CHALMERS
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The EaseFit

An Interactive Sonic Design with E-textile

Master's thesis in Computer science and engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2023

MASTER'S THESIS 2023

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Master's Thesis 2023
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Cover: The figure of a prototype.

Typeset in LaTeX
Gothenburg, Sweden 2023

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Abstract

Electronic textiles (e-textiles) are an emerging trend that has been under development for years but has yet to become a common consumer product. And listening, one of humans' important sensory features, contributes to how we perceive and experience the world. Our project focuses on exploring the potential of combining e-textiles with sonic interaction to develop products that enhance the human sensory experience. Our goal is to investigate how e-textiles and sonic interaction can be utilized to provide a playful and relaxing experience for desk-workers at home.

The main goal of our project is to explore: How can e-textile and sonic interaction be used to provide a playful and relaxing experience for desk-workers at home? Using an iterative design method, we brainstormed potential applications for sonic interaction with e-textiles and chose work-from-home as our theme. We developed several prototypes that reflect our concepts and expertise. We also conducted a comprehensive evaluation of our prototypes to determine their effectiveness in delivering a playful and relaxing experience for desk-workers at home. Our project contributes to the field of e-textiles by highlighting the potential of sonic interaction and its ability to enhance human sensory experience, and by providing design strategies for future e-textile products that prioritize user experience.

Keywords: E-textile, wearable electronic, sonic interaction design, product development, iterative design, soma design, research through design.

Acknowledgements

We would like to express our deepest gratitude to our supervisor Kıvanç Tatar. His patience and kindness gave us bountiful support and encouragement throughout the thesis project. His expertise and knowledge in the field of interaction design have been a great asset to us and guided us to the successful completion of this project.

We would also like to thank Palle Dahlstedt, Kelsey Cotton and Siw Eriksson who gave us constructive feedback and suggestions throughout the process. Thanks to Sjoerd Hendriks and Johnny Hamnesjö for their software and hardware support.
We are deeply grateful for the time and effort paid by the participants of our research evaluation studies. Their contributions have been invaluable and greatly enhanced our thesis's quality.

Thank you all for your unwavering support and encouragement.

Zixi Geng & Lin Luo, Gothenburg, February 2023

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Introduction

1.1 Overview

Electronic textiles (e-textiles) involve the combination of electronics and textiles to endow "smart" functions on clothing. The ideas for e-textiles have been around for years, they have been mostly used in medical monitoring or art area. And there is still a substantial gap between the current e-textiles products to become commercial maturity. From 1997, Philips has started researching the potential of smart clothes as a commercial commodity, however, their projects ended up suspended [1]. This was a valuable attempt even though it failed. Most e-textile products are far away from daily life. To explore the benefits of using e-textile in daily life, we determined to make use of this technology for desk workers.

People are realizing the importance of taking micro-breaks for relaxation purposes. Activities like taking short naps, strolling around the working place, stretching, listening to music and daydreaming were proved to be beneficial to work efficiency. These activities can relax desk workers physically and mentally [2]. In our project, EaseFit, we aimed to design an intelligent garment using sonic interaction to create a relaxing atmosphere, which helps desk workers to balance work and rest as well as promotes a healthy and relaxed lifestyle.

The project, EaseFit, is a smart garment implementing electronic textile(e-textile) technology. It can be played as an embodied interaction product while the function of ordinary clothes remains as well.

While the e-textile discipline has explored incorporating emitting technologies into fabrics, such as embedded LEDs or other light, it has an equally historical interest in embedding audio technology [3]. Among numerous smart clothing applications, sound-related forms of interaction repeatedly appear [4]. Listening, an important sensory feature of humans, helps to construct our perceptions and experiences of the world. From Edison's phonograph, and cellphone, to this century's various sound players, such as speakers, and earphones, sonic technology has been developed to meet consumers' auditory demands. Sonic interaction can promote the functions of products, and sonic design is an essential task of product design [5]. Sound has been considered a way to convey messages, from sound-as-noise to sound-as-information [6]. In our work, we would explore the possibility of using this technology to bring health and relaxation to desk workers.

From 2020, to contain the spread of the global COVID-19 pandemic, physical distancing commands and stay-at-home orders have been applied extensively [7]. The pandemic has caused significant effects - strain, quarantine, travel restrictions, business closures and the lack of goods and materials. Under these conditions, many people suffer from depression, and their productivity and well-being are declined [8, 9]. Telecommuting and studying from home have become commonplace [7, 8]. People who work or study at home face not only potential mental challenges, they usually sit in front of their screens and maintain sustained postures for a long time with little activity. This may lead to muscle or tendon fatigue, musculoskeletal pain, asthenopia, and even nerve compression syndromes [10, 11, 12]. To alleviate these problems, microbreak, which refers to scheduled rest breaks, is often recommended [10]. Scientific microbreaks can reduce people's mental stress, improve their productivity and increase their well-being in life.

To create an interactive sonic design with e-textiles, we need to explore the following areas: The principles of sound design and how to create compelling sonic experiences; Different types of e-textiles and how they can be used to create sound; The use of microcontrollers to control the input and output system; The use of sensors to detect user input and trigger different sonic responses; The integration of e-textiles and sound design into a user-friendly, interactive system.

1.2 Aim and Research Question

The main goal of our project is to explore the following:

> *How can e-textile and sonic interaction be used to provide a playful and relaxing experience for desk-workers at home?*

Our aim is to help users to have a better work-life balance and provide a playful experience in combination with e-textile. The research will explore product concept development, wearable technology, and prototype implementation.

The aim of our project is to explore the commercial possibilities of e-textiles and sonic interaction for improving human sensory experiences, with a focus on the work-from-home context. Our project seeks to encourage body movement and enhance the mood of users, responding to the needs of those who have adapted to remote work during the pandemic. Through iterative design and evaluation, we aim to develop a practical and effective e-textile product that integrates sonic interaction for use in the home.

1.3 Contributions

Our journey began with an extensive study of the history of e-textile, with a particular focus on sonic interaction. Based on our research, we developed our unique design concept and embarked on an iterative product development process to test its feasibility. The end product was a prototype that utilized electronic sensors to capture real-time body data and translated it into sound effects that encouraged users to take microbreaks and relax their bodies.

By mapping motion to sound and leveraging the potential of e-textile, we were able to create a product that promotes wellness in the workplace. We then conducted evaluation studies to gain insights into e-textile and the best practices for developing a product utilizing this technology. Through reflection and discussion, we identified the potential benefits and drawbacks of e-textile applied to work life.

2
Background

Our objective is to create an interactive product which promotes users to take breaks and helps them enjoy their relaxing moments by introducing playfulness and interaction to break activities. This chapter describes theoretical background of our project.

2.1 E-textiles

E-textile is a rapidly growing field in wearable technology that has garnered much attention in recent years. It combines traditional textile materials with electronic components, enabling clothing and accessories to become interactive and functional. The e-textile products in the early years were produced manually and comprised of off-the-shelf portable electronic devices and a power supply, connected using cables, and sewn into pockets of existing clothing [13]. In most cases, users need to detach the portable electronics and battery, and reassemble the e-textile after washing. To improve some features in the early phase of e-textile products, such as their cumbersome nature and lack of pleasing visual and tactile qualities [14], conductive materials were introduced to be compatible with mainstream textile production processes. For most of the current eletronic textile product, the braided conductive wire acts as a cable, providing a higher level of integration than previous designs [15].

The possibilities with e-textiles are vast, ranging from monitoring vital signs, tracking physical activity, and enhancing communication. E-textile products have the potential to revolutionize the way we live our daily lives. With sensors embedded in clothes, they can detect user's heartbeat, heart rate, body temperature, and provide insights into the physical or environmental conditions. There are also sensors such as GSR (Galvanic Skin Response) and FSR (Force Sensitive Resistor) sensors which can capture important data about the body's physiological responses. For example, GSR sensors can detect changes in skin conductance caused by sweat, indicating emotional arousal. FSR sensors, on the other hand, can detect pressure and deformation on the fabric caused by body movement or environmental factors.

2.2 Soma Design

As new technologies and products continue to emerge, our lives and actions are constantly reshaped. Soma design, which refers to design related to body, is a process

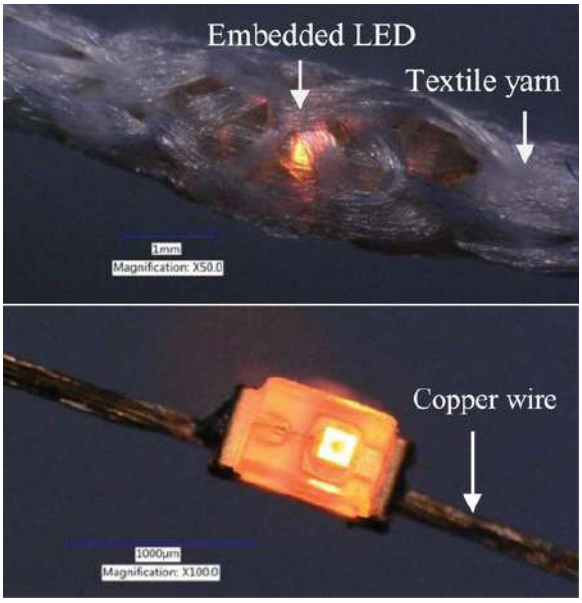


Figure 2.1: An example of e-textile

that allows designers to examine and improve on connections between sensation, feeling, emotion, subjective understanding and values [16]. There are two theoretical backdrops behind the soma design: The primacy of movement and somaesthetics.

The primacy of movement is brought out by Sheets-Johnstone who insists that movement is our primary way of understanding and being in the world [17]. From her view, it is in movement that people find "the start of cognition". The concept "somaesthetics" grounded in pragmatist philosophy and phenomenology, was originally coined by Richard Shusterman in 1996. This word compounds of "soma", the Greek word for body, and "aesthetic", meaning 'sensory perception'[18]. They both emphasize the foundational and momentous status of body and movement awareness. For designers, it's important to train aesthetic sensibilities and knowledge about bodily movement. Carrying out soma design, means designers put efforts on understanding bodies' movement and exploring the possibility of it. Soma design can guide us to understand our bodies as a design material. Through this lens, we can not only encourage bodily movements but also spur the exploration of user's bodily inquiry and inward world [19].

2.3 From User Experience Perspective

Just as Hassenzahl [20] mentioned, "Experience or User Experience is not about technology, industrial design, or interfaces. It is about creating a meaningful experience through a device" The interactive product is a particular mediator of experience. From his UX model, each user assigns some attributes to a product when using it and those attributes differ for each other. When users confront a product, the product features such as content, presentation, functionality and interaction can lead to the *apparent* product character. This character is a cognitive structure which can be categorised into two types: *pragmatic* (utility and usability) and *hedonic* [21]. This model can be helpful when conducting user experience evaluation. The author also brought out a conceptual model which distinguish designing an experience through the interaction with an object in three levels: The *Why*, *What* and *How* level. Starting from *Why* [20], the needs and emotions involved is necessary to clarified. The *What* determines the things people can do which refers to the functionality of the product. Then *How*, is to find aesthetically delight solutions to achieve previous functional requirements.

Design for experience emphasizes the importance of taking all sensory aspects into account. Products with their sensory factors would evoke specific sensations that effect user experience. It is worth mentioning that the way people experience a product is not only determined by their actual interactions with the product but begin to form before them using it. People can picture the usage image when they sense the product through touch or see or other senses, with all these impressions, they will build up anticipations and expectations for the product. In this context, this can lead to two outcomes: *congruence* or *incongruence* [22]. And each of them can result in positive or negative experiences [23]. We need to be aware of the role that individual senses play and the interdependencies between the senses. Our goal is to improve users' work-from-home experience and for our concept, auditory, visual and haptic experiences are involved.

2.4 Sound as a Medium for Interaction

Sound is ubiquitous. It is known that sound can complement, enhance or even substitute other senses [24]. Movement is usually considered to be tightly linked with sound. By way of illustration, Inge and Leman show musical gestures are expressions of music, which also embody the fundamental relationship between music and movement [25]. Movements can change according to the melody, voice quality, timbre and modality of music [26]. Meanwhile, music is influenced by movement, the amplitude and frequency of movements can affect the features of music. From perception and cognition to design and production, sound and movement can coordinate with each other to create many sparks in art and technological fields [27].

The term multimodality was introduced when discussing the coordination of sound and movement. Multimodality can be defined as the interplay between different representational modes [28]. Study of sonic interaction in multimodal environments shows that interactive sonic feedback is important when designing multimodal systems [29]. Sonic interaction design (SID) is interaction design with sound, which is an interdisciplinary topic [30]. It situated at the intersection of interaction design and sound computing, which is the exploration of sound as one of the principal channels conveying information, meaning, and aesthetic/emotional qualities in interactive contexts [31, 5]. SID addresses the difficulties of producing interactive, adaptive audio interactions that respond to one or more users' gestures in real-time. Simultaneously, SID looks at how designed movements and acoustic feedback might be used to convey emotions and engage in expressive and creative activities [5].

Conventionally, we listen and perceive sound pieces created by musicians or our surrounding. But in SID, researchers put their focus mainly on "creating intuitive and solid action-sound relationships" [32]. When it comes to SID, a closed-loop interaction is constantly brought up, it commonly exists when people interact with sound: listening to sounds may not merely activate a representation of how the sound was made but also affect the listener's manipulation or reaction.

3

Literature Review

This section is an overview of previously published research on related works in e-textile. It sets the stage for further research by giving a basic understanding of the state of the research in the field, highlighting established conclusions and methods as well as uncharted territory.

3.1 Related Works

E-textile is ideal for personalized electronic applications of its ubiquitous nature [33]. It has been applied in a range of fields such as intelligent control, personal protection, health tracking, and early warning [34]. It has also been used for artworks that create dynamic and interactive results, such as works of Nicola Woodham [35], Kate Reed [36], lab [37], Krist Kuusk and Angelina Deck [38], Ricardo O'Nascimento [39]. There are many interactive explorations of textiles in these years. In the following, we see the possibilities of e-textile interactive forms, and inspired from applications with sonic interaction.

3.1.1 For Artistic Expression and Performance

Nicola Woodham's project, named Buffer, focuses on controlling sound through e-textiles during live performances [35]. Soft circuits, which are electrical circuits made from textiles, and sensors are used as tools for experimental music performance. Similar works related to e-textiles have also been done by her mentor, Becky Stewart, who used textiles not only to interact with sound but also with light and touch [3]. One of the projects, called Flutter/Stutter, was designed to convey information through textiles by directing dancers for improvised performances using "tickle motors" on their garments. KOBAKANT's Crying Dress [40] is another example of e-textile art, which is a dress designed for funerals that can play the sound of crying.

Music can be a tool for non-language communication. For emotion expression, there is a project called Music Prosthetics [36] which is to translate different emotions such as sad, mad, glad into different sounds. For cultural communication and exchange, Pinyin is a project designed by Ricardo O'Nascimento that interactive dresses can perform the sound from Taiwanese Aboriginal Communities [39].

3.1.2 For Entertainment

From Becky Stewart mentioned above, Excuse Me Swatch [41] has a timing sensor enabling users to play games with clothes by rapidly reacting to the light changes on the textile. Another kind of application in entertainment is to play games, such as dance games and other VR, AR games, in forms of sensing gestures by e-textiles. In addition, the project John Paul George & Me from studioany [42] is a child entertainment and education interaction of e-textile and music. In this project, the garments were treated as wearable musical instruments for kids, to encourage and stimulate their musical interests as well as their collaboration with others to perform music.

