and in Appendices 2 and 3.

Question 2) Starting from a non-expert technical skill level, can one achieve communication with the EEG equipment, using brain waves to transmit a simple human language message? What kind of system could be created for the task?

The answer is yes, a system was created and messages were successfully communicated. While the capability of the system is limited and there are errors, it is able to produce numbers, and from them letters, words and phrases, spoken aloud in human language by a computer speech synthesiser. One caveat to whether the research question has been conclusively answered: any possible involvement of motor action (subtle muscle movement) in the process has not been tested, and therefore it cannot be proven that the origin of the signal is solely brain waves. The whole process still needs improvement, ranging from detecting the signal, interference and errors, as well as the user’s skill in using the interface and in creating mental imagery to send a signal (discussed by e.g. Lotte et al. 2018). The details of the experiment are described in the chapter on experimentation and in Appendices 2 and 4. For the author this was a challenging and very fulfilling task, opening new avenues of learning and skill development.

Question 3) How feasible and easy is it to conduct EDA and EEG experiments without a laboratory, i.e. when the main resources are relatively old, cheap, borrowed or second-hand equipment, free software and online advice from programmers and artificial intelligence?

The simple answer to this simple question is that overall it is surprisingly easy and feasible, although there are still many hurdles. It is surprisingly easy to create proofs of concept and conduct exploratory research. If strict research protocols and high accuracy are needed, more advanced facilities and equipment will be necessary. Some additional insight and experiences of this are in the narratives, the technical experiment descriptions and the equipment list (Appendix 1).

Question 4) How can one classify as signs the main signals used in these experiments? To which categories of signs do they belong?

The systems of Peirce and Hjelmslev have been adapted to shed light on this question. This was also a learning process for the author as an exploration of the sign systems. The chosen signs went through an analytical process, and more understanding about them was created. In this sense, this question has been successfully answered. Insight was gained on what kinds of signs this kind of a system handles, creating a conceptual structure through which to understand the system. The 10 sign classification borrowed from Peirce and the sign structure adapted from Hjelmslev cannot exhaustively describe everything that is happening in the system. But it is a start, a way of understanding the signs in this system, and possibly those of other similar systems. Overall findings:

- The Peircean 10 sign system was adapted for the use of categorising a number of signs that the technical experimentation produced. The author is aware that this sign system is not a one-size-fits-all method of definitive or normative analysis. But even so, at first the author had a tendency to search for optimal matches: trying to analyse which sign type could definitely best match to each signal in question.
    - As the analysis progressed, it became clearer that using the 10 sign system alone was both very wide in scope, but also in a way too limited to achieve that kind of definitive categorisation of signs. The problem is not with the sign system, but with trying to apply it too precisely and explicitly.
        - Very wide scope, in the sense that the criteria of belonging to this or that sign type are very context specific, and also the interpretation can be subjective. The result is that the same signal could be categorised as belonging to several types simultaneously or depending on the situation.
        - Limited, because there were aspects that the sign types did not seem to take into account. For example intent. The same type of sign can be passively received, or actively created and sent. The implications for these two situations are quite different in the process of semiosis.
    - Towards the end of the analysis, the focus of the analysis accordingly shifted a little: away from seeking optimal matches and toward using the 10 sign types a little like differently shaped prisms. To see what kind of a picture the different prisms (i.e. sign types) can reflect when they are used to examine a signal. Exact, absolute matches of sign and classification are unlikely to be found, and one can do better by using the sign types as tools for reflection than strict categorisation.

- The analysis of sign structures on the Hjelmslevian expression and content planes resulted in more uniform and definitive results than what the Peircean 10 sign system produced. The sign layers could be described in a similar manner, one signal at a time. The analysis gave an extra dimension and was a good exercise of looking at sign structure, as an alternative to Peirce. This model generated more discussion especially when matching with the visual mental sign (in the EEG experiment, when a mental visual signal was sent) and the sign as received by a computer. Here questions arose about what parts of the signalling process belong to which planes, and how one could describe the sign structure of a mental visual image.

Here is an inventory of signs that were identified, tested and/or discussed:

- EDA signal sound and acceleration signal as *dicentic indexical sinsign.*
- High pitch corresponding to high data value as *dicentic indexical legisign.*
- Didgeridoo removed from biosignal context as *rhematic indexical sinsign.*
- Brain wave measurements sonified as *dicent indexical sinsign.*
- Brain wave sound without exact data context: *rhematic iconic qualisign.*
- Visual effect “inheriting” the status of *rhematic indexical sinsign.*
- Visual effect becoming a *dicentic indexical sinsign* by indicating sound.
- EDA and EEG signals heard in aggregate with the data mixed, as *rhematic indexical sinsign.* Alternatively *rhematic iconic sinsign* or *rhematic iconic qualisign*.
- A hypothetical visual sign case for *rhematic iconic qualisign.*
- A hypothetical visual sign case for *argument symbolic legisign*.
- *Dicentic indexical sinsign* discussed in a context of receiving or sending.
- The case of a computer receiving the imagined visual signal as *dicent indexical legisign* or *dicent symbolic legisign.*
- The roles of active sender vs. passive recipient in semiosis were also considered: the interplay of sign (representamen), object and interpretant.

These sign categorisations can inform one about different facets of the signs which have been studied. A possible next step is to expand the investigation by including more dimensions from Peirce’s sign system, which had hitherto been limited to the basic 10 signs.

As for the Hjelmslev sign planes and tables, the analyses inform of an alternate way to structure signs. This exercise has been useful in learning about the sign structure, and paves the way for further learning on the topic.

Question 5) How do these experiments feel from maker and user perspective?

Partly also related to question about the technical results and experiences (Question 1), here a closer look is taken at narratives about the experiment process and about using the prototypes.

First a subjective, free form description and discussion from the author’s perspective is given below. After that can be found a basic structure of the whole process and experience. It is based on the discussion, the narratives, and the meaning unit transformations.

Free description and discussion

There is a sense of expansion and introspection: the tools enhance perception. When EDA or EEG signals are captured and amplified, it could be like a magnifying glass looking into ourselves: perceiving aspects of ourselves previously inaccessible. Sharing these signals with others expands their perception too. Boundaries can blur and merge. The technical experiments felt like peering into a microscope, or a different dimension which is usually hidden. EDA and EEG data sonified gave almost a musical experience in the VR space.

Hearing one’s own brain channel or EDA readings feels strange, exhilarating, and sometimes frustrating. It opens new perspectives as you "listen" to your signals. The signals almost become part of your own perception, and awareness of the technology can fade into the background of consciousness. Heidegger’s concepts of readiness-to-hand and present-at-hand[3] (1967, 69–72) come to mind. When using a tool, it becomes an extension of its user, and the user is

[3] “Zuhandenheit” and “Vorhandenheit” in German.

not focused on the technical specifications or numerical dimensions of the tool. The tool is used smoothly and naturally: ready-to-hand. The concept present-at-hand points to a situation where the object at hand is examined on a more abstract level. Such a situation could be, for example, when the tool is being designed, or when a particular tool is undergoing metallurgical testing to see if there are any defects. Then the tool's presence does not melt into the flow of activity: it is the center of attention and of abstract analysis. In this case, as described, the biosignal becomes the center of attention and the existence of technical tools fade into the background.

As a solo feedback loop can be engaging by itself, so loops with two or more people are likely to be as well. One can imagine a peaceful group meditation session where biosignals are shared among the participants. Or an exercise session, with live biosignals encouraging the group to better performance. Or two or more people working in concentration, getting encouragement from each other's signals. The possibilities are numerous, and also funny applications come to mind. A speaker or comedian could hear or otherwise experience (Sugawa et al. 2021) the audience's reactions in real time, besides hearing the laughter or the lack of it. If the signal is sent over a long distance, one could experience another person's presence from the other side of the globe. Imagine practical applications like the simple monitoring of an elderly person's wellbeing, or lovers and family members feeling togetherness even though far apart.

Programming a gadget to "listen" to your body, and then transmitting that as a sound to your own ears feels funny and exhilarating, and at the same time a little bit exhausting. It does not fully feel like a machine interaction anymore, because the signal itself is not a simulation. To borrow Peirce's terminology, the signals become something that has a status between a symbol and an index, and perhaps an icon. The signals indicate biological states, and the visual and/or audio signals have been agreed to carry this symbolic meaning. But how could they be iconic? To be iconic, a sign should have a resemblance of something, a portrait or a photo being typical examples. These biological states don't look or sound ”like anything” in their original form, as they are beyond the range of human senses. One doesn't hear or see EDA or brain waves unless amplified by technology. Here's the twist: now that technology enables one to see and/or hear the signal, this technology-enabled sensory experience becomes the first, original experience of “how it is to see and hear it”. And therefore a resemblance to it could now also come into being.

It is not merely a visual effect or sound indicator observed as abstract numerical information, such as: “Oh, it sounds like my EDA level is approximately 20 % higher than usual”. The streaming visualisation and/or sonification signal reacts in real time to what one does and thinks, and it’s possible to control it to some extent by physical or mental actions. For the user, it evolves into something more immediate than a detached symbolic relationship of a sound pitch being equal to numerical data. As the user is aware that this is not a simulation but real data, their next question becomes “What is this?” And the answer is: “This is me, this is my signal”. When the system is able to give a seamless flow of feedback, it feels intimate. It’s yours, it’s your own signals.

The technology itself is a channel which you can start to ignore, and take the incoming signals and their information almost like an extension of yourself or your perception. That is, of the body image or body schema (as defined in Gallagher 2005, 24; see also Dijkerman & de Haan 2007; de Vignemont 2010), or an extended mind (Clark & Chalmers 1998). An extra channel for perception. It is your real body doing what it does in real time, and you are hearing the sounds or seeing the visuals right away. It does not feel like the technology in the middle is interfering much in the experience.

Technology could also amplify biosignals which are below human detection threshold, turning weak signals into multi-channel feedback. This is a massive increase in information content, as in this case signal sources which were weak or undetectable earlier could now be amplified into strong signals, and could be combined with other (strong or weak) signals into a data stream which can then in turn be presented as human sensory input (e.g. visual and sound). A signal can be a simple data unit or a stream. Biosignal technology opens the possibility for thousands or more streams of signals and data. An overwhelming stream of human unconscious and conscious communication becomes possible. From tip of head to tip of toe, everywhere on the body or nearby can be an emitter of signals: signals from oneself to someone, or from someone else to oneself. A new channel, and a new space for a new language.

This complex interaction can create a ”nexus” where consciousness interprets these signals. This can be understood as multiple complex systems in complex relationships with each other. Despite being various and multiple, the data the devices provide will then be united in a kind of “nexus” when crossing the “explanatory gap” (Chalmers 1996; Levine 1983) where external stimuli cross into human consciousness and are experienced (and interpreted in the process of semiosis). Human consciousness encounters the stimuli, the meeting point of the various data representations now being inside the human experience. Consciousness will be the arbiter of how to interpret the signals, and thus it is also a participant in such biosignal experiments.

What does this mean? A simplified hypothetical example: a person is given visual or audio feedback of their own or someone else’s biosignal, for example EDA, but they aren’t told that it is a biosignal. They will encounter this signal, experience it, and their consciousness will give it some kind of interpretation (i.e. semiosis). Sooner or later, they may observe clues and patterns that lead them to deduce that the signal is connected to a person’s activity level or mental state. This may change their interpretation of the signal, but they may still not know its actual origin. It’s conceivable that someone with no knowledge of technology might give it interpretations that are very different from the technical explanation. It’s also conceivable that the signal could become a part of external (or internal) communication, as the person could perceive emotional and mental states from the signal. Similarly one can imagine the feedback being from another source, e.g. an EEG channel, a muscle or a group of muscles, or even a composite signal of gut wellbeing and microbiota. Even if the feedback signal recipient knows where the source of the signal is, they won’t necessarily have an idea what it means and how to begin to understand it. But the fact of having this feedback signal, that reflects ongoing life processes, is full of potential, even if one cannot articulate the potential yet. Peirce’s sign system gives a vocabulary that can help describe it: *rheme* or *rhematic* represents a quality or a potential. In the absence of any extra information, consciousness will be the arbiter (or the place where the arbitration happens), of what the signal means.