3.1.3 Others

The designs and applications of e-textiles can be found in multiple areas besides the ones mentioned above. For instance, Felted Mushroom Sensors [43] is a project to make accessible contemporary electronic music practice for people with Autistic spectrum disorder. For well-being, Kristi Kuusk and Martijn ten Bhömer from the Eindhoven University of Technology created Vibe-ing [44], which is a self-care tool in the form of a garment. It allows users to feel, move, and heal through vibration therapy coming from e-textile. There are also many applications in the medical area, such as Wei and Yang studied wearable electrical stimulation to improve lymphatic function [45]. With embedded LED light, there is a research applying e-textile as an illuminated safety cycling jacket[46], see Figure3.1.

Figure 3.1: Illuminated Safety Cycling Jacket (Reproduced under the terms of the CC-BY license)

3.2 Mapping Strategies in Sonic Interaction

"Any time something is represented in a form external to itself, a mapping takes place"[47]. From perspective of developing computer music, mapping is often used in relation to algorithmic composition where a parameter is scaled or transformed to control another parameter [48]. One of the main challenges to build our project is defining the connections between user and product - constructing the sound type and sound character to fit with the product as well as interaction. The mapping can be one-to-one, one-to-many, many-to-one or even many-to-many, or can be explicitly defined or generated by some algorithm [48]. Besides these strategies from transforming gestures to synthesis model parameters, this is also studied in the field of sonification which is considered sound as a form to convey information [49].

The question we would like to explore is how to map between the motion and sound while taking advantage of e-textile for microbreak. When it comes to body performance and sound interactions, Skach and Xambó mentioned a systematic cycle between body and computer [50]. On-body part is sensor selection and placement, then these data refer to the selection of audio content for interaction as well as mapping sensor data to audio synthesis controls. A mapping chain which describes the progress from a gesture to a sound created by the synthesis model is introduced by Arfib and Couturier [51]. They dissected the process into three steps. Firstly, extracting gestures into physical data - they defined this as related-to-gesture-perception parameters. Then these data will be transformed into related-to-sound-perception parameters. Finally, the third mapping transforms previous data into synthesis model data.

The study of gesture is vast and complicated. Even the definition may differ depending on the contexts [52]. Cadoz and Wanderley [53] have done a detailed study of different types of gestures. Since the purpose of our project is to encourage people to move around and have some more relaxing activities, we decided to focus on arm movements, such as stretching, waving, and so on. For the capture of these physical gestures, the parameters given can be static or dynamic [51]. Different kinds of inputs contain different sets of values and can be interpreted continuously or discontinuously, then sound features that can be mapped with are considered while studying this along with our experiments to our sensors.

4
Methodology

The methodology for this project involved a combination of product development and iterative design, research through design, first-person design, morphological matrix, pugh matrix, prototyping, and evaluation. We employed a comprehensive approach that allowed us to gather insights, test ideas, and refine our designs based on feedback. By using these methods, we were able to create a robust development process that resulted in a final product that meets user needs and expectations. In this section, we will outline each of these methods and describe how they were used in our development process.

4.1 Product Development and Iterative Design

The product development process which follows a structured flow of activity and information flow can be a guideline for us to plan, manage and give impetus to project.

To create our product, a flexible and responsive way is to build and test prototype models iteratively and rapidly (see Figure 4.1). This highly iterative method is called a spiral product development process. It starts with these phases: planning, concept development, system-level design. In such process, design-build-test cycle can be repeated many times [54]. The process of iteratively designing artifacts is also considered a creative way of investigating what a potential future might be from the Research through Design perspective [55].

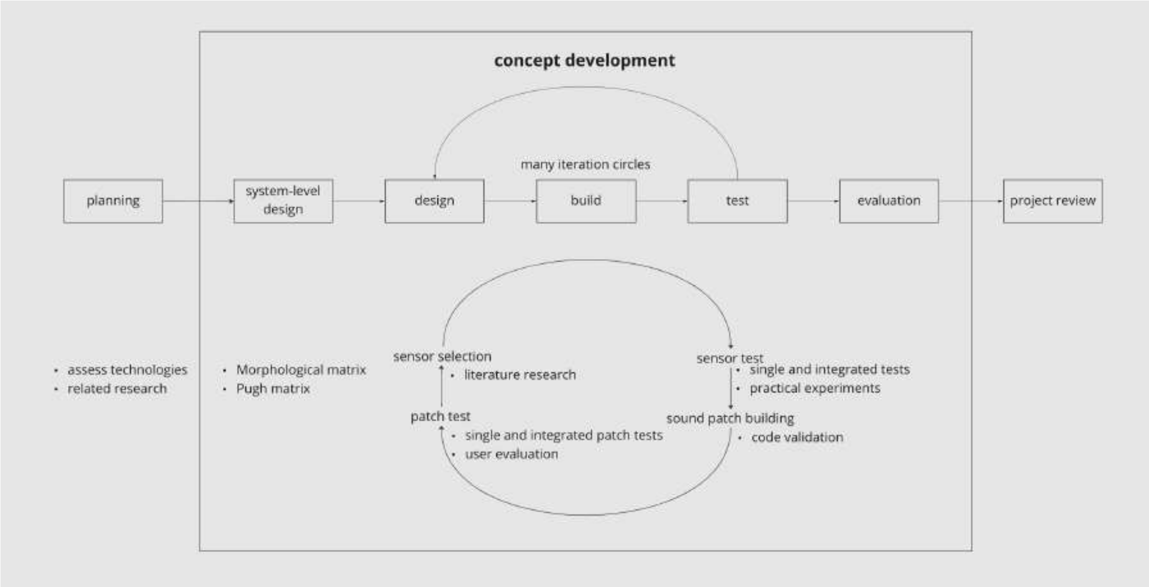


Figure 4.1: Our product development process

Iterative design can be used to assess and pinpoint interface issues, swiftly fix them, and then empirically confirm the effectiveness of the modifications. It's a rapid test-fix-test-fix approach. As soon as an issue is discovered and a clear remedy is apparent, changes to the user interface are performed. This can happen after observing just one participant or testing by designers ourselves. Then the designers would decide whether to make any modifications to the prototype before moving on to the next stage [56].

4.2 Research through Design

Design and research benefit from each other in a mutual relationship that both come with a variety of connotations. They both aim at coming up with something new building on the literature and known knowledge. Design is usually understood as creating a solution which has to fit the here and now, while research is considered the production of generalized knowledge which can be applied to other areas. Research through Design (RtD) develops through these tensions [55]. As the field of Human-Computer Interaction (HCI) has moved beyond the focus on usability, RtD has become an emerging research approach. Zimmerman, Stolterman, and Forlizzi [57] have defined RtD as "a research approach that employs methods and processes from design practice as a legitimate method of inquiry" in the near future. Stappers and Giaccardi discussed which activities are included in RtD, making use of the design process as a research tool and with the intent of generating knowledge is important [55]. It brings a perspective to understand the future and sheds light on design for the future. Through RtD, the prototype can be a provocation, not only about the artifact but also around the part of people's lives that it addresses [55].

4.3 First-person Design

Conventionally, most design method starts from a third-person perspective, designers interview the target group, observe others and bring out ideas. In comparison, the first-person approach uses the designer's own body as a resource and their own experience as a reference [58]. This is strongly based on phenomenology which is the study of structures of consciousness as experienced from the first-person point of view. "It is about how we experience" [59]. Merleau-Ponty goes into how our bodies are in this way interconnected through body language and gaze. "A soma design process relies strongly on a first-person, bodily, felt experience of digital materials and their affordances—or how properties can be shaped in materials to fit with our corporeal selves", mentioned by Höök, Friedman and Stolterman [16]. The first person design is quicker than doing user research since designers may test their ideas straight away and refine the design based on intuition and personal experience. While designers can quickly test new concepts, refine their work, and alter it depending on personal experience, first-person design also permits a more flexible design methodology. This method is also a good option to design body-centric interaction, which enables designers to empathize with users and comprehend their needs and preferences more intuitively and intimately.

4.4 Morphological Matrix

Morphological matrix is a structured methodology used in the concept generation section, it is first provided by Fritz Zwicky in the 1940s [60]. As an effective method, it allows designers to implement and integrate their knowledge of all essential interrelations to ensure interactions of knowledge in different fields. It is treated as an assistant tool to trace information with both sketches and text during the cognitive process of the concept generation session. Fritz believed that morphological matrix can make considerable progress in making effective use of the information embodied in it to eliminate human aberration, and to genuinely promote and utilise human creativity [61].

The basic format of a morphological matrix is a grid, it usually consists of several rows and columns with sub-functions and corresponding solutions. For our project, the system function and sub-functions of our design should be identified before making a morphological matrix. The matrix can also supplement with holistic thinking in terms of energy, material and information flow during implementation [62].

4.5 Pugh Matrix

Pugh matrix is a tool for evaluating discrete designs which was created by Stuart Pugh[63]. It is a method based on criteria to logically score different options[64]. The purpose of using Pugh matrix is to quickly narrow down the number of concepts and help improve the selected concepts.

To prepare the matrix, the team or individual should write down a list of criteria. In this stage, criteria encompass 5 to 10 dimensions and are expressed with relatively high abstraction. The team should select one concept as the benchmark or reference concept against which all the other concepts are rated. A scoring standard that“better than”(+), “same as”(0), “worse than”(-) used to score each cell of the matrix should be established by team consensus. After rating all the concepts, the team should sum up with scores of each concept and rank-order the concepts. Once the team members have a solid grasp of each concept and its relative quality, they determine which concepts require further clarification and analysis. Based on previous processes, the team is likely to have a good sense of which concepts have the most potential [54].

4.6 Prototyping

The prototype - the embodied, materialized concept design, plays an essential role in Research through Design [55]. The prototype gives direction to the research and helps with reflection and exploration. The building process is set up into the following steps: First, collecting gesture data directly through sensors and transducers. Secondly, to map between the sensor outputs and the sound, a microprocessor is needed. Finally, exploring how these different components work together and how to integrate them to the textile.

4.6.1 Exploring E-textile

To build a functional prototype, the integration of sensors and actuators into the textile must be considered. There are various methods of embedding electronics into the fabric. We can make use of the conductive fibers or treated conductive fibers. Besides, conductive fabrics can be produced by several methods. One is by integrating conductive yarns in a textile. Another method is to use conductive ink, which is made from water and conductive metal, which can then be printed on textiles [65].

When creating a wearable electronic clothes, material selection is a significant topic. For conductive materials used in e-textile area, conductive fabric and yarn are widely used. There are a lot of different types of conductive threads. They are mostly embedded with silver or stainless steel [66]. When it comes to dealing with conductive threads, some trade-off decisions need to be made. Silver-coated threads are nylon-based threads coated with silver. They are quite similar to the common thread, easy to use, flexible and thin, but the resistance of silver threads are relatively large. Stainless steel wires have good electrical conductivity and corrosion resistance. However, they are not as easy to handle as regular cotton wires. Due to the metal content, they are a bit bulky and tend to get tangled. Also slippery and hard to tie [67].

4.6.2 Audio Programming Environment

For the purpose of generating interactive computer music and interactive artworks, Miller Puckette created Pure Data (Pd)[1] in the 1990s. It is a visual signal programming language which has been widely used for sound design. It provides a great collection of interfacing objects which enable us to create interactive work and is excellent for audio signal processing. It uses a GUI framework and DSP environment programming in the form of dataflow, as data flows along the connections and then process through objects. One process's output feeds into another process's input, and there may be many steps in the flow. In Pd, objects can be created and connected in a visual environment, so there is no need to write code to construct complicated digital audio projects when . This enables very quick program prototyping for interactive audio, live effects, and synthesis. This programming language is used as our tool to design sounds and create interaction.

As mentioned before, in the Methods phase, part of our mission is to find a way to synthesis our sounds. There are synthesis such as piecewise, addictive, wavetables, subtractive, nonlinear, granular and physical [68] which overlap and function differently. Selecting appropriate methods to build our sounds is significant to our project.

4.6.3 Computing Platform

A microcontroller development board is basically a printed circuit board (PCB) with circuitry and hardware on board to facilitate experimentation with certain features. These development boards facilitate us to connect sensors and actuators. We chose Bela mini[2] as our microcontroller kit (see Figire 4.2) since it brings the platform for creating responsive interactive sound-relative project and enables the easy connection of sensors to the sound-producing software we prefer to use.

Bela uses the libPd library which turns Pd into an embeddable library. This Linux library allows Pd's core DSP functionality to run on the board (see Figure 4.3). Although Pd patch cannot be edited in Bela's IDE, it's feasible to create Pd patches on computer then upload them to Bela. The processes of functioning are:

- Create and edit Pd patch on laptop;
- Upload and run the patch through IDE (see Figure 4.4) to Bela;
- To modify the patch, edit on laptop and repeat the process.

In Pd, The [adc∼] and [dac∼] objects refers to the audio inputs and outputs. On Bela, connecting to [dac∼ 1 2] is to send audio to the stereo output and [adc∼ 1 2] is to access the stereo audio input. At the same time, the [adc∼] and [dac∼ objects can be used to receive and send analog data since Bela's analog inputs and outputs can be treated like audio signals. Digital I/O on the Bela can be read at either a message rate or an audio rate and function in one of two states (HIGH or

[1] `https://puredata.info/`
[2] `https://bela.io/`

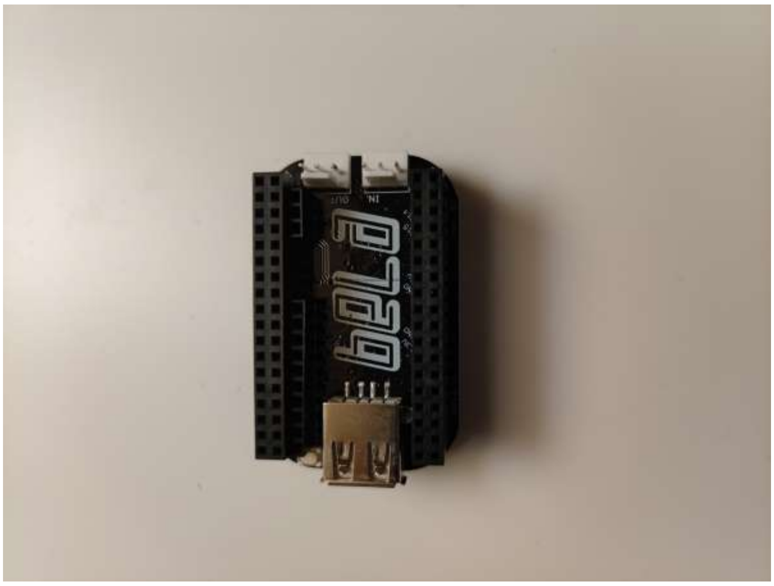


Figure 4.2: Bela mini

LOW). Each digital pin can serve as both an input or an output which needs to be explicitly set in the patch. Each digital pin on Bela refer to a number in Pd. Sending messages to [bela setDigital] to initialized the digital I/O pins. Programming for sonic interaction incorporated sound synthesis theory to enable interactions between gestures and sound.