And if and when the recipient assigns meanings to the signal, or becomes aware of the source and details of the signal, and further of its connection to e.g. health and wellbeing, the Peircean sign attributes *dicisign/dicent* and *argument* also become relevant.

One more topic that stands out to the author of this study: the experienced simplicity of the signals. Though the system can be technically complex, and its semiotic analysis difficult and multidimensional, it does not need to breed more complexity with its output. A simple signal goes in, a simple transformed signal comes out. Additionally, the simplicity and the tight technical constraints on data (in the EEG signal sending case) can force and enable the creation of a simple communication system.

Having been creating and using technology this way, this study again touches upon ”a metaverse”, as mentioned in the beginning of this study. Hiro, the eponymous Protagonist of the book Snow Crash (Stephenson 1992), is a freelance hacker and lives simply in a storage unit. He expands his horizons with technology, creates technology, and navigates the metaverse skilfully. Technologies that used to be science fiction are already now here, in real life. One can adopt, adapt and navigate technologies, use them to expand one’s own horizons outward and inward.

Structure

At the beginning of this exploratory study it was stated that a method is adapted from phenomenology. Using Giorgi’s meaning unit transformation, new insight was gained and it was attempted to ”determine the most invariant constituents of the experience” (Giorgi 2009, 199).

The narrative meaning unit transformation tables were found to be useful in structuring an understanding of the narratives, making the investigator take time to analyse, and “teasing out” some insights that were not obvious at the first telling or reading of the narrative. The chosen methodology (the meaning unit transformations) functioned as a multi-stage notation tool, yielding insights about the experiments and the user experience. The narratives and the identified meaning units can inform the reader about what happened during the creative experimental process, and about the thoughts and motivations of the author. The process helps the narrator/author to notice and understand nuances and perspectives. Going through the meaning unit transformations provides a framework to structure one's thinking. Additional AI language model iterations, while needing to be curated by a human, can offer perspectives and observations too. This technology is expected to advance rapidly, so AI results are likely to be much more advanced in the near future.

Through writing the narratives and the meaning unit transformations, an outline or a general structure of the process emerges. Here is an interpretation of the general structure consisting of the experiments and the user experiences, with some key issues and topics concisely expressed.

In chapter 4, excerpts of the narratives and a list of the identified constituent elements (often individual words) were listed for each stage of the experiments. If one takes those lists, and does one more round of elimination, the words or concepts that still remain in the end are: person, (bio)data, programming, feelings, simplicity/complexity, hunch/intuition, barrier/bottleneck/constraint, pattern recognition/apophenia/apophenoetics, introspection, new communication protocol (and a new alphabet), and "telepathy" i.e. EEG-based communication.

While such a bare list of words might tell something of the essence of the experience, some more structure is needed to tell the story coherently. Looking for a good metaphor, when all the narratives and experiences are taken together, what emerges looks like a *climbing trek to a higher plateau*:

- A journey of technological and personal exploration.
  - Characterised by cycles of frustration, intensive technical problem solving sessions, achievement, joy and introspection.
    - A typically repeating pattern is this: ”emotional high” after struggle and frustration.
  - Constantly constrained by technical limitations. But the extent of what is possible keeps expanding in leaps and bounds as technical problems keep getting solved.

        - Although similar cycles repeat, there is a step by step elevation to higher levels of technical solutions and complexity of signals, leaping upward when key problems are solved: ”a surge of things flowing in the right direction”.
        - Incidentally, there seems to also be another kind of expansion: that of the ”body schema”, or a ”mind schema” in terms of awareness of the ”mind-extending” (see Clark & Chalmers 1998) possibilities and subjective experiences that biosignal loops can offer.
    - Creative engagement, jumping from one problem to the next by solving some problems with quick-and-dirty solutions ”like a bricoleur”. (Although this mode of working does not fit very well in situations where methodical documentation or formal academic research procedures are to be followed.)
- Evolving from a passive recipient to active creator.
    - From passive learning and trying to solve problems to actively proposing and trying different solutions.
    - Incidentally, there is also a transition from passive reception of biosignals to actively generating and sending biosignals (the mental visual image).
- Seeking a sense of connection with self and the technology.
- Seeking an emotional experience from the biosignal loop.

Continuing with the metaphor: with basic climbing gear and variable terrain, this climbing journey has been very rewarding and educational. More peaks can be seen ahead.

Question 6) Where do these results as a whole fit in the academic world, i.e. which existing fields of research and science are a good match?

This study has interacted with and come upon many fields of inquiry during the exploration. After the body of results of the experiments and analysis took shape, some more insights from related fields were sought. Here a few additional fields are discussed. After that this thesis concludes with an inventory of the domains of research and science, that have been noted or discussed during this study, and which seem and feel relevant to the topic.

One potential additional domain to look for insight is the field of interoception:

> Interoception refers to the sensing of the internal state of one's body. Interoception is distinct from the processing of sensory information concerning external (non-self) stimuli (e.g. vision, hearing, touch and smell) and is the afferent axis to internal (autonomic and hormonal) physiological control. (Tsakiris & Critchley 2016, preface)

Tsakiris and Critchley list in their article (2016) many examples of research on interoception: sensing and integrating aspects of the body's state and needs, monitoring of blood chemistry, representations of skin and body temperature and touch, feelings like hunger and thirst, impact on cognition, attention and perception, guiding decision-making, shaping memory and emotion processing, anxiety, depression, addiction and anorexia, and even phenomenal consciousness and body awareness. Garfinkel et al. (2015) studied people's ability (i.e. interoception) to detect their own heartbeats and discussed the three dimensions of interoceptive accuracy, sensibility and awareness. They noted that heartbeat detection tasks dominated previous studies of interoceptive ability because of pragmatic reasons: heartbeats are distinct events, easily discriminated and measured. Feldman, Bliss-Moreau and Lindquist (2024) studied the information flow through the nervous system's interoceptive pathways to the brain, producing affective states. Khalsa et al. (2018) note that the contemporary definition of interoception includes "signals from both the viscera and all other tissues that relay a signal to the central nervous system about the current state of the body", and that interoceptive signalling is present in reflexes, urges, feelings, drives, adaptive responses, and cognitive and emotional experiences.

A question arises: which biosignals, not so distinct ones as a heartbeat, could also be (relatively) "easily discriminated and measured"? This vividly brings back to mind an experience which happened during the experiments in this thesis. After many EDA device measurements in different situations, the author started to consider (or feel) that there is a distinct, but difficult to describe, bodily feeling associated with some typical situations: for example when calming down and the EDA reading was going down, or before a sudden rise in the reading. If this observation is valid, and if one learns to identify this kind of feeling with accuracy, does it mean that one can learn to sense one's own EDA without using signal detection devices? Of course the question goes both ways: if a feeling is identified, it may also be that the feeling indicates a state which is causing the EDA, and not that the EDA is causing the feeling. Whichever the case, the question about learning to identify and “feel” very subtle biosignals is still valid. Rather than developing ever more advanced devices, while useful for measuring signals and producing data (e.g. Jang et al. 2022; Xu et al. 2023), how could one work with detection devices also the other way: train the user to identify (interocept) some biological bodily states without the devices? Or even voluntarily change those states? And taking one step further, can one learn to identify some harmful states and then voluntarily change those (perhaps normally involuntary) states for the better? There are some interesting cases like learning to voluntarily increase high frequency heart rate variability (HF-HRV) through biofeedback (Bornemann, Kovacs & Singer 2019) and the placebo effect (Colagiuri et al. 2015). Figure 11 is borrowed from Khalsa et al. (2018) to illustrate this part of the discussion.

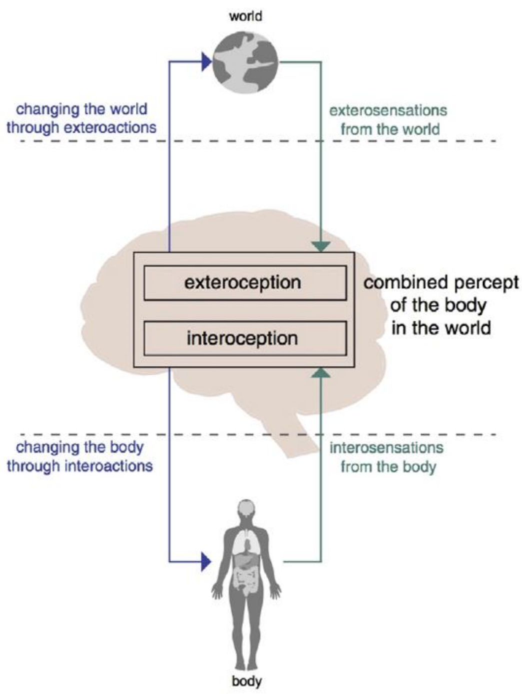


FIGURE 11. Internal and external sensation and perception (Khalsa et al. 2018)

From the above discussion one could branch to the semiotics of interoception, or semiotics of biosignals that are below the threshold of normal human sensory perception. And further, Kull and Favareau (2022, 13) define neurosemiotics as the study of sign processes and sign relations in relationship to the neural components of animals (including humans). There are also numerous other fields and niches of semiotics where one could search for correspondences. But because the potential fields are so numerous, it suffices here to make a conclusion for this study with an inventory of the findings so far.

Here is the concluding note for research question 6 and at the same time for the whole thesis. This study began as a technical experiment, starting from the devices that were available, aiming to create user experiences and prototypes. During the process this study has touched upon many fields of inquiry, which relate to the topics of this multidisciplinary study. These fields of inquiry have begun to form a context, a conceptual space where this study can be located. In other words, starting from ground up (from the experiments), and guided by serendipity or perhaps inevitability, a number of research fields where this thesis conceptually belongs have now been identified.

The list is not exhaustive, and could also be structured into another kind of hierarchy than the mind map presented here. There may be many other fields that are potentially relevant, but this is the preliminary inventory. A grouping under a few main headings will make the task easier. Figure 12 shows a mindmap of topics of research and science.

This concludes the thesis. This body of research, which grew from ground-up experiments, has here identified several potential conceptual “homes” or “ports of call”. These are research fields worthwhile to visit and to learn from. They can provide useful frameworks, tools and inspiration for further exploration, analysis, and the next steps.

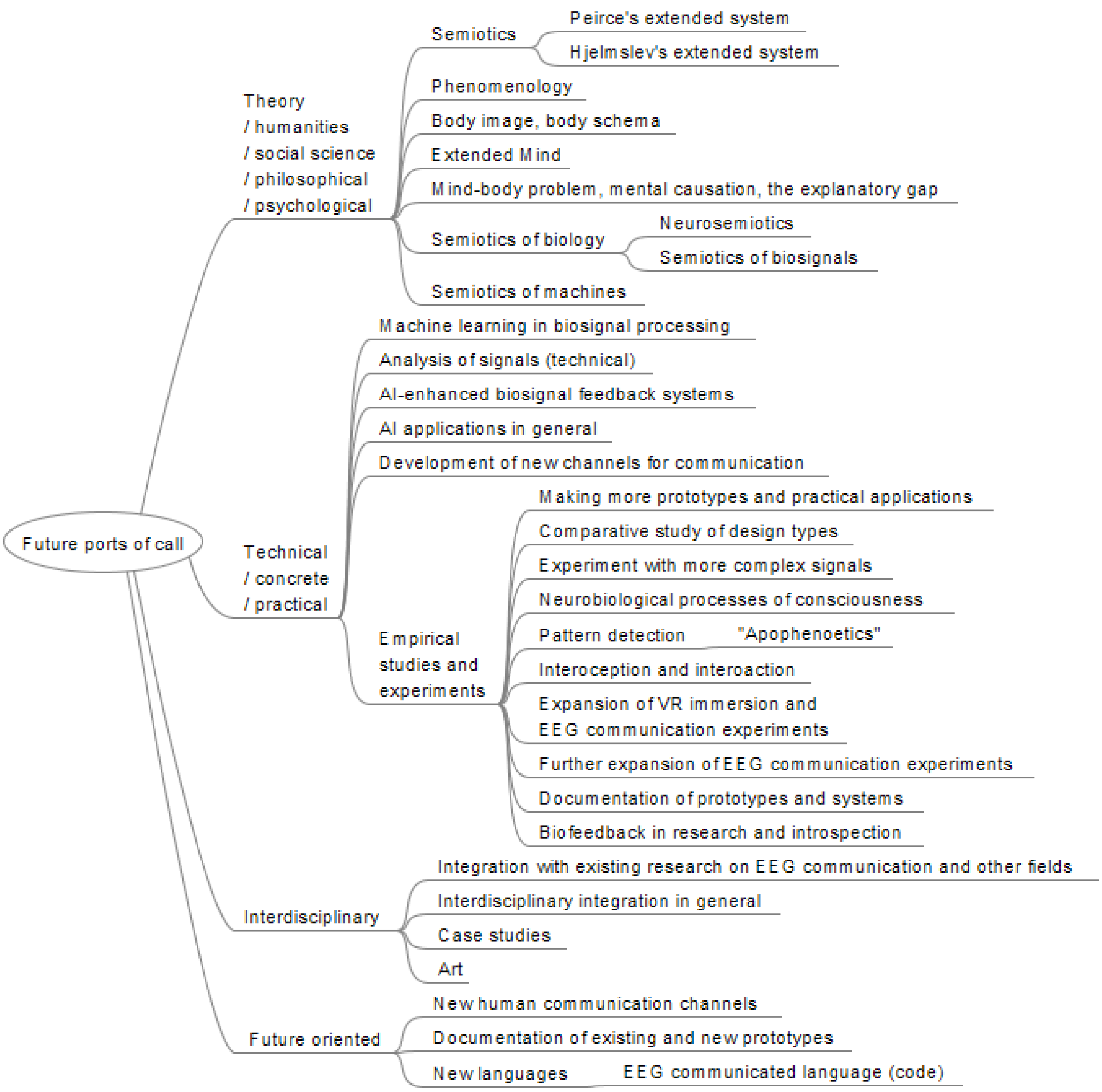


FIGURE 12. Current and future “ports of call” for this study to visit and revisit

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APPENDIX 1: The available equipment

There are many kinds of devices that can collect human biosignals, and also many that can process and present the data in various formats. The pieces of sensor equipment available for this experiment have the ability to detect brain signals (EEG), electrical properties and activities of the skin (EDA) and movement data. It is relevant to list the equipment in detail, because their capabilities and limitations are a deciding factor in which paths this study was able to take: the roadmap of what is realistically possible in this kind of experimenting. It is also relevant to describe the current technical challenges, because they largely explain why one type of experiment was chosen over another. The technical capabilities, challenges and limitations of the equipment and of the people also imply a roadmap for more extensive future experiments. Once each identified challenge can be overcome, more technically demanding experiments and experiences can be designed and performed.

It is clear that the particular technologies described and used in this study will become obsolete at some point, and some of the experimental ideas may become very commonly used applications and no longer new or interesting. In that sense the technical part of this study is not future-proof. But what still stands valid, is the DIY bricoleur idea of taking the resources and elements of the present and the future into your own hands, and using them in interesting and innovative ways to expand perspectives.

The reader is advised to see the section Abbreviations And Terms for more information about the technical terms used below.

The data collection equipment and the available data for this study were:

1. Four Moodmetric rings: EDA and motion. In a nutshell, a high EDA reading corresponds to intense states, and a low reading to restful ones.
2. OpenBCI headset: EEG and motion.
3. Emotiv EPOC X headset: EEG and motion.
4. Emotiv MN8 ear sensors: EEG and motion.

The manufacturer of the Moodmetric rings is now called Nuanic (nuanic.com) and has also new product (ring). OpenBCI stands for open-source brain-computer interface (BCI, see openbci.com). EMOTIV is a bioinformatics company advancing understanding of the human brain using electroencephalography (EEG, see www.emotiv.com).

List of the data presentation/feedback and/or data collection software and equipment in the beginning (during the study a number of new software programs were made):

5. Emotiv software and free API.
6. OpenBCI software and free API.
7. Moodmetric app and free API.
8. VR headset.
9. Two Android phones.
10. One iPhone with LiDAR capability.
11. Two sets of ordinary wireless earphones.

Data processing equipment, programming and related information sources:

12. Two computers.
13. Python programming language.
14. Android development tools.
15. Crucial information was obtained through AI prompts, Stack Overflow website, GitHub website, programmer discussion groups, and a large number and variety of YouTube technical tutoring videos. All of these were extensively consulted when solving the technical issues in this study.

Picture 2 shows from top left to right the VR headset, the OpenBCI EEG headset dongle and the OpenBCI EEG circuit board, OpenBCI electrodes. From bottom left: the Emotic EPOC X EEG headset, the Emotiv MN8 EEG headphones, four Moodmetric EDA rings.

PICTURE 2. The main equipment: VR headset, EEG headsets, EDA rings.

APPENDIX 2: The experiments: full description

This chapter gives a step by step description of the experiments. For the technical terms used here, please refer to the Abbreviations and Terms list at the beginning of the study. For a detailed list of the equipment being mentioned and used, please refer to Appendix 1.

EDA and EEG experiments, navigating the technical limitations

For a non-verbal, non-textual and technologically augmented biosignal-based experience to take place, a number of tasks and conditions need to be fulfilled.

1. One or more people that are the source(s) of data, receive the feedback created from the data, and possibly communicate (feedback to self, or between people).
2. Starting point: detecting human A biosignals.
3. Converting signals to digital data.
4. Transmitting data.
5. Processing data.
6. Creating useful representations of data (i.e feedback).
7. Presenting the results as feedback to human A, or to human B.
8. Detecting human B's biosignals (i.e. reactions), or alternatively detecting human A' biosignals again, then looping back to step 3 and presenting the results again, providing feedback continuously. The feedback loop can thus be from A's data into A's sensory input (a one person loop), or between A and B (a two person loop). The loop(s) could also include more than two people.

Here the above points and their challenges are discussed in more detail:

1. One or more people needed. This study started with the author as the developer and tester of the various combinations of equipment and software code. At later stages, when the prototype was refined enough, another person briefly joined for testing purposes.
2. Signal detection works well with the equipment that is available, although some limitations are caused by occasional problems with electric conductivity (electrodes), which results in the EEG sensors and the EDA ring

getting signals of poor quality. Occasional loss of Bluetooth connection also happens. Because movement can cause conductivity problems, static electricity and other errors, staying immobile is a good way to improve electric signal quality.

3. Converting signals to digital data works well, as the equipment was built to do just that. The sample rates of the equipment are also high enough. Sampling of several times per second is available on some devices, while e.g. one measurement per minute would have been too slow.
4. Transmitting data works well between the biosignal detection devices and their counterpart software programs. It would be optimal if all the equipment used the same open and easily accessible communication protocols, so live streaming data could be easily extracted for processing, but protocols between the devices vary.
5. Processing data in this case means getting access to the received live streaming data, and being able to convert it into formats which enable creating representations in step 6. In the case of data protocols, it relies on the device manufacturers' technical system: their existing software for the user, how they enable the use of live data, and whether they have useful, free or affordable APIs available.
6. Creating useful representations of data means transforming the data into audiovisual or other forms. Live streaming data and creating representations in real time is a technical challenge to be overcome.
7. Presenting the results means playing the result to the receiving person in the form of sound, images or other sensory input. The results should be easily experienced and possibly immersive. Aesthetically low quality input such as a small screen image or patchy low resolution computer sound is thought as likely not useful (but this hypothesis was later challenged by the test results). Environments which are thought more likely to be useful would be e.g. at one extreme a meditative low-sensory, low-stimuli environment with a single signal (such as one musical instrument) or at the other extreme a fully immersive VR world where most contents are created from various biosignals. This is challenging both for the technical execution and for the aesthetical design of the system. Due to various technical hurdles, the low-sensory path was ultimately chosen.

8. Continuous feedback loop: sending the result to the person whose biosignals they were in the first place, or to the other parties of communication. Then the signal collecting and processing starts again, and the results are presented again in a loop.

At points 5, 6 and 7 (processing, transforming and feedback of data) there is a tradeoff between quantity, quality and ease of use. If there is a lot of data and it is processed to create high quality immersive multisensory experiences, a lot of computing capacity, interface compatibility between systems and programming capability is needed. This means more advanced and likely larger equipment. If the amount of data is smaller, and fewer channels are used to create a simpler experience, even equipment like a smartphone and simple earphones could suffice for receiving the biosignal data and sending feedback signals.

The first technical challenges

The Moodmetric electrodermal activity rings, the Emotic MN8 EEG headset, the Emotiv EPOC X EEG headset and the OpenBCI EEG headset (the list of this equipment can be seen in Appendix 1) use Bluetooth and other wireless communication protocols to connect to a computer or mobile phone app to transmit their sensory data. Some use USB port dongles in connecting to a computer. In the case of devices using Bluetooth, if the necessary characteristics and services of the device are known and open (by the UUID), then data could be read directly via Bluetooth with suitable software without dongles.

Initial testing showed that live streaming biodata from Moodmetric could be detected by a computer program. Both of the Emotiv devices and the OpenBCI could also be connected in various ways after configuration. Python programs, using the right Python code libraries, could access enough live data from the devices used in this study.

First crossroads on the tech roadmap: initial choice of the primary equipment and software

Since the Moodmetric ring gives data via Bluetooth (BLE) and a concise SDK was provided, it was thought likely to be the easiest data source to start with. At this stage, getting easily usable live streaming biosignal data was the main challenge. A lot depended on the data handling capabilities of the computer programs and the APIs provided by the device manufacturers. Under these constraints, because the ease of access of the Emotiv and OpenBCI programs and APIs for processing live streaming data was yet unknown to the author, the most realistic path seemed to be using Moodmetric data via BLE.

The Python programming language could offer relatively straightforward solutions for the sonification of Bluetooth data. While not optimal for any smartphone programming, it was chosen to start with. This entailed installing Python, Visual Studio C++ environment and other elements on a computer. Figure 13 shows the tools and resources available at the outset. The diagrams in this study are created in Figma. The icons and images in this and the other similar figures in this study are from Figma (Material Design), Icons8, Iconduck, Moodmetric and Emotiv.

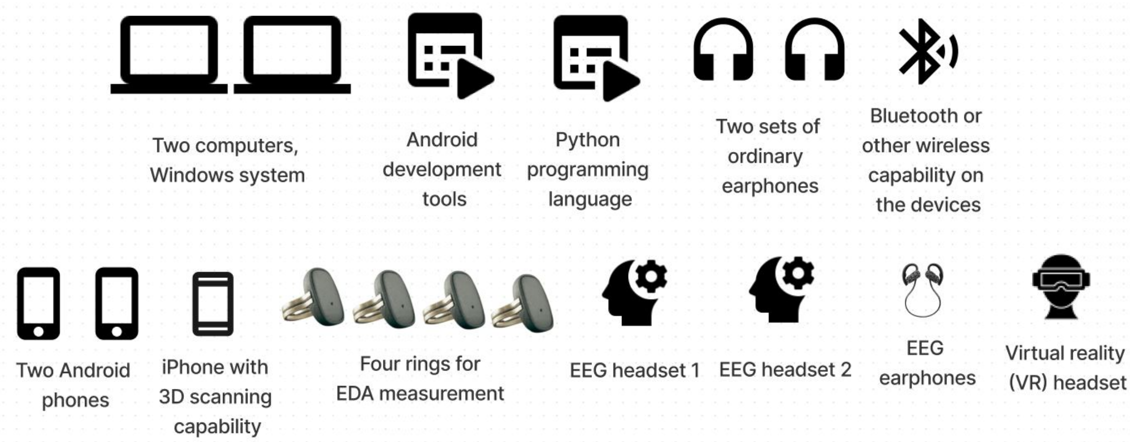

FIGURE 13. Resources available at the outset

First success on the tech roadmap: sonification of movement and EDA, and some ad hoc experiments

Several tasks were completed one by one.

- Adjusting a Python script to show a list of all the Bluetooth (BLE) devices within reach, which allow themselves to be detected.

- Adding Python code to connect the ring. After establishing connection to a BLE device, it is possible to access the data being sent by the device.
- More code was added to read the streaming data and to print it on a computer screen. The data arrived as a string called byte array, which looks like a line of letters, numbers and other characters. Transformed into integer numbers, it looks like for example [2, 40, 63, 210, 160, 94, 170]. These numbers can convey biosignal and other data.
- Next, simple audio capabilities were added to the Python code. A beep sound with variable frequency (pitch) was added. As a first proof of concept, the system started giving a reading of the user's EDA and the ring's movement approximately once per second, with the data displayed live on a computer screen. Additionally, 1–3 beeps varying from very low to medium frequency played in accordance with the data in each measurement.