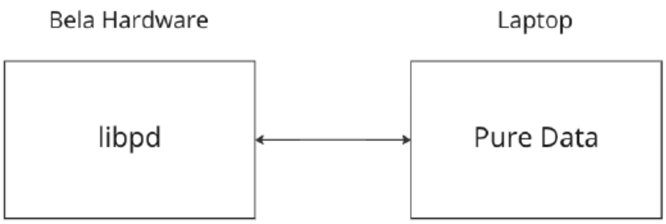


Figure 4.3: The details of how Bela and Pure Data relate

4.7 Evaluation

While the designers trying to manufacture specific character for their customers, there is no guarantee that users will perceive the product the way designers intended it to be perceived [21]. To make different sounds combined harmoniously is challenging and crucial to test. The interactive products usually have user-focused evaluation [69]. A user experience design is iterative. For this project, we evaluated from the perspective of ourselves and users.

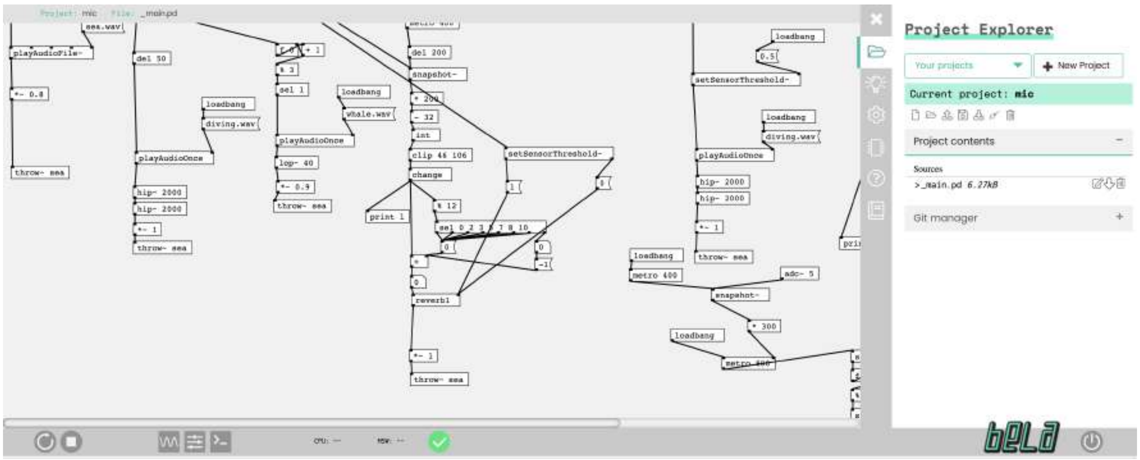


Figure 4.4: IDE in Bela

Within the research through design field, embracing First-person method is a good way to evaluate the project. First-person research involved data collection and experiences from the researcher themselves [70], through which researcher inquiry senses and experiences from his/her perspective. Testing how our product works, the simplest way is to try it on by ourselves for a day. In our project, one of the designers wore the product for a day when she was working at home and used a Journey Map to record her feelings. Journey Map is a useful tool in service design and UX design field which focusing on a diachronic outline of a user's experience with a product over time. It depicts major changes in the user's needs and mood, levels of product satisfaction, or other usage metrics over the course of the user experience [71].

From the sonic interaction design point of view, the designer must determine how the sound affects the user's interaction with the interface in order to assess the success of a sonically enhanced interactive interface [5]. The authors emphasized that users' ability to successfully adjust their gestures and movements is more crucial in closed-loop sonic interactions than their conscious awareness of the information. Strict engineering standards and formal listening tests are no longer valid in SID and should be replaced with more exploratory design and evaluation principles.

For users' experience evaluation, to test if users find the design attractive and intriguing, we turned to a method in UX area [72]. AttrakDiff facilitates the anonymous assessment of a chosen product by customers, users, etc. The evaluation data allows us to gauge whether optimization is required and how users perceive the product's attractiveness in terms of usability and appearance. Both the hedonic and pragmatic aspects of user experience are examined using semantic differentials in the AttrakDiff questionnaire. A basic version (free – limited to 20 subjects) of AttrakDiff is available online . The questionnare we used is shown in Appendix A.1.

5 Design Phase I: Preconceptualization

In this chapter, we look back upon the time before we identified our research question and explain how we doped out the topic of design for work-from-home. We began from brainstorming surrounded e-textile. After some extension and elimination, we had a brief topic and started drawing up a plan. Then a subsequent concept crystallized is proceed. We looked for several methods such as the Morphological matrix and Pugh matrix to help us brainstorm different solutions and combinations. This assisted us to consider more diversely and divergently, meanwhile, lent a hand to our decision-making.

5.1 Ideation

When we first conceptualized our project, we were eager to create a wearable device using e-textile technology with sonic interaction capabilities. While visual interactive design has been explored extensively, we were interested in exploring the auditory system's potential for wearable technology. Research shows that the auditory system requires less energy to process information compared to the visual system, making it an efficient mode of interaction. Additionally, e-textile technology's seamless integration with textiles allows for subtle and elegant designs, which has piqued the interest of artists and technology enthusiasts alike, including our team.

As we explored the possibilities of combining e-textile and sonic interaction technology, we faced the challenge of determining what kind of wearable product could best showcase their potential. To generate ideas, we engaged in a sound travelogue exercise, allowing us to think freely and in multiple directions. Our brainstorming sessions led us to consider different using scenarios and functions, from home usage to art exhibition. Ultimately, we selected a design that incorporated both technologies in a harmonious way, while also promoting ease of use and user engagement.
From Figure 5.1, the concept generation started with the discussion of different usage scenarios, to be used outside, at home, or as an art piece for the exhibition. To use outside, the first concept is a product that can deliver personal moods and senses as physical social media. Another idea is to detect and record the body data of users, especially when they exercise. When the using scenario change to be at home, ideas are mostly focused on home entertainment and relaxation, the e-textile

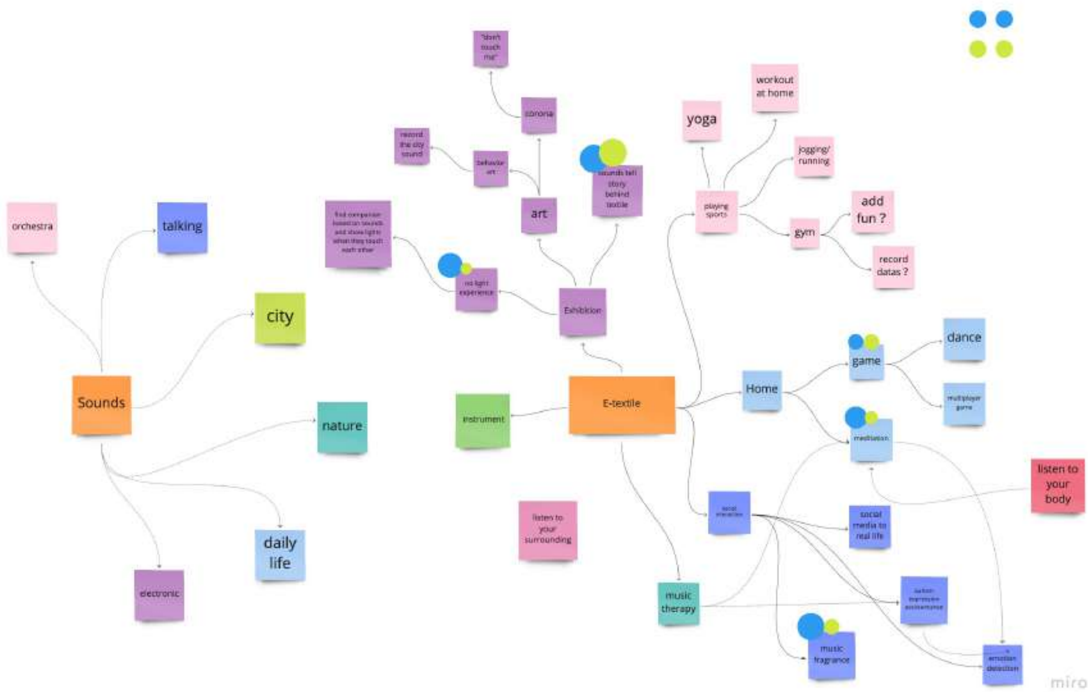


Figure 5.1: Design concepts brainstorming

can transform body data to sound, to composite the unique sound of the body.

5.2 Concept Evaluation

5.2.1 Elimination Matrix

When the concept generation was done, the first step of concept evaluation is to remove disqualified concepts. After literature review and information searching, we found that most e-textile products were designed to express and deliver the artists' own perceptions and feelings, or sometimes for specific purposes, such as live performance and medical therapy. Our goal is to design a product that integrate e-textile into the daily lives of ordinary people, and benefit more from e-textile technology. As a result, the concepts related to the exhibition scenario were eliminated (see Figure 5.2).

Regarding social interaction design, it was eliminated for a similar reason. Usually, to express personality requests unorthodox design, which seems to be designed for the Avant-Garde, a group of people who are experimental, radical and unorthodox, especially in the art field. Or, in another theme, a social interaction concept works as an assistant tool for the Autism to communicate with others and accept some music therapy. Since these kinds of designs would be contrary to the intention to design a product more friendly to all people, this category was eliminated (see Figure 5.3).

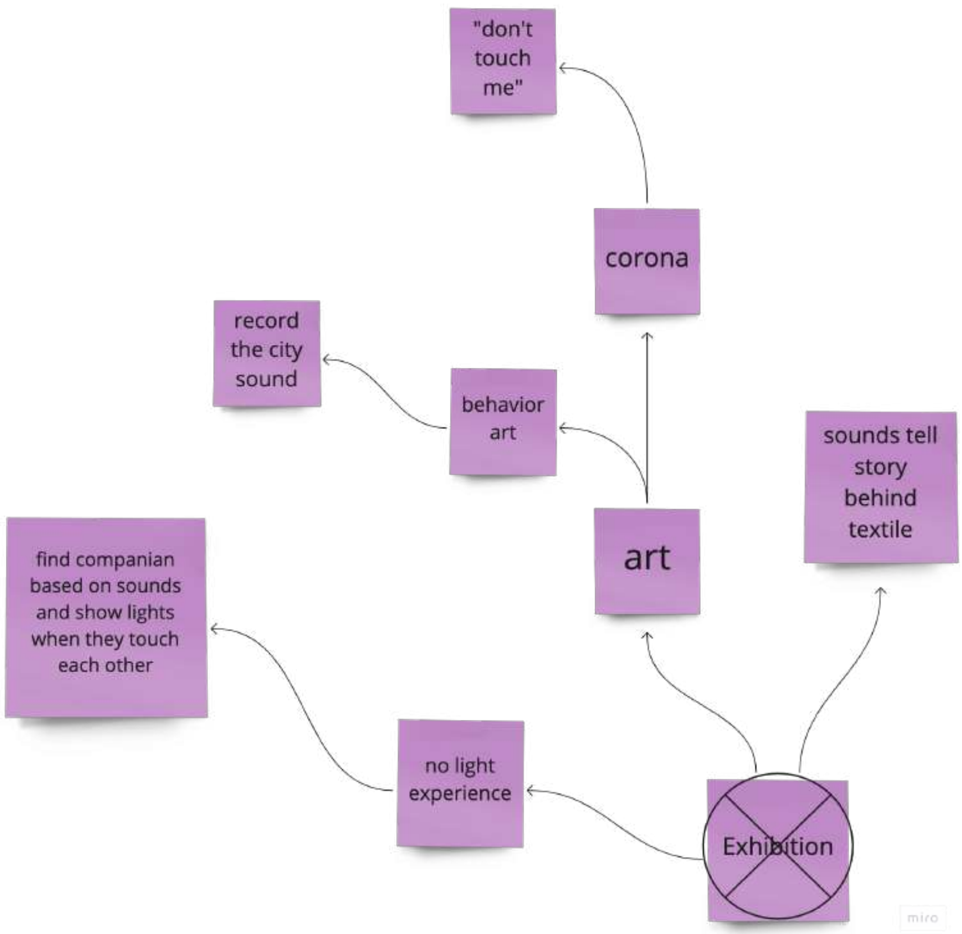


Figure 5.2: Elimination for exhibition ideas

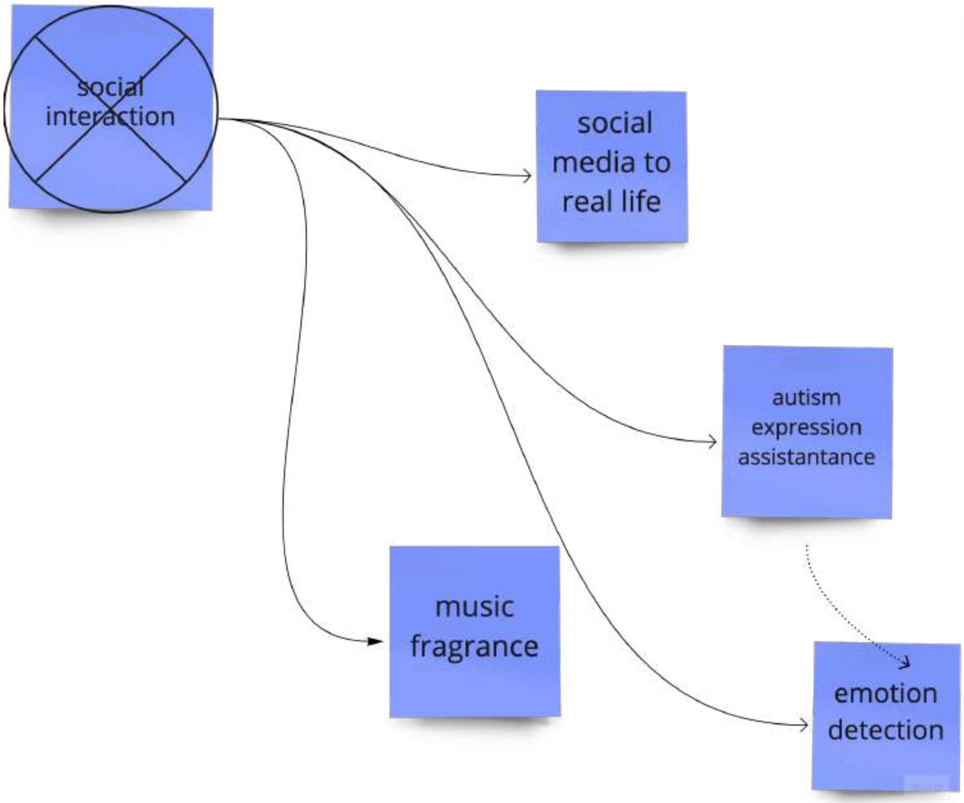


Figure 5.3: Elimination for social interaction ideas

The preliminary concepts were sorted into two categories, out-of-home and at-home. The out-of-home concepts included Jogging, Doing Sports and Listening to the Surrounding three themes. The at-home concepts included Home Gaming, Instrument Player, Work Assistant, and Music Therapy four themes. For different concepts, different functions are required for different needs and aims. Considering functions that different themes should achieve, several function trees were generated to figure out the sub-functions. The initial concepts were sorted in a table shown in Figure 5.1.