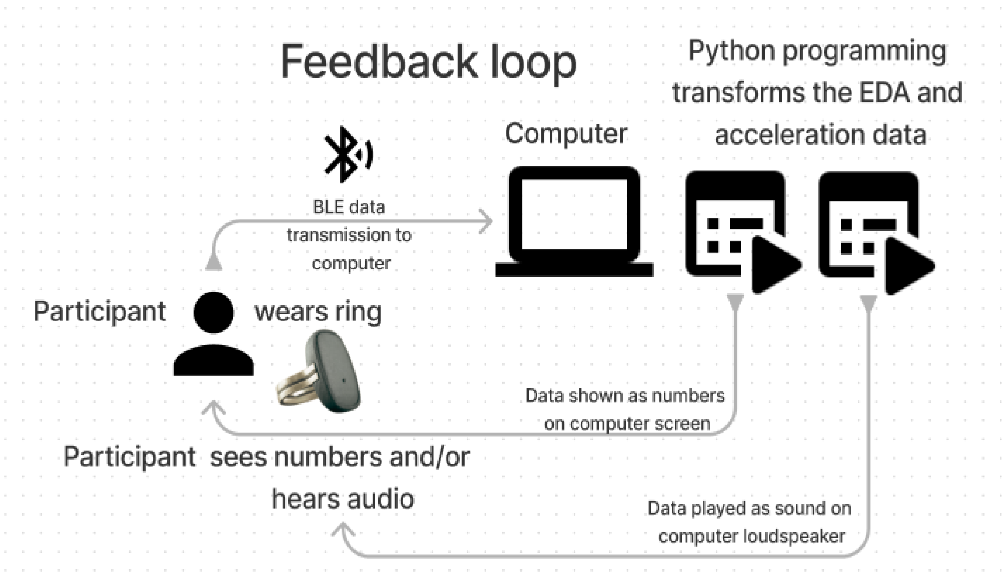

FIGURE 14. The first feedback loop: EDA data successfully sonified

Advancing on the tech roadmap: going mobile (slightly) but experiencing problems with sound and Python code quality

The next step was going slightly mobile: so far the program had worked with the computer loudspeakers, but now Bluetooth earphones were connected to the computer. They worked fine in combination with BLE. This enabled walking around the workspace while wearing an EDA measurement ring and entering different rooms within a few metres' radius, as long as the ring BLE transmission could still be received by the computer.

It was deemed that the current sound quality needed improvement from the simple computer beeps. The new idea was to have short sound files play in a program thread separate from the BLE data functionality. Both codes would work separately but in concert, and they wouldn't interfere with each other causing the program to get jammed.

Program threading in Python was more difficult than expected. The program threads apparently kept interfering with each other. Part of the objectives were still achieved:

- Two threads were created: one for data, the other for sound. But it was decided to try avoiding any complex program structures from now on.
- With the improved code, it became possible to play music clips, sound effects and samples, and their pitch could vary according to the user's biosignal and movement, albeit with a delay. A variety of new sounds were considered for use in the sonification: a heartbeat, a wind chime sound effect, and a sound clip of a didgeridoo, the Western name given to an ancient Australian aboriginal music instrument (see Aboriginal Art & Culture 2024). The audio effect variety and quality improved, but some new audio related challenges appeared and they are discussed later.

Uncanny valley, and the choice between rich immersion and minimalistic data

A little surprisingly, the new high quality sound clips felt clumsier and less personal than the simple sine wave beeping sounds played in the first experiment. The immediate "beep beep" sounds which followed the first EDA and movement measurements felt more immediate and personal. There was an aspect akin to uncanny valley (Mori 1970) when using the more advanced sound effects. They felt unpleasant. A short singing tune was also recorded and played back, but it felt strange when the sound was processed and distorted. This turned out to be yet another technical challenge: unless the audio environment and audio quality is technically very high and well synchronised, an uncanny valley effect is likely to make the system a little unpleasant to use. Finally a clip of didgeridoo sound and another deep murmuring and humming sound effect were found to be pleasant enough in the system. But there were still some glitches in the playback, such as a silent gap at the end of the sound clip before it played again, due to programming constraints.

In summary, a system had now been created where biosignal sensor data is transmitted to a computer and then sonified (and/or presented visually) for human senses. Tradeoffs were detected between programming speed and complexity, sample frequency and richness of presentation, due to computing resource coordination issues.

- Complex sounds in quick succession (due to sensor data coming rapidly from the sensor) could result in unpleasant sound quality or malfunction.
- Simple beep-beep sine wave sounds worked better when the data came in at high frequency, for example one or more reading per second.
- Playing long or detailed sound files or complex waveforms worked better when the data came in at longer intervals, for example once every few seconds or longer. This way any discontinuities or distortions were less noticeable and changes in e.g. pitch felt more gradual and natural.

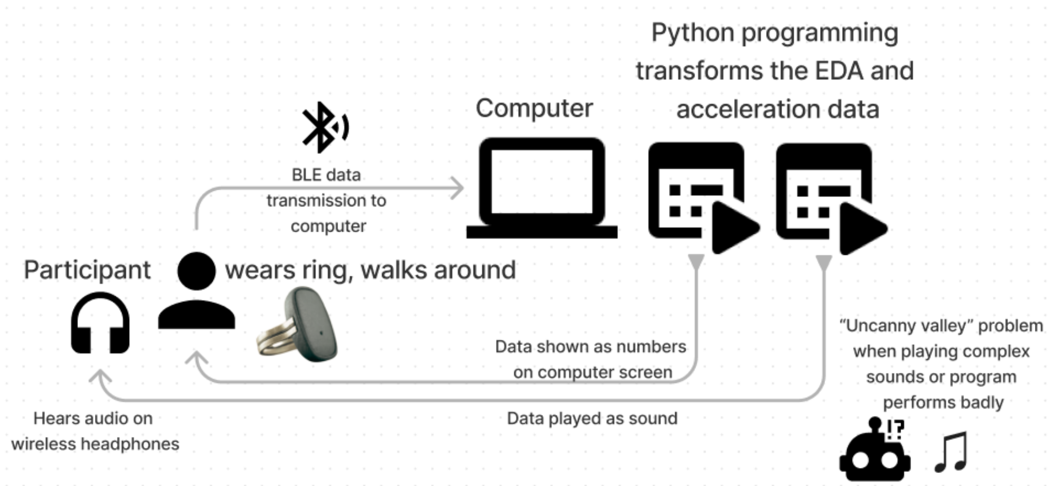

FIGURE 15. More mobility, and improved sounds but with challenges

Advancing on the tech roadmap: visuals

Next, a Python script transformed the EDA reading to a live graph, moving with the sound. In the graph in Figure 16, the vertical direction (y) is sound pitch high vs. low, and the horizontal direction (x) is measurements over time.

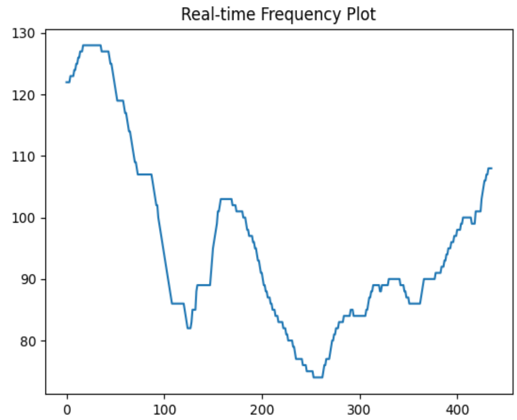

FIGURE 16. Visual and audio EDA presentation

Thus another technical hurdle had been surpassed: now there was both audio and visual feedback from the system. The next possibilities came immediately to mind: one could get data not only from EDA rings, but also from one or even more brain wave detecting devices simultaneously. One could add to this for example a three-dimensional visual effect and sounds (within the technical limits). The possibilities for new observations and ideas multiplied.

The next steps were considered:

- How to get the sound files play seamlessly, with no jolts or gaps. The sound pitch and/or speed should follow data readings smoothly.
- Experimenting with listening to another person’s biosignal in real time.

Advancing on the tech roadmap: first experiment with EEG, testing interoperability with EDA, and encountering new challenges

It was possible to access data from the OpenBCI EEG device with the help of a Python code library. Electrodes were attached for actual EEG readings. This particular OpenBCI device could provide 16 channels and also detect acceleration, but just two channels were enough to start with. The signal from the two channels was successfully brought into a Python program, and another Python library was used to plot the live EEG data as a moving graph. Then both the EEG device and the EDA ring were worn simultaneously. Measurement data of both was sent in real time into a Python program. The live data was shown first as numbers and then as a moving graph and a sound corresponding to the EDA data (but no sound yet for EEG data). At a later stage it became possible to play EDA and EEG sonifications simultaneously.

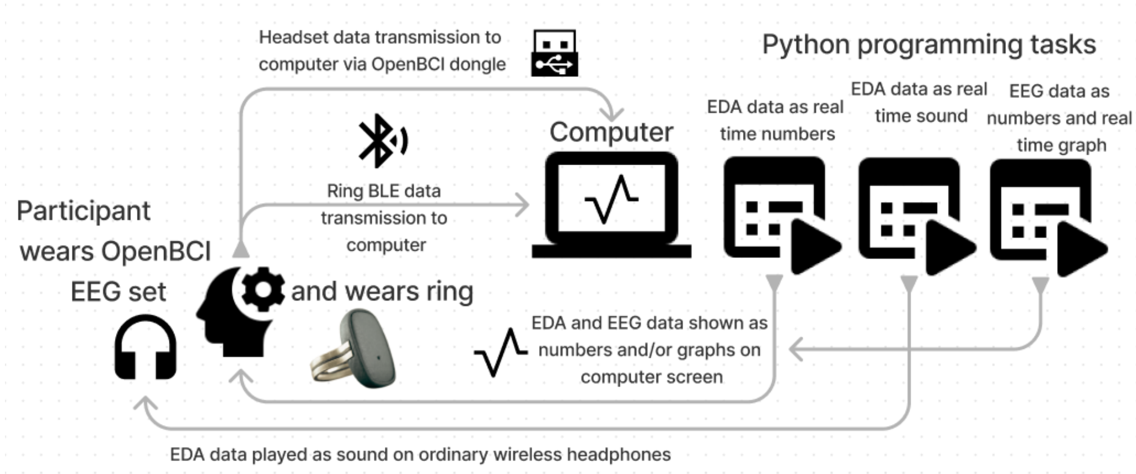

FIGURE 17. EDA audio and data, EEG data and graph

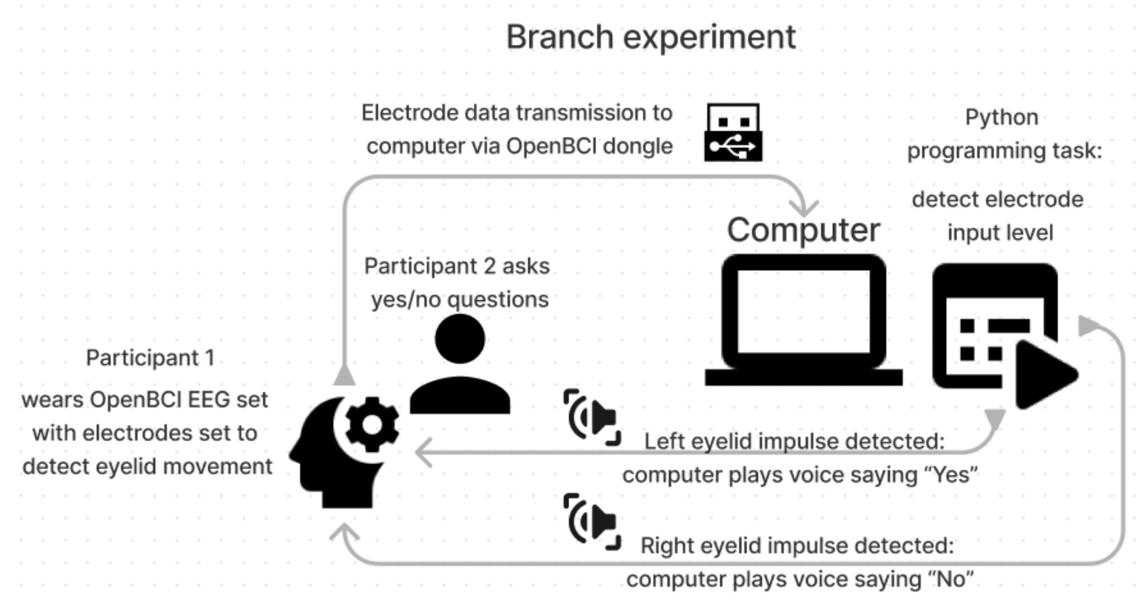

FIGURE 18. Experiment with EEG equipment: yes and no answers

While signals from brain wave channels are the main interest for feedback in this kind of sonification, another signal was now noted: the blinking of an eye produced a rapid signal which could be easily recognised by a program. This resulted in a branch experiment of how the signal could be used in communication (Figure 18). A Python program enabled this. After moving both BCI electrodes to a suitable location, the system could read which eye was blinking, and the computer was programmed to speak aloud “yes” or “no” accordingly. The left and right blinking could be interpreted as 1 or 0, making it a possible starting point for any kind of communication, though with low information intensity. While this data was from eyelid muscles, the same OpenBCI system can also detect signals from the brain, making possible a communication system using just brain activity.