Initial Concepts										
Concepts	Subfunctions									
	1	2	3	4	5	6	7	8	9	10
	Motion Detect	Body Data	Environment Data	Audio Output	Audio Input	Signal Transmission	Other Interactions	Timer	Control Pannel	SOC
Out of home										
Jogging	☑	☑	☑	☑	☐	☑	☑	☑	☐	☑
Sports	☑	☑	☑	☑	☐	☑	☐	☐	☐	☑
Listen to Surrounding	☐	☐	☑	☑	☑	☑	☐	☐	☐	☑
At Home										
Home Gaming	☑	☑	☐	☑	☐	☑	☑	☐	☑	☑
Instrument Player	☐	☐	☐	☑	☐	☑	☐	☐	☑	☑
Work at Home	☑	☐	☐	☑	☐	☑	☐	☑	☑	☑
Music Therapy	☐	☑	☑	☑	☐	☑	☐	☑	☐	☑

Table 5.1: Table of initial concepts

With the help of Elimination Matrix (Figure 5.2), we compared different concepts considering 4 aspects: Whether it is a benefit to use e-textile; whether it is a merit to have sonic interaction; whether it will contribute to corresponding research field; whether there are available resources to refer. The chosen option of Elimination Matrix was Work at Home concept.

Elimination Matrix						
Solution alternative	Using e-textile is preferred	Having sonic interaction is merit	Contribution to research field	Resource availibility	(+) Fulfills criteria (-) Do not fulfill criteria (?) More info needed Continue Remove Test Comment	Decision
Themes						
Jogging	+	+	-		E-textile can be designed as sweat wristband/ Sonic interaction maybe a merit/ The application in this field has been relatively mature.	
Sports	+	+	-		- similar as above.	
Listen to Surrounding	-				Other types of equipment could be more convenient and precise.	
Home Gaming	+	+	-		A mature market already exists.	
Instrument Player	+	+	?	+	Hard to innovate.	
Work at Home	+	+	+	+		
Music Therapy	+	+	+	?	Mental therapy could be a totally new field to us.	

Table 5.2: Elimination matrix

5.3 Time Plan

After determining the topic, we started by making a plan for the following process. We also carried out some deeper study towards specific technologies such as sensors and conductive materials.

In order to draw out a suitable time plan for us to perform, our workload is divided into four phases: preconceptualization, design and iteration, evaluation, and project display. We started by doing user study and learning the technology. Then we focused on testing different sensors and mapping. With these technical tests, we can find out what we are capable of and what kinds of interactions we find attractive. Centering around the interactions we would like to create, we moved on to our vital part - prototyping. We progressed iteratively to our prototype building followed the product development structure. The time plan is shown in Appendix A.1.

5.4 Concept Theme Determination

Inspired by some home entertainment equipment, relaxing themes concepts and combining our personal experience during the pandemic, we determined the theme of home use. Our product is designed to assist desk workers when they are working or studying at home. We named the design EaseFit.

During our break time, it's suggested not to choose playing with phones or video games. Such activities provide instant gratification and make it difficult for people to enjoy the next moment of focus. Instead, activities that allow our minds to relax and unwind, such as gazing into the distance, listening to music, meditating, and so on are recommended.

Our vision is to design a garment that reminds and attracts desk workers to take regular breaks and move their bodies without staring screen. The following was the scenario we imagined in this phase: Users can turn on the product when they feel like they want to take a break. During the interval, the wearable interface aims to encourage movement through playful sonic interaction. The sensors integrated into clothes capture the user's movement, and a feature space will be defined based on the input data. These data are translated into different sound effects, which provide a delightful experience. As a sonic interaction design, movement detection, processor, and audio output would be included so that interaction between user and garment can be built up. Different gestures trigger different sounds, and while the user moving or stretching, the factors of the sounds, such as the tempo, pitch, or timbre, would change.

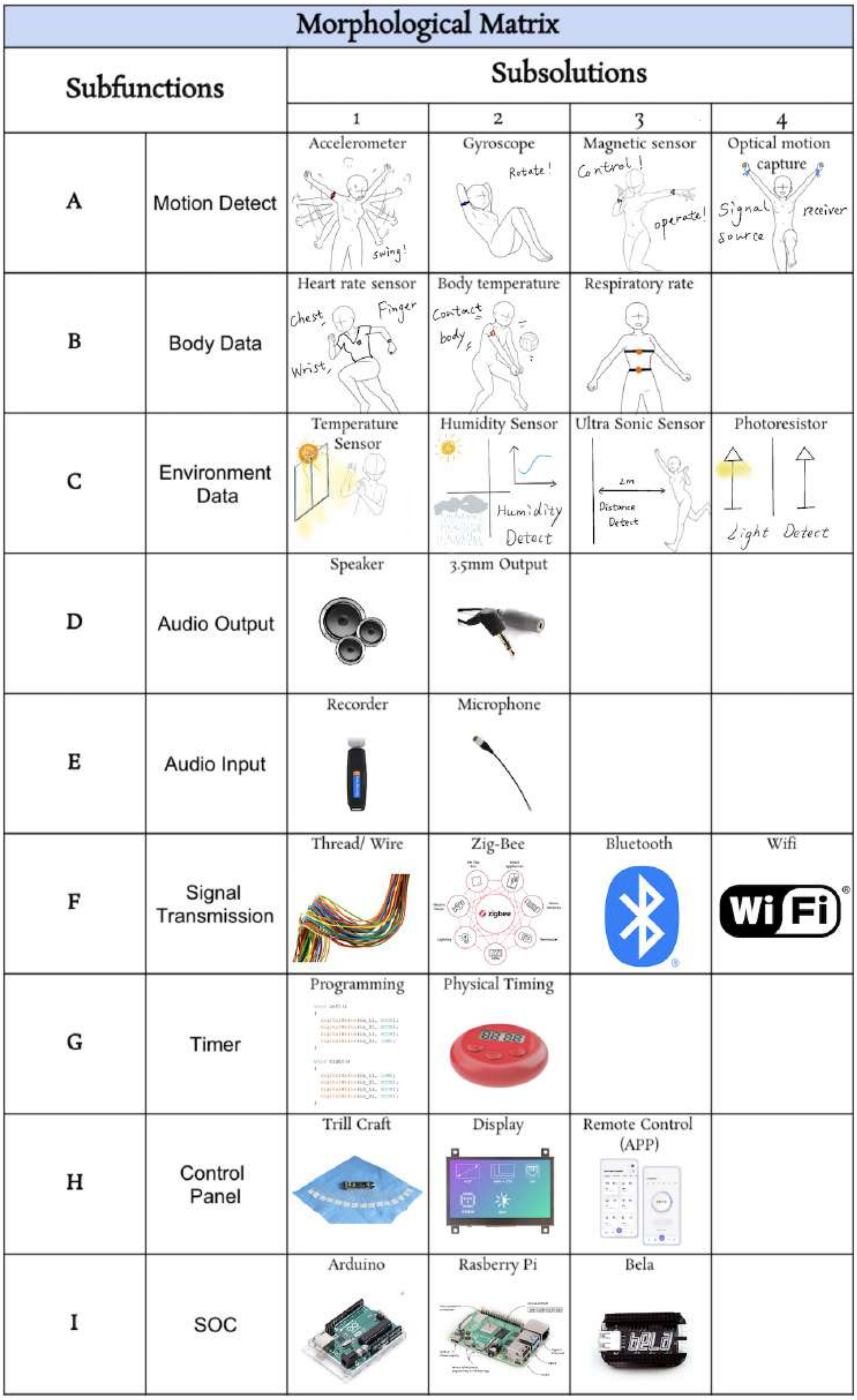
5.4.1 Morphological Matrix

E-textile technology has evolved alongside the development of electronic technology and material science. Studying and testing different electronic components are vital as the beginning steps. Nowadays, sensor and actuator technologies have reached an adequate level of feasibility, affordability and miniaturization, which collect and transfer data efficiently and can be applied to various conditions.

When using sensors, there are both conceptual and technical considerations [66]. There are some aspects we would look into when selecting sensors: Firstly, the connection type. According to different manufacturers and expected usage, sensors may have male or female plugs, may be pins, JST connectors, or terminals. Some sensors have small holes which enable us to sew them on clothes. Secondly, the shape, size, and weight of the sensor are crucial, these factors would affect our choice and placement of the sensors. Lastly, the sensor's output signal type and transmission path, need to be studied combined with the microprocessor. There are a variety of sensors for wearable technology which are accessible and optional, such as touch sensor, pressure sensor, step sensor, movement sensor, heartbeat sensor, etc. [65, 73]. The final elements are selected by experiencing and evaluating different kinds of sensors.

Then we need to consider the positions they should be placed in to ensure that they are safe, harmless, comfortable for the wearers and cannot break easily.

To assemble the concept with solutions that fulfil the required functions, we made a morphological graph (see Table 5.3).



Morphological Matrix					
Subfunctions		Subsolutions			
		1	2	3	4
A	Motion Detect	Accelerometer	Gyroscope	Magnetic sensor	Optical motion capture
B	Body Data	Heart rate sensor	Body temperature	Respiratory rate	
C	Environment Data	Temperature Sensor	Humidity Sensor	Ultra Sonic Sensor	Photoresistor
D	Audio Output	Speaker	3.5mm Output		
E	Audio Input	Recorder	Microphone		
F	Signal Transmission	Thread/ Wire	Zig-Bee	Bluetooth	Wifi
G	Timer	Programming	Physical Timing		
H	Control Panel	Trill Craft	Display	Remote Control (APP)	
I	SOC	Arduino	Rasberry Pi	Bela	

Table 5.3: Morphological graph

As the morphological graph listed, four alternatives are mostly used in the current designs and products to capture the user movement. There are inertial methods using sensors like accelerometer and gyroscope sensor, and magnetic sensors; and optical motion capture method, which includes a camera and optical signs.

Concerning body condition sensors, our original idea was to provide different sonic scenarios of interaction according to varied body conditions. For example, a user with a high heartbeat and respiratory rate would be given a soothing and relaxing sonic interaction. And the sonic mode would turn out to be more energetic when the heartbeat rate was low. Heart rate, body temperature and breathing rate can be collected for the function of body condition detection. Different types of data can embody multiple physical and psychological conditions of humans.

And environment data were also included to enrich the interaction design. For example, ultrasonic sensor and photoresistors can be explored for interaction in dark environments. Imagine that you are working late in the evening, the light is off, you listen to the ambience, and every step may trigger different sound effects. Choices like temperature sensor, humidity sensor, ultrasonic sensor (detect distance), and photoresistor(whose resistance varied by the change of light) were listed.

We can choose between speakers and a 3.5mm output port to output the audio. Speaker refers to the self-assembled speaker components, and a 3.5mm output port can connect to numerous commercial acoustic products. A recorder or a microphone could fulfil the audio input function. This input can be used as a way to operate and activate a certain function, or it can work as a way to enrich the form of interaction, with the program being able to morph the input sound into a new form of presentation.

Signal transactions through thread/wire or different IEEE communication protocols, such as Zigbee, Bluetooth and WiFi, were also thoroughly considered. Besides, we also want the timing function as a reminder during work, and choices include a programming timer and a physical timer.

To control the wearable equipment, except for the interaction between the body and the product, we need an area on the equipment or an additional object to control and adjust the product accurately. A switch is a device that allows, blocks or diverts electrical current and can come in a wide variety of forms. On garments, there are choices like simple buttons to switch between different functions, or embedding a touchable display to be visible assistance. An app on user's smart devices was also considered to be more intelligent to remote control the equipment.

To fulfil all the functions, the input data collected from the body, environment and so on should be processed as output data. The processor usually points to different SOCs (systems on a chip). We decided to compare the processor among Arduino, Raspberry Pi and Bela.

5.4.2 Combination

According to the Morphological graph, sub-functions can be addressed by sub-solutions, which give Work-from-home concept choices for combinations. We have determined what types of sensors we would like to use. And in this phase, we needed to find a way to integrate all the electronic components. A table with five combinations of sub-solutions was completed (see Table 5.4), where each combination was chosen from multiple sub-solutions combinations to fulfil the functions of the theme working from home.

Concepts List	A	B	C	D	E	F	G	H	I
	Motion Detect	Body Data	Environment Data	Audio Output	Audio Input	Signal Transmission	Timer	Control Panel	SOC
Work from Home									
Pure 1	A1			D1		F1	G1	H1	I3
Pure 2	A1,A2	B1		D2		F1	G2	H1	I3
Joyful 1	A1	B1	C1, C2	D2		F1	G1	H2	I1
Joyful 2	A3	B2	C3,C4	D1	E1	F3	G1	H3	I1
Joyful 3	A4	B3	C3,C4	D2	E2	F4	G1	H3	I2

Table 5.4: Concepts list

5.4.3 Pugh Matrix

As we mentioned before, our garment should meet various demands. Besides, there are three detailed requirements regarding the design vision. Pugh Matrix was introduced as an elimination tool to screen all these combinations. There are several criteria to evaluate the different aspects of all the combinations.

The component selection criteria were divided into two main sections, data quality and resource availability. Data quality can be categorized into validity, reliability, and relevance. Validity here can be loosely described as readable information that can help analyze the body and environmental conditions. Reliability indicates the data accuracy, integrity, consistency, completeness, and auditability.
Relevance refers to suitability with the theme of Work from Home. To fulfil this theme, three more aspects need to be specified:

- The design should be simplified at most, reduce redundant functions and only necessary functions remain so that users can explore more play modes themselves;
- the product should also be designed to rest eyes since desk workers might have eyes overuse issues;
- The product should independently realize all the functions without other devices' cooperation.

Turning to resource availability, physical resources and learning materials were both considered. Physical resources include electronic components and accessories. Learning materials include accessible research material and Forums and tutorials, data sheets and product descriptions provided by the manufacturers.

In this step, we scored the items mainly by doing literature research to ensure we have a holistic understanding with respect to different concepts. The following is the detail of scoring for different functions.

To score the motion detection solution, we evaluated the validity and reliability of the data that the sub-solutions provided. As one of the choices, the accelerometer measures the change of acceleration of 3 different axes. The acceleration is measured by force acting on its internal, and then the acceleration is used to determine in which direction the person is moving or the approximate frequency. Since it is an inertial-frame sensor, it may have gravity influence as noise during data generation. The accelerometer can capture most movements during test with relatively high accuracy and consistency.

Gyroscope is another solution which senses the angular velocity of its rotation. The rotation of wrists and arms rarely occurs when relaxing bodies. Given how it works, we believed its data might be less relevant to our concept when using it as a motion detection sensor.

For magnetic sensor, also called a magnetometer, is a magnetic field sensor. It can sense the Earth's magnetic field when there is no strong magnetic field nearby. As mentioned, the magnetic sensor is very sensitive to external influences. Like anything slightly magnetized on the side, it can even be affected by other things inside the device. Since we may have speakers embedded into the garment, magnetic fields will be affected by electricity. The magnetic sensor may not be an appropriate choice.

As for optical motion capture, no matter whether passive optical motion capture or active optical motion capture, a camera is always required. Regarding one of our design visions that the product should be able to work independently, this solution is less relevant to our theme

For heart beat rate sensor, it uses a technique called photoplethysmography (PPG), which shines light into the skin, collects the different amounts of light refracted by changes in blood flow, and measures blood perfusion in the dermis and subcutaneous tissue (different layers of skin) to detect. As for its working principle, this sensor will give inaccurate results when the user moves. So it may be inappropriate to our concept but deserves to be explored more in the practical test as a part of the assignment mechanism.

Taking "Working from Home" theme into consideration, body temperature and respiratory rate have little relevance to work and relaxation, as well as environmental data like temperature and humidity. We imagined that distance and light could be joyful data applied in the exploration of the dark environment. This idea is away from the theme that some functions would be redundant.

For audio output, if we choose 3.5mm output, it needs cooperation with other devices like headphones and Bluetooth speakers. This solution disobeys the vision of independent product design, but considering sound quality, this subsolution remains to be tested and revised.

Regarding Signal Transmission, Timer and Control Panel, most solutions need other equipment or devices to control and transfer instructions. Zigbee, Bluetooth, WiFi and Remote Control have the need for cooperation with other equipment, which is not the best choice referring to the vision of design. As for the physical timer, its function can be realised by the microprocessors listed in the Morphological Matrix. And for display, more screen use would affect the relaxing of eyes.

Arduino, Raspberry Pi and Bela are all with mature technology, and there are plenty of literature resources and physical resources. While we were going to design an e-textile product with sonic interaction, Bela has a more friendly integrated environment to work with Pure Data.

Considering the above, the Pugh Matrix was scored and shown in Figure 5.5. The concept Pure 2 was decided to use Bela as a processor instead of Raspberry Pi.

Pugh Matrix					
Criteria	**Alternative**				
Data Quality / Resource Availability	Pure 1	Pure 2	Joyful 1 (Reference)	Joyful 2	Joyful 3
Validity	+	0	0	-	-
Accuracy	0	0	0	0	+
Consistency	+	0	0	0	+
Completeness	+	0	0	0	+
Relevance	+	+	0	-	-
Physical Resources	+	+	0	0	-
Learning Materials	+	0	0	0	0
$\Sigma +$	6	2	0	0	3
$\Sigma -$	0	0	0	2	3
$\Sigma 0$	1	5	7	5	1
Total	6	2	0	−2	0
Further Development	YES	Revise	NO	NO	NO
Contents	Accelerometer, Speakers, Thread/Wire, Programming timer, Trill Craft, Bela	Accelerometer and Gyroscope, Heart Rate Sensor, 3.5mm output, Thread/Wire, Physical Timer, Trill Craft, Raspberry Pi	Accelerometer, Heart Rate Sensor, Temperature Sensor and Humidity Sensor, 3.5mm output, Thread/Wire, Timer Programming, Display, Arduino	Magnetic Sensor, Body Temperature, Ultra Sonic Sensor and Photoresitor, Speaker, Recorder, Blue tooth, Timer Programming, Remote Control (App), Arduino	Optical Motion Capture, Respiratory Rate Sensor, Ultra Sonic Sensor and Photoresitor, 3.5mm output, Microphone, Wifi, Timer Programming, Remote Control (App), Raspberry Pi

Table 5.5: Pugh matrix

6

Design Phase II: Soma Design

In this chapter, we explain how we follow through with our iterative design progress and start to build our prototype. During this phase, we purchased some conductive threads, electronic kits and searched for components that were readily available, then experimented with them openly. At the same time, we began to learn the theory and method of sound synthesis in Pure data and explored diverse algorithms and patches. Then we tried to map between the sensors with the microcontroller.

6.1 Practical Tests and Analysis

We first conducted tests of different components to develop the selected concepts further. We have tried the following sensors to connect with Bela: Accelerometer, Gyroscope, Heart rate sensor, trill craft and trill flex sensor. Speakers and different types of wire or conductive material were also tested during this phase.

6.1.1 Sensor Preparation and Comparison

For movement detection, two kinds of sensors were tested, accelerometer (Figure 6.1a) and gyroscope (Figure 6.1b). We first conducted sensor tests by wearing them on different parts of our bodies. We placed each sensor on wrist, arms, back and waist to see the changes of the input data. We found that the most frequent movements that occurred were raising arms when we wanted to stretch out, and accelerometer caught more different data when we tried to relax our bodies. During tests, the gyroscope sensor created less valuable data than the accelerometer, which means there were less movements detected by gyroscope. To avoid input interference, we chose accelerometer as the only sensor for movement detection and placed them on each arm.

While we were doing the test of the heartbeat sensor, we found that the data of the heartbeat would be affected when it is moving. It became less accurate when it was in motion. Since it was unavoidable to be moving, the heartbeat sensor was taken out of consideration.

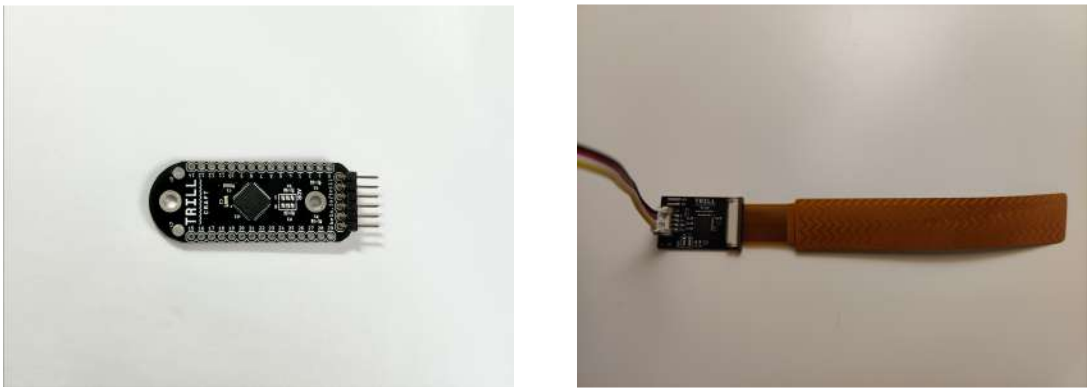
Data from trill sensors are a bit more complicated, we have tested two kinds of trill sensors, Trill Flex and Trill Craft. The Trill Craft is a touch sensor that can be extended, see Figure 6.2a. We tested it with fingers, wires and conductive threads separately, the trill craft sensed the touches very fast through any of them. There

(a) Accelerometer sensor

(b) Gyroscope sensor

Figure 6.1: Motion sensors

are 30 channels on the trill craft board, which can be assigned to control different tasks. It was selected to be further explored in the following sections. Trill Flex sensors (Figure 6.2b) can not only detect the position where it's being touched but also a bit of “pressure”. Since they would keep track of the change in capacitance, instead of measuring the actual force of the sensor it is more the contacted area that is measured, which is called Touch Size. This is similar to the force used by your fingers, when you lightly press your fingers and the contact area of the object will be smaller, but when you press hard, the contact area will be increased.



(a) Trill Craft sensor

(b) Trill Flex sensor

Figure 6.2: Trill sensors

After experimenting with those sensors separately, we sought for the possibility to make them connected. To achieve this, we decided to use the Trill craft sensor as an additional touch interaction module. By choosing different channels from the thrill craft sensor, it can switch mapping mode from Pure Data (Pd). This also made it possible to use the same sensors to generate different sounds.

In terms of sensor selection from a conceptual standpoint, we concluded that the accelerometer sensor was the optimal choice for our project. This sensor was selected due to its ability to detect and record a wide range of body movements, providing variable data that could be utilized in our design. The Trill craft can be used as an additional touch interaction module which enable the product invoke different channels in Bela and won't be in conflict with each other.

After determining our main components, some experiments surrounding the accelerometer sensor were conducted. We placed the accelerometer sensor at different positions on the body by using tape to inquire into the range of data changes and the actions people do when the sensor is in the corresponding position. We had decided to make a top, so we taped the sensors on different parts of our upper body: near our wrists, upper arms, back and waist. Then our movements and the corresponding parameter changes are recorded by a video camera and screen recording.

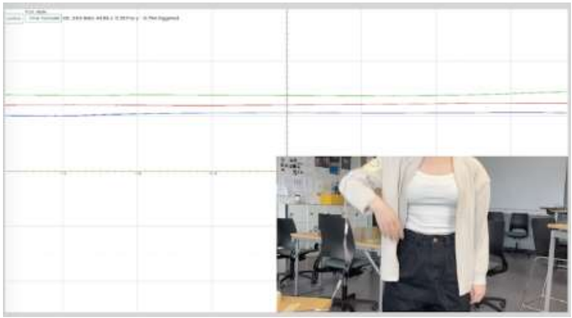
It's natural that we tended to move the body part where the sensor is located to stimulate the sensor to obtain more variable feedback and data. When the sensor is on our arm, we would raise our hands or wave our arms more often. While it is on our back or waist, it can spur us to do more body twisting. And the accelerometer sensor can collect data from three dimensions-x, y, z, we also took the chance to observe the data variability through our motions 6.3. We decided to start with the most simple and straightforward way, putting sensors on the arms was considered our first choice. Arm movements can have many variations, while the movement of the body can also easily affect the speed of the arm thus changing the data. And we are going to use 2 accelerometer sensors for each arm. When it comes to choosing which dimension from the accelerometer sensor we would like to collect, we have come out with four options:

- Choose one dimension for each accelerometer sensor that is related to the maximum range movement of the arms and can have the largest scale variety.
- Choose more dimensions for each arm which can generate more varying interactions.
- Merge different dimensions from one accelerometer sensor into one channel, this enables us to capture arm movements in every dimension.
- Combine data from two accelerometer sensors into one control input, for instance, the x-dimension movement data of both arms are merged into one control input. After some tests, we decided to build prototype from the simplest way, so we selected the first option and choose the y-dimension as our controlled input.

As a selection to proceed with the following prototype and research, we chose the electronic components listed in Table 6.1.

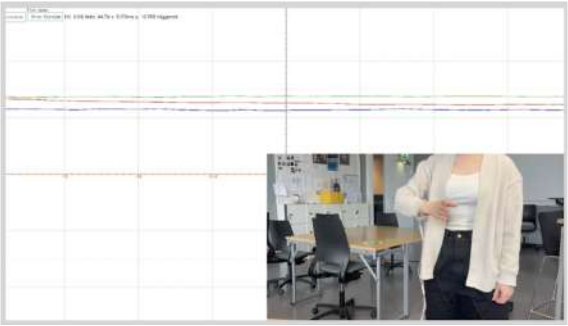
Motion Detect	***Audio Output***	***Signal Transmiss***	***Control Panel***	***SOC***
Accelerometer	Speakers	Thread/ Wire	Trill craft	Bela mini

Table 6.1: The selection of electronic components

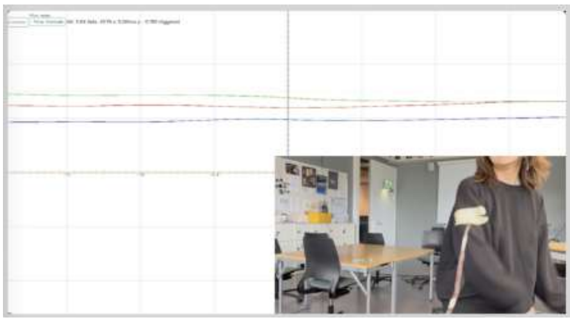


(a) Putting sensor on author's wrist

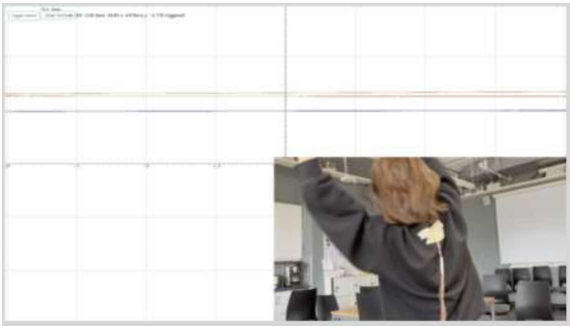
(b) Putting sensor on author's back



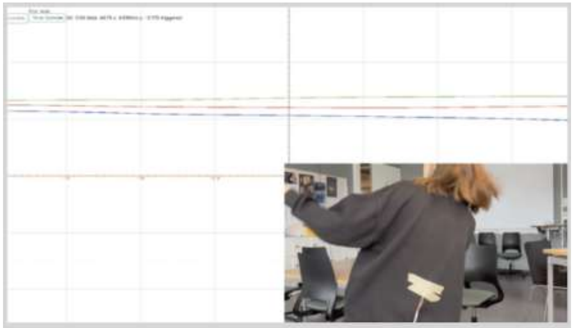
(c) Putting sensor on author's arm



(d) Putting sensor on author's arm



(e) Putting sensor on author's back



(f) Putting sensor on author's waist

Figure 6.3: Collecting and comparing data of accelerameter sensor at different positions

6.1.2 Connection

At the beginning stage, we made use of Pd and Bela to test how our sensors would work and what kind of interactions they can generate. The Bela IDE is not a Pd patching environment, so the Pd objects cannot be made up directly in the IDE. Instead, they must be created and edited in Pd and then uploaded to the Bela project.

Bela systems handle three different types of signals: digital, analog and audio. Digital signals only have one of two discrete states (on or off), whereas analog signals can vary continuously in time between a minimum and maximum value. Bela has different outlets to support digital and analog for both inputs and outputs. The ports of Bela have their corresponding objects Pd. For Pd, there is also a difference between audio objects with others. Digital I/O signals in Bela operate in two states and can be read at message rate or audio rate. Each digital pin on Bela can also be set and functioned as either input or output by initializing in Pd.

Bela's analog inputs and outputs are treated as audio signals. When it comes to audio signals in Pd, firstly, the audio objects would end with a tilde symbol (∼), and the connecting cables between them are wider which indicates that the data is processed at the audio signal rate set by the audio interface. It is worth noting that Pd has to process these signals in real-time, which can consume a lot of CPU. When we experimented with some Pd patches which caused too much calculation, the Bela automatically stopped and shut down due to exceeding its CPU capacity.

In our selected sensors, the Gravity: Heart Rate Monitor Sensor can output either digital signals or analog signals. The pressure sensor and accelerometer sensor can output analog signals. The trill sensor series is compatible with any system that supports I2C communication. Through Pd, the data taken from sensors providing analog signals can be either continuous or intermittent. These dynamic signals can be transferred directly by pure data. Or in another way, be a static value which is captured by a "snapshot" in Pd at a certain time point. Both of them can be used to modify different parameters in synthesis.

In Pd, with the initialized setting, making use of the metronome objects can transfer data collected by sensors into a list message in real time. For Trill Flex, the list would contain [<touches number> <position> <size>], with the first number showing how many touches it has detected and the rest numbers showing the positions and touch sizes. For Trill Craft, the list message would include data from each channel in order. Figure 6.4 show how we tested different sensors. The left one shows the test of pressure sensor connecting with Bela; middle one shows the test of Trill craft sensor; right one shows the test of Trill Flex sensor. The figure on the left illustrates the connection test of the pressure sensor with Bela. The middle figure demonstrates the functionality test of the Trill craft sensor. Finally, the figure on the right shows the test of the Trill Flex sensor. In Table 6.2, we listed the signal type of each sensor and possible ways to use them.