From the experiences so far, some limitations started to become apparent. The more variety there is in the data channels, and the more complex the data is processing is, for example simultaneous audiovisual presentations of different kinds of readings from different channels and different devices, then the more likely it is that one encounters bottlenecks and technical hurdles.

Back to the basic task: choosing the smoothest possible technical path to create a simple but rich enough, not-too-uncanny biosignal feedback loop for one person, which would in principle be usable also for two or more people. First priority was to improve on “what already works” and to make the feedback loop pleasant. Or if not pleasant, at least well functioning and not too distracting. The focus was to make the human experience of these prototypes work.

In order to make the experience pleasant and to prove the concept, it was now decided to definitely allow a “bricoleur method”: using the means at hand, trying by trial and error to adapt them, not hesitating to change whenever necessary. “Quick and dirty”, if necessary cutting some corners and choosing easy solutions instead of well designed technical ones. Instead of striving for technical perfection, for example by integrating everything on one well synchronised Python program, it would be allowed to use several devices, for example running one live data processing and feedback system on one computer and another one on another computer, thereby avoiding synchronisation and data processing complexities. Even unorthodox playback solutions would be allowed, for example using outside loudspeakers combined with two sets of earphones on top of each other. The important point now was the subjective and intuitive experience of the user, not the technical elegance of the solution. In the end, it turned out that many low-tech workaround solutions were not necessary, but the study benefited from giving itself permission to take some shortcuts, and not get stuck in solving all technical problems in a puritanical engineering way.

Transferring the system to an Android phone

Next came experimenting with smartphones. The computer and a phone were set up in Android development mode. A program code for a new Android solution was successfully patched together and uploaded into the phone. The app connected to an EDA ring. The function of the program was the same as the earlier computer version written in Python: take the EDA data produced by the ring, then turn it into sound.

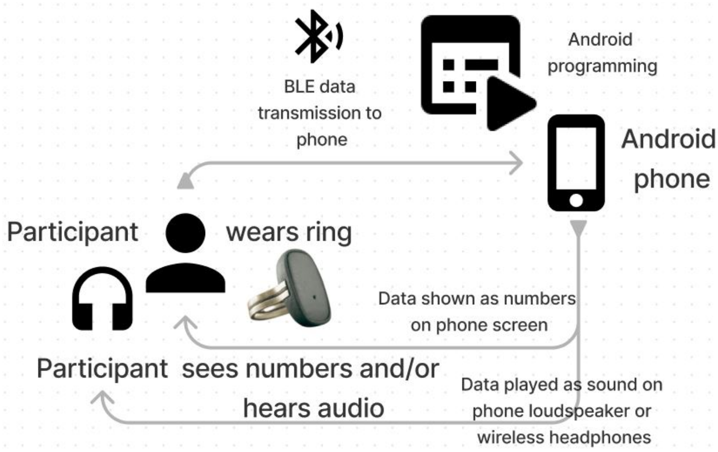

FIGURE 19. EDA sonification with Android

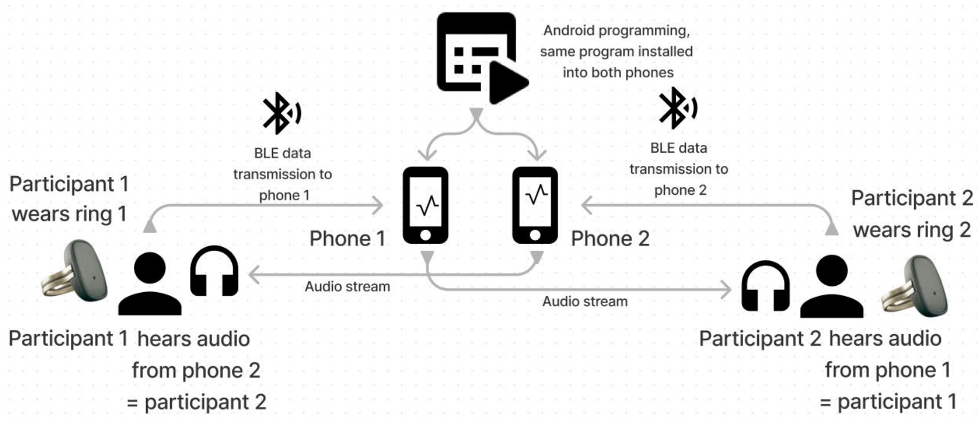

FIGURE 20. People listening to each other

The mobile phone as a platform could provide an easy and portable way to use EDA/EEG data, and to experiment alone or in pairs/groups. Figure 20 illustrates this. One phone and one ring were connected so that the ring's sonified sound played only on that phone, and another ring and phone were similarly coupled. Now two people only have to put their ring on the other person's finger to be able to hear that person's biosignals.

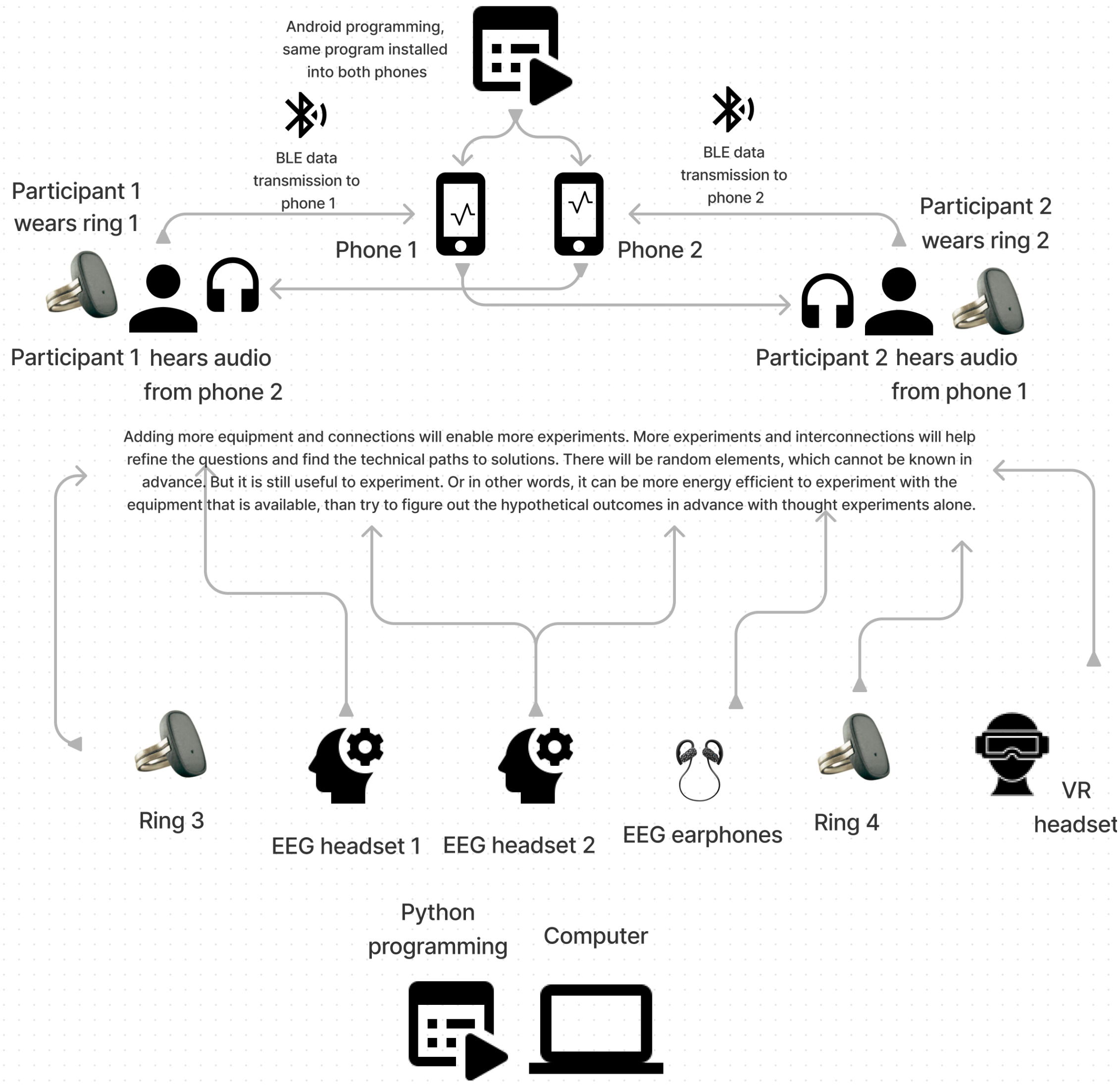

FIGURE 21. A multitude of possibilities for new combinations

Now that there was a functioning prototype that gave a somewhat pleasant user experience, it was time to return to the idea of combining many devices and inputs, and see what happens. There was now a collection of equipment, functionalities and possibilities for new, hitherto unimagined combinations to emerge. Figure 21 imagines the multiple possibilities of adding different kinds of devices and data streams and combining them in various ways.

Android or not: now transforming brain waves into sound

The Android solution worked. But the in the next iteration of experiments, it was decided to return to a Python based solution on the computer. This was because studying the possibilities offered by the Emotiv MN8 earphone/EEG device made Python the convenient choice again. Data was available via API, and the Python program environment had already been set up. The MN8 headset's EEG and movement data was successfully received, displayed, and the EEG signal sonified by a Python script. With this, an orchestra of little devices and applications playing real-time EDA and EEG data was starting to take shape.

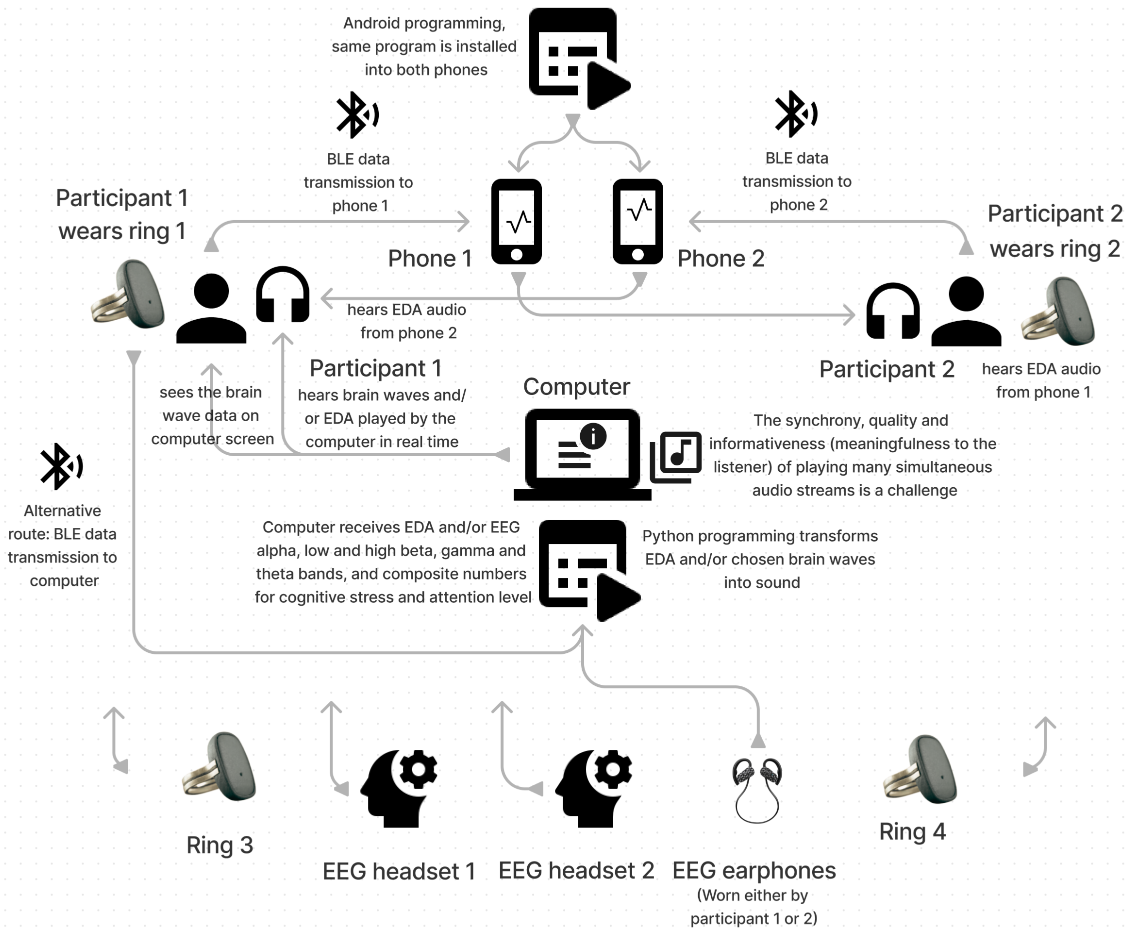

FIGURE 22. EEG and EDA sonified simultaneously

With this setup, accessing multiple biosignal channels is possible. However, adding too many data sources complicated the programming and computer resource allocation. But if the data sources were not too numerous, so they wouldn't clog the system, all programs (EDA & EEG wireless data collection and sonification) could now successfully and simultaneously be run on a single computer. The trick was to run wholly separate instances of Python code on the computer, not trying to thread or multitask too many things inside one piece of code.

While adding too many live data sources at the same time was a little complicated and often crashed different versions of Python programs when data was being input, it was found that the output of playing out the sonified data (i.e. the feedback) worked better than was expected. Even though there were multiple Bluetooth data streams going to and fro, with all the devices sending biosignal data wirelessly, a sonified ensemble of EDA and EEG data could still flawlessly be heard on Bluetooth wireless earphones connected to the same computer.

Wearing (almost) all of the equipment at the same time and seeing the data pulsate in an immersive 3D world

This part is presented in chapter 3.1.1 of the main text of his study.

APPENDIX 3: The narrative tables

The table and font sizes have been adjusted to fit most tables on one page. The AI (language model) text styles and formatting in each narrative differ from each other. These are the styles and formats given by the model in its output.

Table 3. First narrative: EDA and acceleration sonified by beeping sounds (Duplicate of Table 3 in Chapter 4.1.1)

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
This is mad! This is great! First it seemed that all is lost in some labyrinth of Bluetooth signal transfer protocols and this whole thing will take ages. But now suddenly the live data came in from the ring, and it was printed on the screen. And after getting the data in, turning it programmatically into sound (sonification) was quite simple. Beep, boop, bleep, bloop, it sounds a bit like R2-D2! While wearing the EDA ring, my EDA level and hand movement give a combined immediate sound. Hand goes up: bleep, bloob, biip biip. Feels somehow rewarding. Hand goes sideways and palm up: beep, boop, bleep. It's amazing and so cool! Palm down: another set of movement sounds emanate, until it stabilises to the new position. Hearing one beep is a neutral experience, I know it's just a simple waveform by computer. But hearing different sequences is suddenly like a funny, crazy retro scifi situation. I think the fact I'm so involved in creating it makes it fun too. Creating both the system and the biosignal. If it was a random program downloaded from somewhere and playing random beep sounds, I wouldn't care much.	1: -The person expressed worry that the work would be complex and take a long time, then pleasure in that initial results were achieved, and that some parts of the programming (sonification) were less challenging. -They referred to science fiction (a Star Wars robot sound) and described a rewarding feeling while recounting different movements producing different sounds. Hearing one sound is "neutral" but a sequence is "funny, crazy retro scifi". For this experience to happen, it is important to be involved in creating the sound. 2: -Worrying about complexity and feeling relief about achieving successes. EDA and EEG data are the main stated interests in this study. -But while EDA is mentioned, the excitement expressed here is not much about EDA, but about interactive sounds from movement data. -A sound becomes engaging and "non-neutral", when one is involved in creating the system to make the sound and/or creating the biosignal itself.	Frustration - Bluetooth signal transfer protocols Success - Live data transfer, visual representation Simplicity - Data sonification Association: R2-D2 sounds, Star Wars, familiarity Interaction - EDA ring, auditory feedback, hand-raising Emotional reaction - Joy, accomplishment, unique sounds Description - Movements, sounds, positive impression Transition - Computer-generated sound, sci-fi experience, sound patterns Pleasure - Personal participation, system creation, bio-signal production Introspection - Personal significance, impersonal vs. personal encounter.	One observation which was not subjectively obvious when doing the experiments, but emerges from the narrative: The system and its signal becomes *engaging* if you are *involved* in creating it. Movement was more interesting and fun for the user than the official main topic of EDA data. The AI language model manages to capture some keywords and feelings, and connect them to events in the narrative. The topic of involvement is also noticed by the model: "personal participation and significance, impersonal versus personal encounter".

TABLE 12. Second narrative: EDA reading sonified with sound clip

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
This is better than expected! Data transfer from one device and sound effects to another work just fine through Bluetooth. But now I'm totally stuck here, staring at the computer screen into early morning hours. I know this part can be solved, but no idea how long it will take. I'm disappointed by Python's ability to handle multiple program loops and sounds. It gets stuck, the program loop abruptly terminates, or the sound turns into noise. I also know that it's as likely a problem of programming skills. People on programmer forums give me encouragement: I'm not the only one finding Python threads problematic. They advise to to avoid threading. I was too optimistic about weaving a responsive program loop, which could adjust sound pitch smoothly and immediately in response to the live biosignal data. Someone suggested a not-so-elegant workaround solution. Good idea. I dropped the multiple loops. It worked like a charm! So now I have an unending variety of sound effects. Downloaded a few free: didgeridoo, wind chime, throat singing, heavy metal vocals, a heartbeat… For reasons like pitch, rhythm, sample quality and others, some sounds feel good, others sound strange, unpleasant or unnatural. It seems that I just have to try them one by one and see what works. Despite programming glitches, the didgeridoo sound clip was kind of meditative from the start. A low, almost languid blaring. One can imagine the hollowness of the tube, the sound is intense, almost tangible. Evokes an image of a player deeply concentrated on making the mystical sound. I suppose my choice of this audio file was not random. I had heard the instrument before.	1: -The person again celebrates successes and complains of obstacles. They blame both the programming language and their own ability. -Complexity of programming loops and sound quality are a problem. Other people give helpful advice, which results in emotional encouragement and some obstacles being overcome by changing the way of programming. -More complex sound effects are now possible, but a new obstacle: the experience of hearing the new sounds doesn't work as expected. Some sound unpleasant, unnatural. Need find ones that work. -The single didgeridoo sound clip was a favourite from start: meditative, intense, evocative of deep concentration and something mystical. 2: -Celebration of successes and complaints of difficulties continue. -They ask for the help of others in solving some technical problems, which gives both emotional support and suggests some working solutions. -While technically more advanced, now more advanced sound effects feels surprisingly unpleasant. The person believes that the new types of sound files can still work, if right sounding ones are found. -The user chose a favourite type of sound clip early on, based on their experience and impression of the type of instrument and its connotations.	1. Bluetooth Performance Satisfaction 2. Frustration and Despair 3. Technical Issues with Python 4. Self-doubt and Skill Questioning 5. Solidarity in Struggles 6. Perspective Shift and Python Critique 7. Adaptation and Simpler Solutions 8. Sound Experimentation Enthusiasm 9. Subjective Sound Perception 10. Personal Resonance and Didgeridoo Symbolism	Joy and frustration: worry and success and celebration are surprisingly prominent topics in this narrative, as compared to the memory of the process which was more "stable". The narrative and its analysis read a little like a rollercoaster of emotions. Frustration turns to a state of flow when problems are solved and things move forward. Asking for help pays off, and workarounds work. Bottlenecks guide the work towards simplicity in sound and in technical solutions. Choices of the soundscapes didn't emerge from the experiments, but were chosen intentionally, although a little unconsciously. The AI language model has written short summaries, which are like titles of paragraphs for the text.

TABLE 13. Third narrative: EDA readings sonified with sound clip loops

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
Well, this is a little disappointing. I downloaded some great audio clips, but many sound strange or jittery when the pitch is adjusted. They are supposed to give me a feeling of my EDA level, but instead they annoy. I long for something simple, and it feels the "computer beep" was nicer compared to these richer sounds. These sounds are supposed to be richer, but the complexity jams the program or the experience somehow. The audio clips sound unnatural, something in the experience breaks when the sound pitch is changed. A heartbeat turns into a little annoying noise, the wind chimes sound nervous or depressing then the pitch goes high or low. For some reason, the audio clips of a didgeridoo and throat singing are still able to produce an effect that is mesmerising and relaxing, when played in a loop: the same clip over and over again, but with the pitch adjusted each time. The sounds are a little spooky at the same time. Maybe it's because they are already in their original form somehow "otherworldly" sounds, so pitch changes didn't cause discomfort to the listener? But this could also be a personal, subjective experience. Another person could find them disturbing, and prefer something different.	1: -The person goes on further to describe diffculties in the choice of sounds and complexity of making the program function smoothly. -They expect a "feeling" of the EDA level, but the sound annoys instead. But some audio clips are described as "mesmerising and relaxing" while "a little spooky". -They speculate that these sounds may have an "otherworldly" character already, which causes their experience to be less susceptible to changes due to changes in pitch. 2: -Disappointment due to difficulty and complexity is mentioned again, while they seem to yearn for a feeling. -Adjectives used in describing the experience at this stage included jittery, simple, nicer, richer, unnatural, annoying, nervous, depressing, mesmerising, relaxing, spooky, otherworldly, disturbing. -Simplicity is better.	Keywords: 1. Dissatisfaction, downloaded audio clips, quality, effects, expectation, disappointment, pitch adjustment. 2. Emotional reaction, irritation, discomfort, enriched representation, EDA levels, auditory experience, divergence from expectation. 3.Resentment, complex sounds, attraction, simpler sounds, basic computer beep, struggle, unease. 4. Criticism, artificiality, manipulated sounds, pitch modification, natural sounds, heartbeat sounds, wind chimes, user experience. 5. Selective appreciation, calming effects, didgeridoo, throat singing, pitch change. 6. Paradoxical response, eeriness, captivating sound clips, positive experience. 7. Contradictory reactions, original nature of sounds, enjoyment, pitch-altered versions, disruption, harmonious peculiarity. 8. Individuality, subjective experiences, reaction to sounds, sound preferences, sound manipulation.	Complaints and concerns about audio quality are suprisingly prominent, compared to the subjective memory of the events. There seem to be two different processes and logics ongoing: a technical experimentation which goes in the direction "whatever works smoothly", and a search for feeling and for agreeable soundscapes. "Otherworldliness"? This time the language model listed lots of words, which could be used in a word cloud, for example.