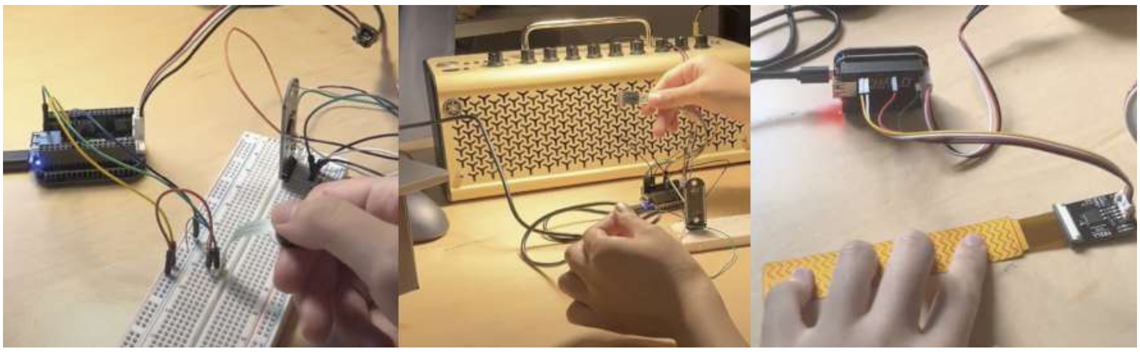


Figure 6.4: Sensors testings

Sensor	Signal type	Function
Pressure sensor	Analog signal	Work as a trigger based on threshold setting; Modify parameters in synthesis
Heart rate sensor	Digital signal	Work as a trigger
Accelerometer sensor	Analog signal	Work as a trigger based on threshold setting; Modify parameters in synthesis
Trill Craft	I2C	Work as several triggers
Trill Flex	I2C	Work as several triggers

Table 6.2: The signal types of different sensors and how they can work in the project

6.1.3 Sounds Synthesis

Synthesis is a way to generate or modify sounds by creating sound waves from electronic signals. There are many different types of synthesis which capable of producing various kinds of sounds. Figure 6.5 shows some of the common synthesis methods, they can also be combined to produce many new sounds. During our project, we tried many ways of synthesis using Pure Data based on the tutorials such as Kreidler [74] and Farnell [68]. With a basic understanding of how sounds can be generated by Pure Data, we united it with Bela and sensors. In this stage, we did some pilot tests to see how Pure Data, Bela and sensors can work together.

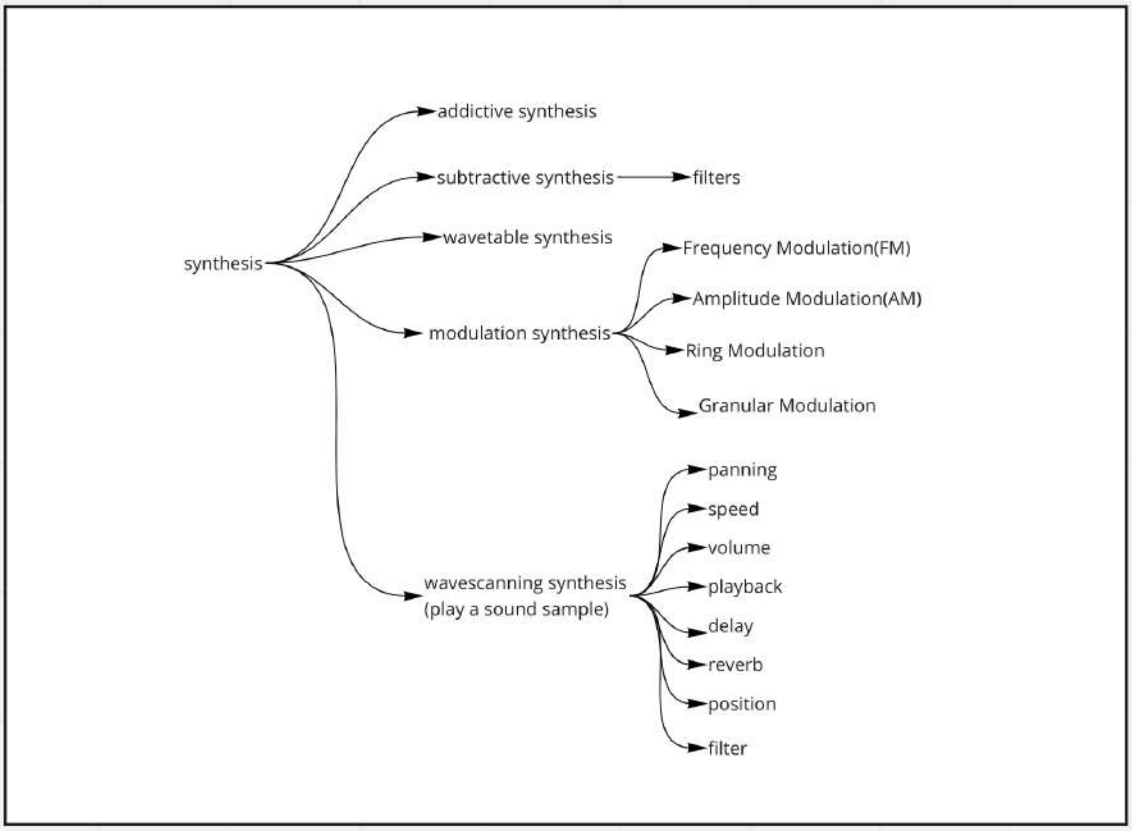


Figure 6.5: Synthesis Method

6.2 Concretization and Idea Selection

To determine the form and function of our product, and the way to integrate sensors, we used a questionnaire to find out how people around us work and study at home and what their preferences are. We asked 17 people of similar age who were either already working or still studying, and all of them had the experience of working or studying at home. 70.6% of them worked or studied at home more than three days a week. It is noteworthy that 70.6% of them believe that a reasonable distribution of work and rest time (e.g. Pomodoro Technique) can help improve productivity, but 82.4% of them do not use such a scientific or strict rest routine, and they gave us the answer that they usually just take a break when they feel it's necessary. At the same time, 82.4% of people choose to play with their cell phones as a way to relax, accounting for the highest percentage. Next people tend to move their bodies, accounting for 70.6 %. Others will choose to simply empty themselves, listen to music, or take a nap.

With these insights, we were able to develop two operational sonic interaction scenarios and came out with two form ideas. To operate, we draw a storyboard to picture the possible using scenario (Figure 6.6), there can be two feasible operating scenarios: 1). To give users the freedom to practice their favorite work and rest routines, they can turn on and off the motion mode whenever they want. Additionally, over time, the garment can provide reminders for users based on the collected data, which helps the users to build a better and personalized work and rest routine. 2). Making use of Pomodoro method to help users execute a scientific and high-efficient routine, users can set their preferred work time and rest time, when the time is up, the product can change its mode automatically.

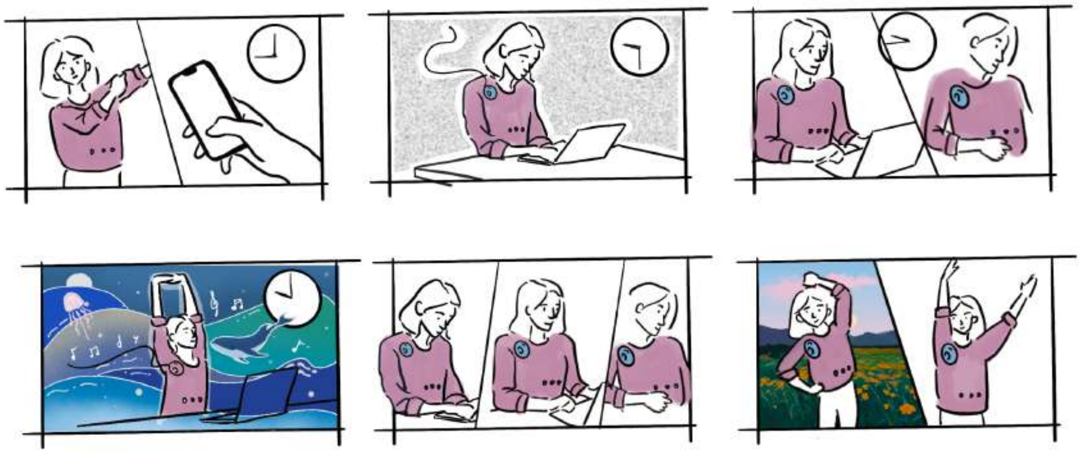


Figure 6.6: Storyboard

For the form, we brainstormed different ways to integrate the sensors (Figure 6.7). Our first idea revolved around building a top such as a sweater or a shirt. To ensure that the clothing could be washed, some electronic components will be made detachable. Velcro, button or magnet could be used as medias to connect different parts. The circuit structure could be realized by conductive threads sewn on the garment or hide in the inter layer. This top can take various forms, such as an undershirt, coat, jacket, or vest.

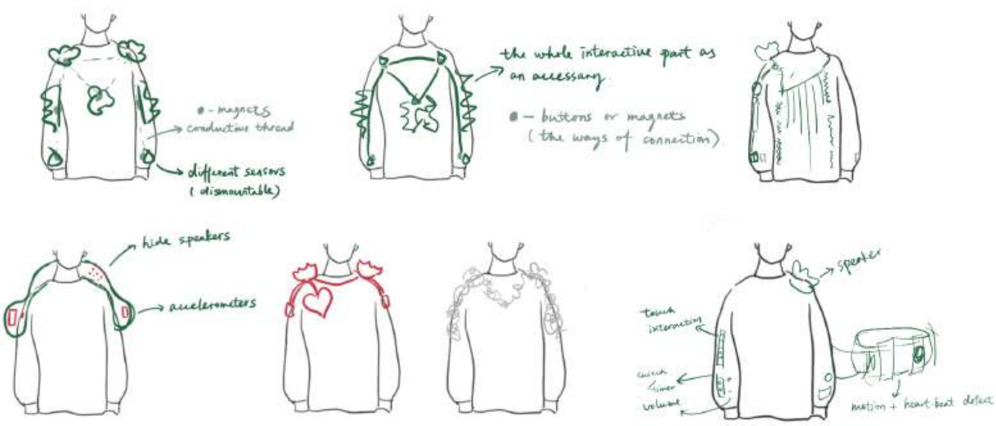


Figure 6.7: Illustration of brainstorming sketch

The second concept was to create a neck pillow with extended tentacles (Figure 6.8). Accelerometer sensors can be put in the tentacles part which will be pinned onto the arm and used to track and record data of arms' activity. The pillow part can accommodate the speakers and the processor at the same time (Figure 6.9). It could also be equipped with pressure and touch sensors. Additionally, it could work as a venting toy which users could hug and press to help users relieve stress. However, the structure of this concept may restrict the movement of the users and need some extra efforts to connect the tentacles to the arm which might be hard to use.

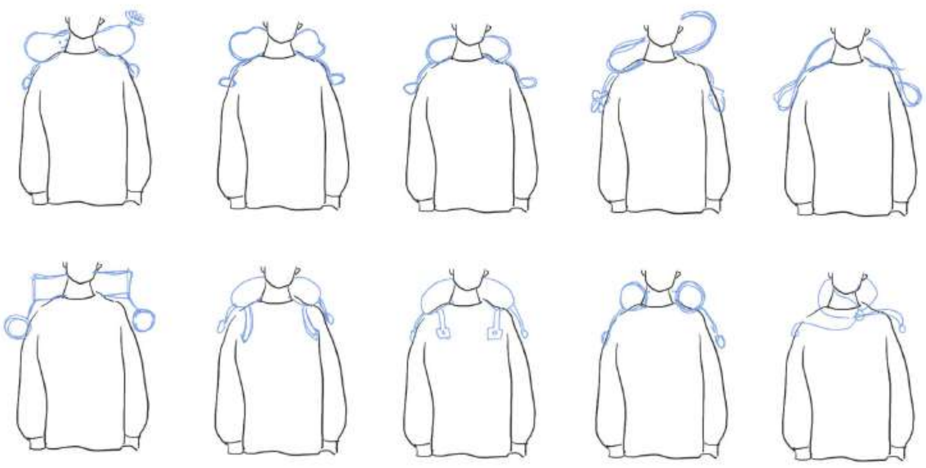


Figure 6.8: Neck pillow design sketch

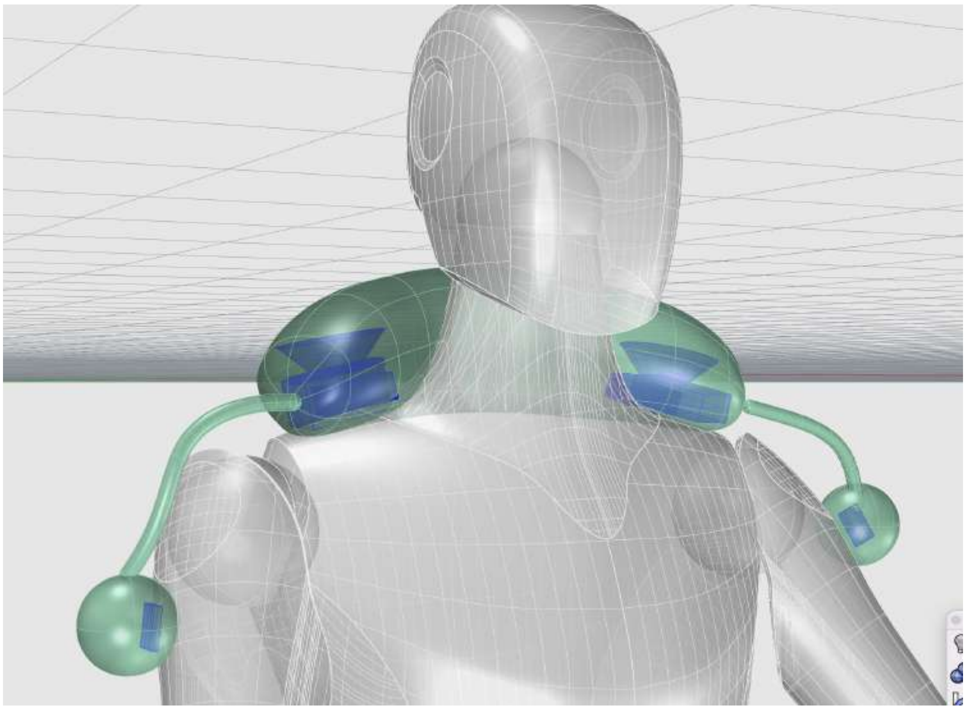


Figure 6.9: Neck pillow structure in 3D view

We have summarized four different ideas for our wearable e-textile prototype, as shown in Figure 6.10. The first idea involves integrating electronic circuits into a top, where sensors and processors can be attached to the main part and conveniently removed for washing. The second idea is to create a separate accessory that can be mounted onto clothing. The third concept revolves around a neck pillow design that incorporates sensors to track body movements and provide relaxation cues. Finally, for the fourth idea, we have chosen a vest shape that includes bandages to connect accelerometer sensors on the arms for more accurate motion tracking.

		Description	Reflection
No.1		All components are integrated in a pullover. The speakers are put on shoulders. Accelerometer sensors can be placed near the wrists. Conductive threads are sewn onto the garment to connect the circuits, and magnets or metal buttons are used to attach the different components.	Restricted to some seasons; Connection parts might be complicated.
No.2		All components are integrated in a pullover. The speakers are put on shoulders. Accelerometer sensors can be placed near the wrists. Separating all the electronic parts, including the wiring, they will be able to be additionally assembled onto the garment.	Restricted to some seasons; Connection parts might be complicated.
No.3		All components are integrated in a neck pillow. The speakers are put on shoulders. Accelerometer sensors can be placed on upper arms. The neck pillow has a shell and an filling part, the elements are placed in the inner part and the shell can be removed and washed.	This design is versatile for all seasons, so as to produce cervical support; Easier to make. Maybe inconvenient for movement; Not suitable for working environment.
No.4		All components are integrated in a vest. The speakers are put on shoulders. Accelerometer sensors can be placed on upper arms.	Available in more situations; Easier to make.