TABLE 14. Fourth narrative: EEG readings sonified with sound clip loops

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
Solving the technical problems seems to follow a pattern: first there is a hunch, an intuition of what might be interesting to experiment with, and how it could be made to work. Then there is a dense jungle of programming hurdles and barriers, unknown paths which might lead one astray. And they do! I have now spent many evenings into the early morning hours, trying to overcome single obstacles. It always seems to be "one single thing" which stands in the way. A programming trick which should work, but doesn't, and then a long, tedious search for the reason. Sometimes a reason is suddenly found, and at other times I decide to quit trying that trick, and choose a less technical and simpler workaround. In both cases success feels like floodgates were opened, and suddenly there is a surge of things flowing in the right direction. I forget now which audio clip it was that first worked with the EEG sonification. Could have been the didgeridoo, the throat singing, or a computer generated noise sound clip. They all have a murmuring, rumbling quality to them. It's an overwhelming, exhilarating, almost mystical effect, you sit there with the EEG headset on, press play, and all of a sudden a strange and powerful symphony of your own brain waves floods the earphones. Goosebumps. At this stage the simple computer beep was not used. Low key "roaring" sounds somehow seemed more appropriate to represent a stream of brain waves (and by imagined extension, of consciousness). It might have been less thrilling if the sound was just a clean "beep".	1: -The person describes the pattern of experimenting: intuition, overcoming hurdles, going astray on wrong paths, working to solve problems late at night. -Two types of solution situations are described: either a solution is suddenly found and the hurdle thus overcome, or the original attempt is abandoned and a less technical workaround solves the problem. In both cases it is like (or feels like) floodgates opened and things move in the right direction. -In terms of audio clips representing the data reading, those that have a murmuring, rumbling quality are favoured. The first EEG sonification experience is described as a strange and powerful symphony, and reported to give an overwhelming, exhilarating, almost mystical effect, which a clean "beep" sound probably couldn't. 2: -A pattern in the experimentation process is identified. Details of technical solutions are not given in the narrative, except that it's usually single bottlenecks which significantly stall the progress until a solution is found. The description tells of how it feels like things are flowing after a solution is found. -The person favours certain types of audio clips to represent the data readings, seemingly aiming for emotional effects. -But it remains unclear if the sound clip types were solely for such subjective reasons, or also for technical feasibility (as technical difficulties with sound handling were described earlier).	Meaning unit 1: This signifies the initial process of problem-solving in a technical scenario that involves intuitive guessing and experimentation. Meaning unit 2: Discusses the challenges encountered during the problem-solving process, requiring substantial efforts and time to overcome. Meaning unit 3: Refers to the most common issue faced wherein a particular component of the programming doesn't function as expected, thereby cautioning an in-depth investigation for the fault. Meaning unit 4: Illuminates the unexpected ways a solution can pop up, possibly from abandoning a complex approach to a less complicated workaround. Meaning unit 5: Represents the feeling of achievement when a solution is found, allowing the work to progress as intended. Meaning unit 6: Reflects the author's personal experience working with audio clips using EEG sonification, even though he doesn't remember when he succeeded at it the first time. Meaning unit 7: Discusses the consistent quality ('murmuring, rumbling') these audio clips possessed. Meaning unit 8: Describes the experience of utilizing EEG sonification, understanding it to be an evocative, spiritual event reflected in the metaphor of the brain waves creating their music. Meaning unit 9: Shares an instance where simpler sounds like ordinary computer beeps were not utilized in this phase of the project. Meaning unit 10: Explains the preference for 'roaring' sounds for depicting the flow of brain waves and the idea of consciousness over simple 'beep' sounds as they possibly carry more emotional impact.	A pattern of technical exploration and development is being learned. Maybe the "mystical" is very subjective. Maybe it is not at all interesting to someone else. The language is a little hyperbolic, perhaps conveying an excitement.

TABLE 15. Fifth narrative: Multiple EDA and EEG readings sonified

Original narrative	Transformations 1 and 2	AI language model's result	Discussion / learnings
”Going for the extreme”. I knew this would be a bit of an overwhelming experience. The question was just about the exact nature of it: in what way would it be overwhelming? Putting on six devices at the same time felt quite interesting. Four EDA rings, an EEG device and a VR headset. The exact readings of all EDA and EEG data merged into a quietly roaring stream of sound, from which it was impossible to identify single data sources. It was quiet if the sound volume was turned down, and loud if turned up. But even with the quieter version, you can hear the stream of data, and you know it's the multitude of information your own body is transmitting. It felt overwhelming even with lower sound volume. It's not about the growling river of sound: you could listen to any artificial sound track of the same. The effect comes from when one thinks that these are the actual signals of one's body transformed to sound in real time. ”A promise of great introspection, a deeper connection to yourself”. Like holding a magnifying glass over oneself and seeing streams of data normally invisible to the eye. And an actual visual effect also happens inside the VR space, the virtual room. A virtual paint brush was used to draw shapes and points over some wall surfaces of the room. These painted parts pulsated in rhythm with the combined EDA / EEG sound effect. It added another potential element, which could strengthen the experience, but the sound effect was a little bit out of sync with the sound. A technical thing to be solved later. This resulted in the sound giving the immediate immersive experience, and the pulsating visuals being a nice touch, but not yet enough to become a uniting, integral element which would make the experience more immersive. Maybe the presence of visual pulses was less important, than the simple fact that a VR headset was being worn. Wearing the headset put me in virtual visual space, removed from the actual workspace. This maybe helped magnify the felt effect of the sound, whether there were pulsating lights or not.	1: -The person describes the experience of using several biosignal detection devices simultaneously and merging the data into streaming sound. -Sound volume and type of audio clip is reported to be of lesser or no importance (contradicting some earlier narratives about audio clip choices). -The overwhelming experience is reported to be due to the fact that one knows the origin of the signals is one's own body, and this promises ability for introspection and deeper connection to oneself. “Like a magnifying glass seeing streams of data”. -An actual visual effect is achieved by using a VR headset, in synchronisation with the audio stream. The visual effect is “a nice touch” but needs technical improvement. In fact the person reported that perhaps simply being in a virtual space was the important thing, the visual field thus fully immersed and away from their actual workspace. The pulsating visual effect being of lesser importance. 2: -Many signal detection devices are worn at the same time. The sonification output is unified to one sound stream. -The user's attention turns from following one signal's sound effect (as in earlier narratives) more towards thinking about the source: the biological processes emitting the signals which can then be heard and seen. Introspection. -But introspection remains just a promise at this stage, as the person's attention and reporting seems to linger on the technology rather than the actual signals.	Meaning Unit 1: Introduction to a profound, challenging experience. This unit captures the uncertain, anticipatory feeling of entering a potentially intense experience, conveying the suspense and thrill that comes with the unknown. Unit 2: Addressing the uncertainty of the experience. This conveys a sense of curiosity and ambiguity about what the experience could entail or become. Unit 3: Elaboration on the physical aspect of the setting - the usage of multiple devices, suggesting a technological, sensory-filled experience. Unit 4: Description of the complex sensory input, the blending of different types of data into a unified auditory output, indicating an intense, potentially disorienting sensory experience. Unit 5: Recognition and acknowledgement of the difficulty in processing and dealing with the heavy blast of information, and the attempt to adjust for comfort. Unit 6: Reflection on the power and intensity of the experience - the sudden realization that the sounds generated are from the user's own body data, adding a personal, introspective facet to the experience. Unit 7: Suggestion of potential utility of the experience for deep self-insight, highlighting the transformative potential of the experience. Unit 8: Introduction and description of the visual aspect of the experience, the synchronization of sound and visuals to bring a new layer to the immersion. Unit 9: Identification of potential discrepancies between visual elements and sound, and recognition of it as a problem that needs to be solved for a better holistic experience in the future. Unit 10: Comparison of different aspects of the experience and the effects they have on perception, including the difference in immersive qualities of visuals and sound. Unit 11: Reflection on the inherent power of virtual reality and contemplation on the role of VR in enhancing the user's perception of the sound data, and the isolation it provides from the real world context.	Has something changed? Is the audio type no longer that important? Has moving into a visual immersive space taken the attention? Or is it the big number of devices which now demand the attention? Or is it because the sound clip was switched to a more generic one, so attention naturally shifted? While nice, the visuals aren't yet as impressive as anticipated. AI language model input: In this round, the language model produced much more eloquent pieces of writing.

TABLE 16. Sixth narrative: Sending messages with brain waves

Original narrative	Transformations 1 and 2	AI language model’s result	Discussion / learnings
This was a very different experience from all the others. In the other experiments I was mainly receiving audio and visual stimuli based on biosignals, feeling more like a passive than an active participant. But in this one I should try actively create biosignals (brain waves), so that they could be detected by the EEG device. Some audio beeps were programmed to help in the training, so but that was the only input. With the beeps I could hear, according to the pitch of the sound, whether my current EEG signals were being identified correctly or not. Emitting the right kind of EEG signal had to do with visuals. One tried to modify one type of brain wave simply by imagining that one was seeing something, but eyes closed and not moving. It was mentally a really strenuous exercise. I tried seeing scenes of multiple suns suddenly exploding from darkness, massive whales suddenly jumping from a calm ocean surface and then crashing in massive waves, and different kinds of geometrical shapes moving and rotating. The EEG signal reacted and was often detected correctly, but errors kept coming. I felt the errors were mine: for example I was unable to switch quickly from mentally ”seeing” something to imagining seeing ”nothing”. It was like the brain’s visual system needed some time to calm down. But of course I know it was also a problem with the detection system: the programming was still quite simple. Very frustrating and tiring. I had never tried so intensively to create images in the mind. Finally I settled for a kind of 3D pyramid-like frame, rotating it with increasing velocity in the visual mind. I had read somewhere that the complexity of the 3D movement could create a good identifiable signal. Also the signal detection algorithm was adjusted many times, aiming to get the right balance, in order to identify ones and zeroes from the brain wave.	1: -The person contrasted this experience with the experience of the previous experiments. Previous experiences were mainly about receiving signals, this one was about sending. -But there was also some receiving: a beep sound effect was programmed to tell the user whether the EEG signal they sent was being identified the way they intended. This was meant to help train the user. -In order to create an EEG signal to be identified by the system, the person had to imagine seeing something, while actually eyes closed. They imagined various visually striking sceneries, with the aim of creating a brain wave signal that could be correctly detected. This was mentally strenuous activity. -There were many errors in the signal detection, due to for example them being unable to quickly switch the visual system of the brain from “seeing” something to “seeing” nothing. They felt they made the error, while also knowing that the programming of the system was simple, which could also be a reason for errors. -Finally, imagining the movement of a 3D pyramid-like frame and adjustment of the detection algorithm, resulted in a stable enough system so that they could use the EEG signal to choose phrases which the computer would then say aloud to the person in the next room. -They described the simplicity of the system: one brain wave band producing only ones and zeroes. This kind of simplicity, due to technical constraints, was seen as good, as it made for an interesting exercise. This meant trying to use only a little data to transmit much information. Some constraints and errors could be fixed by technical solutions later. -They also described they felt this was like learning a new skill. With practice one could possibly become proficient in sending data this way, akin to a Morse code operator.	1. Distinguishing current subject experiment - active role (Keywords: current experiment, previous experiences, passive role, active role) 2. Subject's role - control and creation of detectable biosignals supported by auditory cues (Keywords: active role, biosignals, auditory cues) 3. Audio cues facilitating assessment of brain wave modulation effectiveness (Keywords: audio cues, effectiveness, brain wave modulation) 4. Utilization of visual imagination for EEG signal alteration/generation (Keywords: visual imagination, EEG signals) 5. Task mental exertion - necessity for dynamic, intense imaginative effort (Keywords: mental exertion, dynamic, intense, imaginative effort) 6. Difficulty controlling brain wave signals - user errors, transitioning difficulty (Keywords: challenges, controlling, brain wave signals, user errors, visualization states) 7. Acknowledgment of mental rest need and detection system's limitations (Keywords: mental rest, limitations, detection system) 8. Task of intensive mental imagery - tiring and frustrating (Keywords: mental images, intensive, tiring, frustrating) 9. Developing effective biosignal generation strategies - complex 3D imagery utilization (Keywords: strategies, biosignal generation, complex 3D imagery) 10. Refinement of signal detection algorithm for specific EEG patterns (Keywords: refinement, detection algorithm, EEG patterns) 11. Initial success controlling mental imagery for intended data reading (Keywords: success, controlling, mental imagery, intended data) 12. Continued errors, muscle involvement doubts, emphasis on physical stillness (Keywords: errors, muscle involvement, physical stillness) 13. Manipulated biosignals for machine phrases initiation success (Keywords: manipulated biosignals, machine phrases, success) 14. Successful machine phrases transmission to Bluetooth speaker (Keywords: machine phrases, transmission, Bluetooth speaker) 15. Simplification shift of EEG signalling - basic alpha wave strength differentiation (Keywords: simplification, EEG signalling, alpha wave strength) 16. Weighing knowledge and chal-	Now active role vs. passive earlier. Receiving vs. sending. Perseverance in training and programming. Difficulties. Creation. A process of trying various paths and going for the simplest possible. Forced by the technical constraints. The constraints could be a good environment for (lean) creation. New language.

Finally, finally came some feelings of accomplishment! I could control the mental visuals just enough, so that the EEG device and software could identify short strings of data which I intended to send. It was still extremely prone to error. And I was wondering whether muscle movement was involved as well, not purely brain waves. But in effect, I was sitting eyes closed, immobile. And the machine was saying aloud a number of selected phrases I told it to say, just by modulating my biosignal. The person sitting in the next room heard this speech from a Bluetooth loudspeaker. And about the signal… This was probably as simple as it could get. Using brain alpha waves strong-weak to send a signal meaning zero-one. And that's good, because in this way it also became an interesting exercise: trying to use as little data as possible to transmit as much meaning as possible. The simplifed alphabet worked as a concept, but the signal detection system (or actually the signal sending part) was too prone to errors, so finally a set of predefined phrases was used instead. The error level can surely be fixed later technically, for example by using a higher signal sampling rate and a more advanced programming code and algorithm. How did the signal or signalling feel? A lot of frustration that needed perseverance. But there was a feeling like I was developing a new unusual skill. I mean, trying to precisely trick your alpha wave by mental images was something new. But with practice and precise detection, I suppose it could become easy and quick, like when someone has learned Morse code.	2: -This experiment was different from the others: the mode of mainly being a signal recipient vs. mainly being a sender. Some receiving was still required too: a training signal. -Mental visual imagining was difficult. Switching between two modes of was hard: picturing highly stimulating images in the mind, and imagining seeing nothing. This produced errors. The signal detection program being simple could also be a reason for errors. -One type of visual imagery was found which produced better results than others. The detection program was also adjusted to improve results. The coding of the message's meaning had to be simplified from using an alphabet to using set phrases. In this way, by gradual improvement of the mental activity and the detection program, and by simplifying the coding of the message's meaning, a satisfactory rate of successful signal sending was achieved. -While technical solutions could solve the difficulties of sending and detecting the signal, another way could be training for it, like one trains for Morse code.	lenges for maximal meaningful transmission (Keywords: knowledge, challenges, meaningful transmission) 17. Affirmation of simplified alpha wave alphabet approach, limitations acknowledgment (Keywords: simplified approach, alpha wave alphabet, limitations) 18. Reflections on potential signal detection system enhancements (Keywords: reflections, technical enhancements, signal detection system) 19. Emotional experiences during signal control task - frustration, perseverance (Keywords: emotional responses, signal control, frustration, perseverance) 20. Appreciation of gained skill - brain wave control via mental imagery (Keywords: appreciation, unique skill, controlling brain waves, mental imagery) 21. Proficiency potential improvement, mental imagery practice - learning Morse code comparison (Keywords: potential improvement, proficiency, practice, Morse code).	

APPENDIX 4: Making a brain signal communication system

This section describes the process of devising the signalling system.

Morse code was initially considered, as it has been proven to work well with humans, but it is not a binary code because there are pauses between the letters. Instead, a sort of reduced alphabet could be used, based on substituting letters that can stand for each other (such as removing C but keeping K), and a frequency table of letters in the English language (see Cornell University n.d.).

This left a new alphabet of 14 letters, approximately ordered according to frequency: E, D, A, O, I, N, S, R, H, L, W, K, M, P. As a mnemonic, one can remember all the letters by the anagram LED WORKMANSHIP.

Several letters are substituted by others, so the 14 letter limit can be reached. For example P is P, but also stands for B. Others are (in columns for clarity):

K substitutes for C, G and Q.	D is also T.
P or PH stands for F.	I is also J.
W stands also for U, V and Y.	KS (if needed) is X.
S or DS (if needed) is Z.	

There are many alternative substitutions: T could also stand for D and not the other way around, so this choice is arbitrary. The author chose these particular substitutions, simply so that the alphabet could be used to spell “hello world”, which a message that is traditionally used when first learning a programming language. In addition, abbreviations and a creative phonetic spelling can be used to make things work smoother (e.g. “ty” for thank you). Short words can also be chosen instead of long ones (e.g. “ask” instead of “inquire”).

Example: “This is like a new language, but it is readable” becomes “Dis is like a new lankwake, pat id is readaple”. At first glance it looks strange, “pat one kan soon learn id”.

Why make a minimised alphabet? It is useful to have fewer letters, because then each four bits of data can signify one letter, and even a three bit system can be made to work (this is explained below). This eases communication when sending each bit takes a lot of work, and the probability of errors is high. The fewer bits in each letter, the better. Otherwise the system would need to use five bits, significantly increasing the workload, time needed, and the possibility for error.

This can be also taken as an opportunity to use the tight constraints on the amount of data and the high probability for errors, to create a simple and economical signal system.

If one numbers the 14 letter alphabet E, D, A, O, I, N, S, R, H, L, W, K, M, P beginning with E = 1 and ending P = 14, one can write the alphabet in binary code. In this mini-alphabet “Hello” becomes 9 1 10 10 4 and in binary 1001 0001 1010 1010 0100. Every four bit sequence can signify any number between 1 and 16 (or 0 and 15 if so agreed by convention), so it can point to any letter of the 14 letter alphabet, with two bits left unused. These two extra bits can be programmed to mean for example “delete the previous erroneous letter and start again” or anything else the system may necessitate.

For saving more space and time, one could leave out letters where possible, so “hello” would become “helo” instead. Even garbled letters can be read, and the context also helps a lot, and in-groups can have their own vocabularies as well, so a sentence like “Hello, how are you?” could be conveyed even with “hi, hw r w?”

Several different brain channels and mental activities were considered as potential signals, tried out and then abandoned in the course of the study. A lot of time was spent on attempting different approaches. The description for a working solution is given below. The solution that at first gave a few satisfactory results was a combination of a mental visual image, a computer-enforced timer, and a rudimentary algorithm to set a brain wave baseline and to correct signal errors.

The actual technical setup is best explained from user perspective. The user wears an EEG headset and a set of Bluetooth earphones. The earphones are worn in order to get feedback on the user’s own brain wave level. Then they start the computer program and close their eyes. The computer initiates a sequence of detecting a visual cortex alpha brain signal, sent by the EEG headset. In this system, the person wearing the EEG headset would have to change their brain waves between two states, in order for the program to be able to understand the data as one or zero. The changing of the states would need to be consistent enough for the computer program to be able to make the judgement without too many errors. If it is decided that 1 represents the first mental state, and 0 represents the second mental state, then if order to communication “hello” as a shortened “helo”, the headset wearer would need to alternate between the two states in this order: 1001 = H, 0001 = E, 1010 = L, 0100 = O.

The alphabetical codification system with four bits was first experimented with: a four bit binary number can represent 16 values, so the shortened English alphabet (described above) can thus be used. The rate of erroneous readings with the four bit system was still too high to make it usable without example extensive signal correction algorithms, but it was possible to spell out a “Hi!” and the computer spoke it aloud with a speech synthesiser.

When trying to send signals with this mental image method, the logic was sound but the implementation difficult. It was possible to mentally spell a few letters with the binary code, but then some error in controlling the visual image or the alpha wave garbled the message. It turned out that it is difficult to calm one’s visual system down after having visualised things, perhaps a similar issue as seen by Pukkila (2019): “Really difficult to shift the thinking pattern from a concentration state of mind to a different pattern, relaxed state during a short time in one game”. After sending a “1”, it was difficult to send a “0” next: brain signals kept coming strong for a while, causing the computer to interpret the next one as a “1” as well. Therefore a short pause was added into the system after each 1 and 0 had been received, in order for the brain-visual system to get ready to send the next message clearly.

A couple of hypotheses occurred now: either this just needed more practice, in order to learn how to hold a visual image (a one) and alternate it with blankness (a zero). The other hypothesis was that adding some other brain channel to the visual one might make the signal more stable and comprehensible for the computer. For example, one could combine visuals with motor imagery: visualising vivid images while at the same combining the signal from brain signals emitted by mental images of movement. A stable and strong signal should in some way be possible to be produced and controlled as it's possible to even fly a drone with mental commands, and the software tools are available (OpenBCI 2023).

It is possible to engage in design fiction enabled by this prototype. A new, compact language could emerge, motivated by the extreme constraints of the difficulty of mental EEG control, error propensity and the simplicity of the 1 or 0 signal. Users of such a system would quickly begin to streamline the language, to reduce the possibility for errors and to make it more user friendly. Words would likely begin to be abbreviated, and the alphabet of 0001 0010 0011 would be made more convenient by rearranging the letters and agreeing of linguistic conventions, new words would be invented, or possibly the whole language system would be rearranged to suit the constraints of such minimalistic communication channel and minimal tools.

Could such a language be designed in advance? The yes and no answers experiment described in Appendix 2, Figure 18, shares some similarities with this topic. While creating a signal by blinking an eye is easier than creating an EEG signal, the logic is the same: it's a one or a zero. So communication by blinking, or in fact by anything such as tapping with hands or feet, that produces a one and zero, could be used to design the language.

This experiment forced one to radically simplify the language code and to shorten the vocabulary. There were different options: using short versions of similar words (e.g. "hi" instead of "hello"), omitting plurals ("car" instead of "cars"), choosing basic or short forms (always "is" instead of "are"), or omitting most vowels, just like some human languages are able to.

As a real world example of shortened human language, there is the compact short messaging system (SMS) language which was born out of necessity when texting with early mobile phones: ttyl, brb (talk to you later, I'll be right back). One could also choose another language than English to communicate. Korean has a writing subsystem called Jamo, which conveniently consists of just 14 characters, so these characters could be wholly be communicated in four data bits. These characters are in fact used for quick informal online communication by Koreans. Saying “thank you” 감사합니다 “kamsa hamnida” can be reduced even to just two phonemes k and s: ㄱㅅ.

Of course in English “thank you” also can be abbreviated as “ty”, but some languages have an especially large existing repertoire of abbreviations and potential for brevity. Some Tagalog and Indonesian speakers abbreviate a lot in informal online discussions. For example “Where are you”, in Indonesian “Kamu di mana” is understandable as “km dmn” or even “k dm”. In Tagalog, the same sentence is “Nasaan ka”, potentially abbreviated to “saan ka”, “san k” or even “sn k”. Spaces between words are of course a potential problem: a string of letters will become unintelligible at some point. However, one could imagine that conventions and abbreviations would quickly become established among people communicating this way.

Finally, by trial and error, and by calibrating the program, a two signal, three bit system was found to be useful for this demonstration. In this system, the computer takes two readings of the visual cortex EEG signal (o1 channel), and if both or one of the readings are below a certain threshold number (indicating high visual activity, such as imagining strong visual images), a sound signalling the result is heard, and it is recorded as a 1. If both of the readings are above the threshold number (indicating low visual activity, with eyes closed and no visual imagining taking place), it is indicated by a different sound and recorded as a 0. Each 1 and 0 is recorded sequentially. A sequence of three recordings is a three bit number, for example 001, 010 or 011. Three bits can signify any number between 1 and 8.

7 is half of the 14 letter alphabet, so it could be agreed that the system’s default setting is that it points to the first half of the alphabet (the 7 first letters). But if it receives number 8 (which is 111 in the binary system), then it switches to using the other half, in this case the letters 8 to 14 of the alphabet. In this way the 3 bit system can use the whole 14 letter alphabet and spell out full words.

The computer can be programmed to interpret the numbers as signifying a set of predetermined phrases, or letters of the alphabet. But it is not limited to that: the same binary code could also be programmed to command a home appliance, or perform some other task.

In one session, the user sent a high visual activity signal twice and a blank visual signal once in sequential order, the binary number is 110, and it corresponds to an agreed language code programmed in the computer. In this test case, the EEG headset user (participant 1) was in one room and participant 2 in another room. The brain signal number was successfully transmitted to the computer, and participant 2 heard the corresponding message spoken by the computer through a wireless loudspeaker: “Bring me coffee, please”. When the EEG user thought of another visual scene, such as geometrical shapes moving, then emptied their visual mind into a blank, then again restarted the visual scene in their mind, this was recorded as 101, and the computer spoke “How are you?” With this, the concept was proven, working both with the alphabet and the set phrases.