Figure 6.10: Concepts evaluation

After a brief evaluation, we decided to create the product in the shape of a vest as our first attempt. It is relatively easy to build and the vest itself is common, fashionable and versatile. A 3D model was created to visualize the ideal shape and connecting method (Figure 6.11). The speakers were put on the shoulders and there were detachable bandage connected sensors to the arms. Microprocessor was integrated in a big shell which was put near the waist. There were control button on it.

(a) Detail of speaker on the shoulder

(b) Detail of connection between the main control part to the clothes

(c) Detail of connection between the main body and arm part

(d) The overall effect picture

Figure 6.11: Concept form effect pictures

7

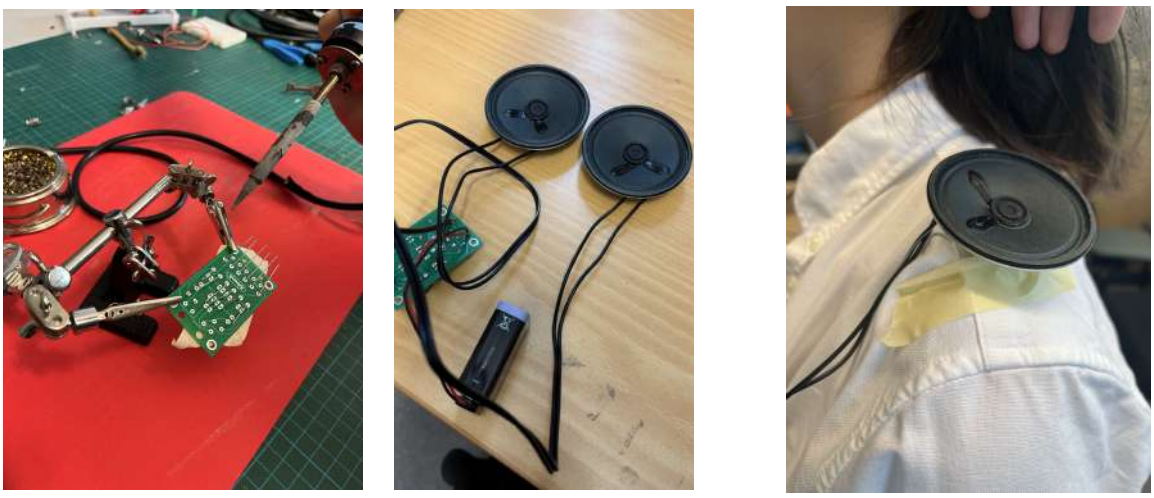
Design Phase III :Iterative Design Process

In this phase, we developed and tested a prototype of the interactive system we proposed. This involves selecting and designing the e-textile components, programming the microcontrollers and sensors, and integrating the sonic feedback.

7.1 Prototype Building

7.1.1 Audio Electronics

Speakers convert electrical signals into audible signals. Dynamic speakers are the most widely used because of their simple construction, wide frequency response and low distortion. For audio circuits to drive other circuit components or devices efficiently, electrical signals always need to be amplified. The speakers we used for our first prototype is a Kitronik Stereo Amplifier. It contains a NJM2073D audio amplifier IC which can output 1W per channel. And the kit is supplied with two 8 ohm 0.5 W speakers. The positions of these speakers are also tested (Figure 7.1).



(a) Building amplifier kit **(b)** Connecting speakers **(c)** Testing position

Figure 7.1: Building and testing speaker

7.1.2 Components Arrangement

The first prototype was built using a black knit vest as the basic foundation since it closely matched our desired shape and was easy to set up cables if needed. The components were arranged as shown in Figure 7.2, with speakers placed around the shoulders and accelerometer sensors integrated through additional settings. The core components were placed near the waist for easy access. To attach the accelerometer sensors to the arms, 35mm black flexible bandages were purchased, and the sensors were knitted onto them (Figure 7.3). Electronic cables were used instead of conductive thread for easier and faster construction. During this stage, our main goal was to quickly test the interaction and functionality of our concept. The cables were secured to the clothes using threads to prevent movement.

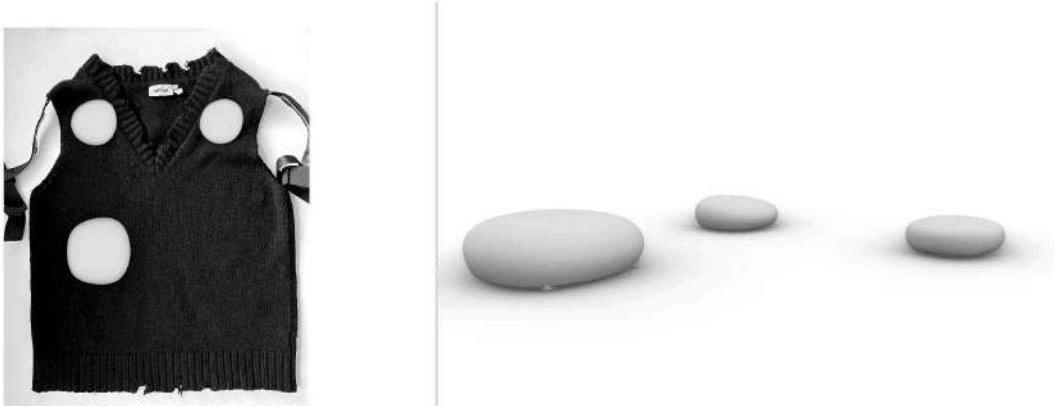


Figure 7.2: The set up for the prototype

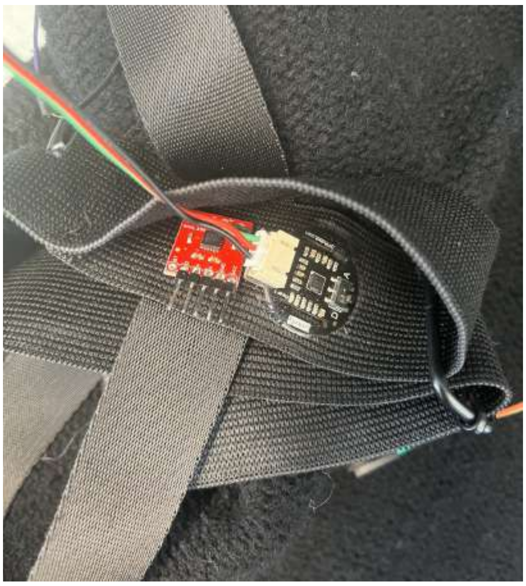


Figure 7.3: Knitting sensors onto bandage

Initially, the speakers were not enclosed, but feedback from testing the prototype suggested that an enclosure would be beneficial for both aesthetics and protection.

We experimented with various materials for the covering, starting with wool felt due to its malleability, compatibility with clothing, and design potential. We designed the covering to resemble pebbles, and chose gray felt to convey a sense of nature and neutrality (Figure 7.4). However, shaping wool felt required significant manual skill and did not provide adequate protection for the electronic components. As a result, we opted for 3D printing as our next material option.

Figure 7.4: Trying out felt covering

We designed a 3D model to cover the speakers with a bottom base and a cap. The sound should have space for reflection. A solid material could be better than a soft one regarding the sound absorption principle [75]. Additionally, some holes were needed for sound transmission. We refined the 3D model, which contained the features mentioned above. The shell of the speaker part was divided into three parts (Figure 7.5). 3D printer is a very convenient tool for prototyping, making redesigning and manufacturing easy. With the help of a 3D printer, we printed two versions of models with different printing processes (see Figure 7.6 and Figure 7.7).

Figure 7.5: 3D shapes for the protection of speakers

(a) The Speakers' bottom bases

(b) The Original Caps

Figure 7.6: 3D printed covers

For the refined 3D models, we printed them with two different printing processes. We can see from Figure 7.7a & 7.7b, the inner sides of models differed by process design. For our project, 3D printing strategies of centring, trees, and bottom built were more suitable to select for our design.

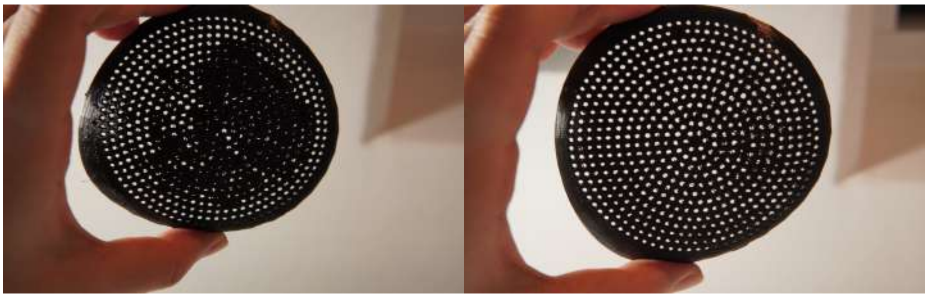
For the cover of Bela, a larger cap was designed for placing it and other components: amplifier board and trill craft. Three holes were pierced for the conductive thread to pass through (Figure 7.8b).

7.2 Audio Synthesis and Data Mapping

The sonic interaction design process was started by thinking about the experience we would like to create for our users. Some specific themes which could make users relax were narrowed down. Since our usage scenario is when users are taking a short break, instead of developing addictive games, we wanted to find a way to simply encourage people to take breaks with movement and give people a good transition to continue working. Research has shown that auditory stimulation of

(a) Printing process 1: rough inside

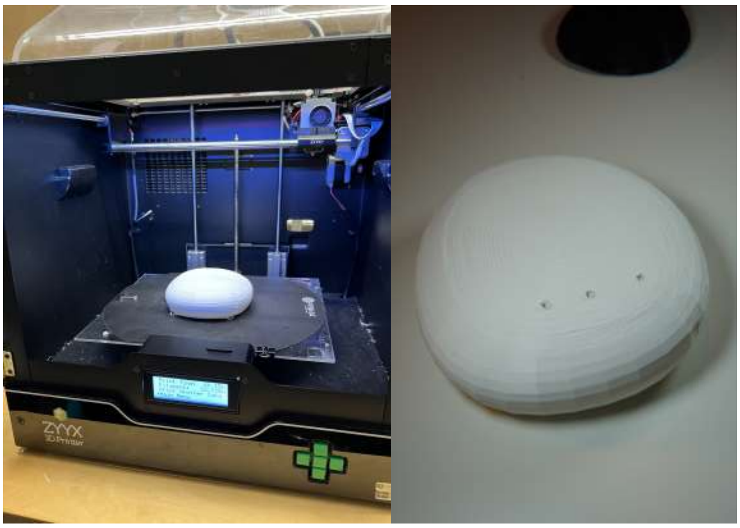
(b) Printing process 2: neat inside



(c) Printing process 1: hard to clean

(d) Printing process 2: easy to clean

Figure 7.7: Comparison of 3D printed covers



(a) Printing by 3D printer

(b) Printing result of the shell

Figure 7.8: 3D-printed cover for Bela

natural facilitate recovery after psychological stress Alvarsson, Wiens and Nilsson [76]. We decided to make use of nature soundscapes in our project. To enhance the user experience in our project, we incorporated nature soundscapes, which proved to be effective in promoting relaxation and movement. After thorough brainstorming, we selected three themes to build our soundscapes: under the sea, in a forest, and an instrument-like one. The first two themes were intended to induce a sense of calm and relaxation through the use of sounds such as waves crashing and leaves rustling. In contrast, the instrument-like soundscape was designed to encourage movement and activity. By utilizing these themes, we aimed to create an immersive experience for users that would help them achieve a state of mindfulness and improve their overall wellbeing.

7.2.1 Under the sea

Just as in air, sound can travel through water, but at a different speed. In theory, water is just wind that makes no sound at all. The sounds in water are an implicit production caused by obstructions of other things. It's complicated to listen under the water. The ocean contains many targets such as bubbles, seabed clutter, surface waves, floating debris, fish, and marine mammals. All these targets combine to give a continuous acoustic background called reverberation. Besides, in the ocean, sound propagation would be influenced by temperature, pressure, and salinity [77].

To further enhance the under the sea soundscape, we decided to incorporate an ambient effect with a diffused style. As Brian Eno stated in his definition of ambient music, it should be able to accommodate different levels of listening attention without enforcing one in particular, and it should be as ignorable as it is interesting [78]. Thus, we plan to add a soft and soothing melody that can be controlled by the user's gesture, allowing them to personalize their experience and further promote relaxation.

Our scenario was the journey starts with the sound of diving into the water, then an undersea ambient background would arise, when users wave their arms, there would be a sound of making strokes and an ambient melody, there could also be sounds of bubbles, whales or other marine animals tripled by some gestures or specific frequency.

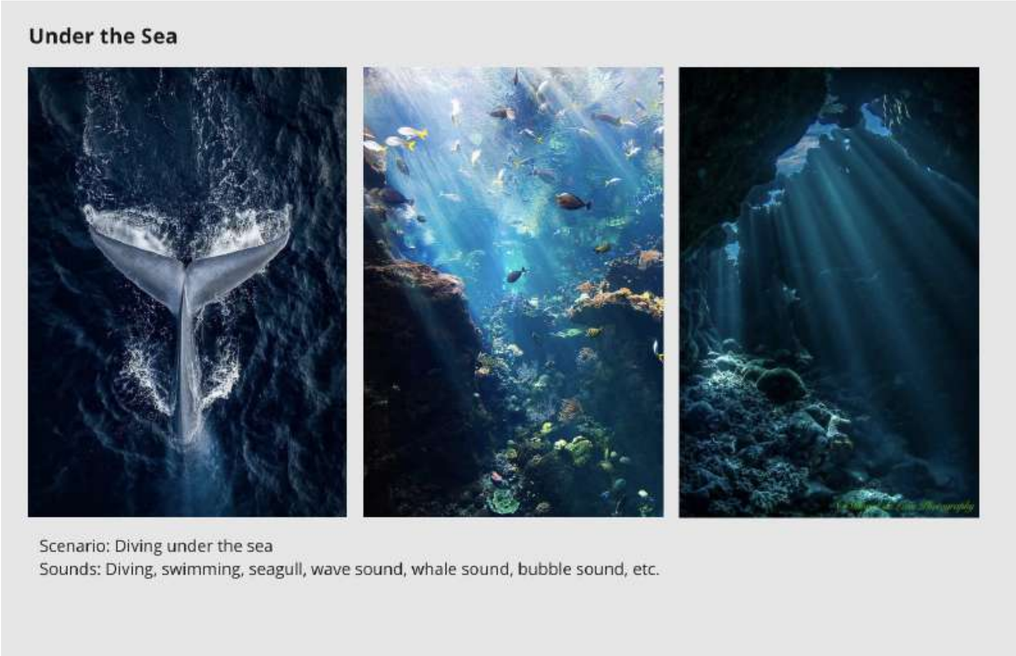


Figure 7.9: The sound scenario of Under the Sea

Moving on to the PureData programming part, we downloaded some sound samples from a sound resource website[1]. A background sound and a whale sound licensed under a CC0 1.0 Universal licence [2] are selected. We adjusted the abstraction patch from Stewart [79] to play sound samples in pure data. Initialy, there was only stroke sound and bubble sound when user waving their arms. After some testing, a synthesis melody was added. The y-dimension data from accelerometer sensors is used to generate an ambient melody, control a stroking sound and triggle the whale sound. When user's hands were raised, a stroking sound would occur.The stroke sound sample is attributed to the tyops shared with CC by 4.0 International licence[3]. And occasionally, a whale sound would appear. The patch setting is shown in Appendix A.2, A.3).

7.2.2 Zen and nature

In this scenario, zen and natural sense was our theme. After some research on Zen related instruments (Figure 7.10), we decided to add this patch with a lot of natural sound in combination with music. To test this idea, our inspiration came from a song that recites the Heart Sutra [80] and we decided to choose this musical style for testing. For this patch, explorations of using gestures to control a song were carried out. There were many ways to modify the sound. Since we couldn't use copyrighted songs, we decided to compose our own song in the same musical style. We started from creating the initial melody in GarageBand (Figure 7.11). Music is divided into three parts: A bass percussive accompany, a high percussive accompany, a guitar

[1] `https://freesound.org/`
[2] `https://creativecommons.org/publicdomain/zero/1.0/`
[3] `https://creativecommons.org/licenses/by/4.0/`

melody. We firstly tried to use some sound filters in Pd to distort the sound but the effect either took too much CPU for Bela or hard to distinguish or take control of the change. Then we switched to a method which users would be able to switch the timbre by keeping arms at different height. Because for this patch, instead of waving the arms, we would prefer users to sway their body to the melody. So three different tones for each track were selected from the contents of GarageBand, they would be played when users keep their arms in a range of height and switched when users move their arms to another range of height. After some adjustments, the final version patch is shown in Appendix A.5.

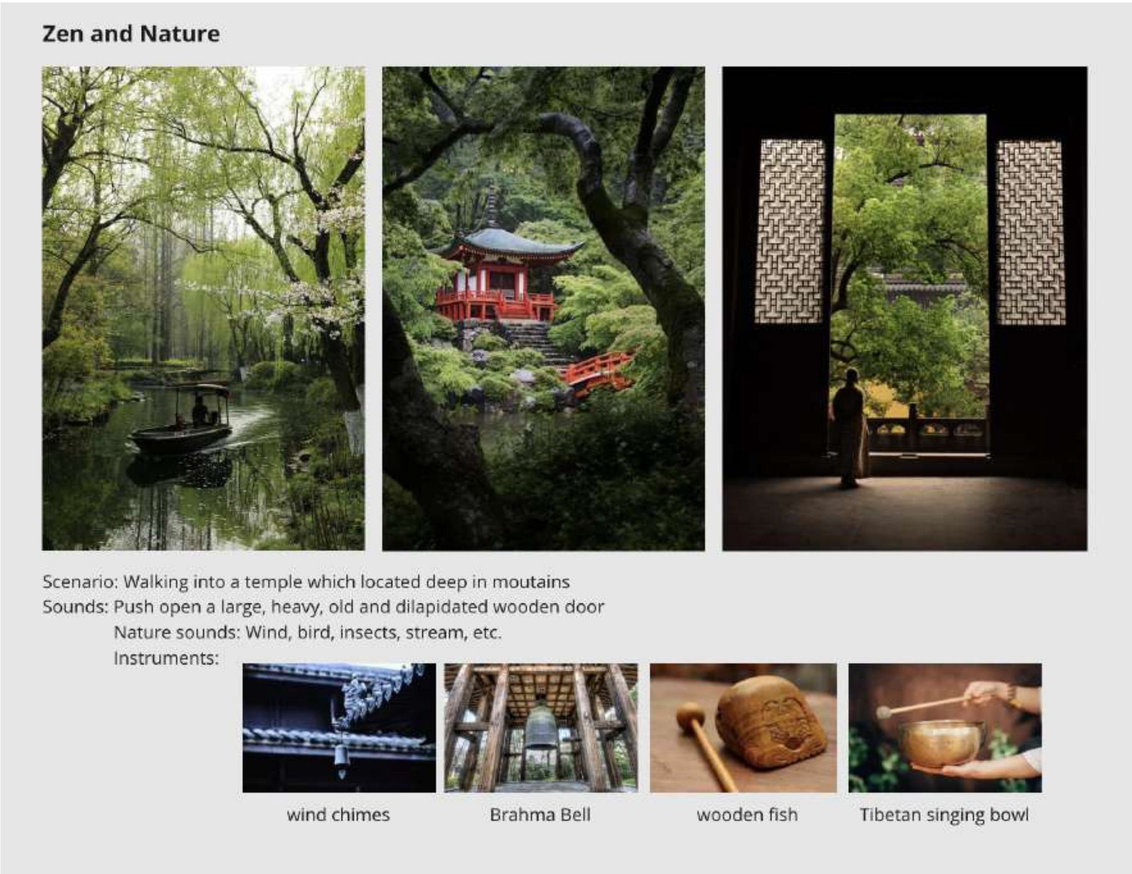


Figure 7.10: The sound scenario of Nature

Figure 7.11: The sound tracks in Garageband

7.2.3 An instrument

This theme aims at exploring the interactive effect of imitating a musical instrument. In this theme, we selected a harp patch, shared as open source code and created by Miguel Moreno [4]. Different tempos were set for two arms. The users could play the melody when they moved their arms around. In order to make the sound effect richer, we also added a forest background sound which attributed by klankbeeld and is lisenced under Attribution 4.0 International licence[3]. This patch setting is shown in Appendix A.7.

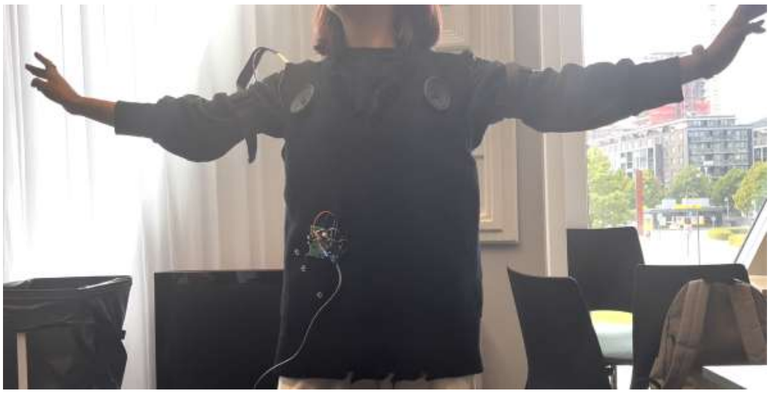
7.2.4 Combination

With each patch, we tested by our own firstly to try out if the mapping fit with our expectation (Figure 7.12). After setting all interaction scenarios as separate patches, we needed to find a way to combine them and help users switch between different modes. The trill craft sensor is a feasible choice for us to use. All the previous sound patches were created as an abstraction in Pd. In Pure Data, abstraction is a very helpful technique for producing reusable patches that are simple to transfer between projects. An abstraction can be invoked by another patch. So a final setting was set (see Figure 7.13).

[4]https://mikemorenoaudio.wordpress.com/

(a) Testing the prototype while sitting

(b) Testing the prototype while standing



(c) Testing the prototype while standing

Figure 7.12: Testing the prototype

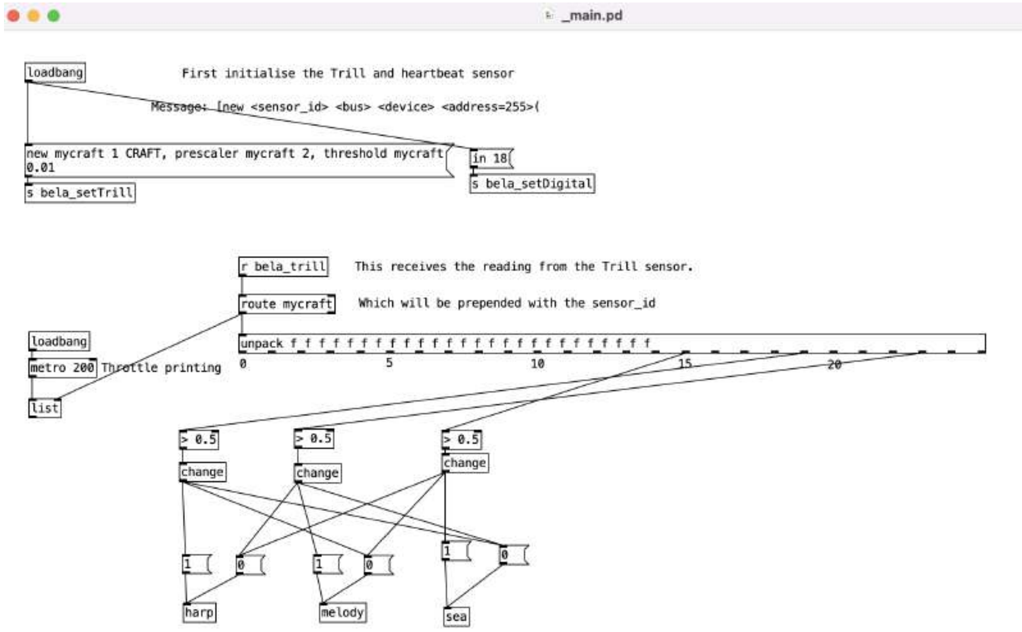


Figure 7.13: The overall patch setting

7.3 Prototype Display

We embedded all the electronic components on an ordinary sweater bought in a shop. After testing different components, our final design of the first version prototype uses two accelerometers, a trill craft, a speaker kit, a Bela and wires. The speaker kit consists of two speakers and an amplifier board. We put the speakers in the shoulder position to decrease the influence of gravity on the sweater. In this position, speakers can build the surrounding sound effect to users' ears. And the amplifier board was located in the lower position near the Bela since it needed to be powered. Cotton thread fixed all components on the sweater to ensure their locations. We used an adjusting strap to place the accelerometers so they could fit different users.

There are two caps to cover the speakers. The 3D-printed covers follow the printing process with less support in this phase prototype. The inside and outside of this version were relatively neat, as shown in Figure 7.14.

(a) The outside of the final cover **(b)** The outside of the final cover

Figure 7.14: Final covers of speakers

In the lower position, we placed the Bela, amplifier board and trill craft together with a power bank inside of the sweater as a group (Figure 7.15). To place the power bank, A pocket was sewn inside (Figure 7.15b). For the cover of the Bela group, a 3D-printed cap was connected to Bela with conductive thread wrapped around the button on the sweater (Figure 7.16a). The inner wiring is shown in Figure 7.17a

(a) Bela Group **(b)** Power bank pocket

Figure 7.15: Bela group

(a) Bela's Cap **(b)** Conductive Thread

Figure 7.16: Bela's cover and connection

(a) The wiring inside the sweater

(b) The outside of the sweater

Figure 7.17: The final inside and outside of the prototype

7.4 Evaluation

Evaluation enables designers to check whether their design is appropriate and acceptable for the wider user population. The evaluation of our design is in multiple folds, including a first-person evaluation from the designer's perspective, and a user study which involved ten participants doing a series testing. The following sections brought more details regarding those two evaluations.

7.4.1 First-person evaluation

Under the Soma design frame, one critical element is to test the design ourselves. We need to evaluate our prototype from the first-person perspective. We planned one day to wear it and recorded how we felt about being with it.

The diary study was implemented at Lin Luo's home. Lin had a daily working routine with at least 8 hours of work. She usually started to work at 8:00 and had lunch and a nap between 12:00 and 13:00, and the work finished at 17:00 or around. The diary study was conducted throughout the whole working hours. During the study, Lin recorded her activities and feelings at different times of the day. If any thoughts or inspirations were generated, she wrote them down at the moment.
Lin played with the prototype twice in the morning, at 8:50 and 11:00, before and after meetings. The interaction woke up the body and activated the brain when she was going to work. It also relaxed her after sitting for a long time working.

> *"I chose mode 1 first which generated the sound of the ocean. The mode made me so calm, and I felt a bit sleepy. So I changed to mode 2. By randomly moving my body, the conflicting feeling of disorder refreshed my brain, which is good before a meeting."*

The user changed the scenario from a relaxing one to a more energetic one to prepare for work. Different kinds of sound themes could fulfil users' corresponding requirements. As a direction, various sound scenarios should be explored with different themes in the future. Lin reminded herself to take micro-breaks by setting up timers on her phone. It would be good if the product had timing and reminder functions. Since the working styles vary by person, the timer setting mechanism is well worth considering.
After lunch and a nap, the user began the afternoon part of the work. The attraction of the intelligent garment was lower compared to the morning.

> *"During the afternoon, my motivation to interact with my prototype somehow weakened. I preferred to do some daily activities to take a break from work."*

We realized that the function of our prototype might be too simple to keep attention of users. More features could be introduced to increase the duration of user engagement. For example, detecting body condition and position could be considered as a health assistant to increase the wearing time. Also, as a wearable equipment, to warm and cool the body when the environment temperature is too low or high could be a value-adding feature. And the most basic improvement could be equipping the prototype with higher level entertainment technology, such as adding more complicated interaction scenarios, increasing the amounts of sound types and so on.

7.4.2 User study

The user study was purposed to obtain the participants' feelings and experience using our prototype. We also tried to explore the users' preferences in the appearance and context of the first version prototype. Once the information was gathered, the consideration of promoting the design could be more directive. All the participants were given a consent form before the study.

There were ten participants in total. We recruited participants online and invited some interaction design students when we were finalising our prototype in the studio of the Interaction Design department. The testing consists of two studies. We had two participants in the first study, which gave us considerable feedback to improve our first version prototype. After improving the prototype, we run a second study of testing with eight other participants.

The participants were students and desk workers who regularly studied and worked from home. There were six desk workers. Five had a hybrid work style: they worked on-site for at least two weekdays. And one of them was working fully remotely, which meant this participant worked from home every weekday. These desk workers shared average home working days of 3.5 per week, and working hours on average is 8 hours per day when working from home. Of the four student participants, two of them preferred to study on campus, such as in the library and study room, while two were more into studying at home. They shared an average of 2.25 days of studying at home per week, and they spent 6.7 hours on average when studying at home.

The information we gathered from the participants was mainly in two forms, through interviews and observing the participants' movements. By analysing different participants' movements, we got the chance to discover various body moving trajectories. Therefore we could align sonic interaction with corresponding movements. On the other hand, we utilized the interviews to evaluate the prototype's efficiency, effectiveness and satisfaction. The form of the questionnaire referred to Attrikdiff[81]. We had fifteen questions to scale their feelings about different sound scenarios. Five-level rating scales are commonly used and are enough to capture the users' perception of the product while reducing the burden of the review process. Following those questions, we asked three additional open questions to know about the features of each scenario that impressed them most, their acknowledgement of how to interact with it, and to describe their movements with words. After testing all three interaction scenarios, there were five more questions regarding the general feelings of the prototype.

There were two rounds of tests. In the first study, we did short tests to gather quick feedback regarding the function of the prototype. In the second study, we focused more on the movement of participants to study how they moved and get a holistic acknowledgement of user experience.
In the first round of the study, we invited two participants to experience the original prototype. The speakers were naked without any dressing, and most electronic components were covered for safety considerations without aesthetic design. In this case, we wanted to see how this prototype worked and what people would expect to improve for this version's design. The participants gave us some feedback on the appearance of the prototype. One of the participants mentioned that it would not attract users to wear and play since it was not good-looking. And we got comments on the mechanism of activating sonic interaction. One of the participants mentioned:

> *"It could be strange to raise my arm only for some music."*

This comment drew our attention to the following question regarding our design: should we drive the body to move or generate sound with spontaneous movements? After the first study, we modified the sound interaction mechanism of scenarios and tried to increase the flowing consistency when moving arms fast.
When a participant puts on the prototype, we need to figure out which movements are spontaneous and which are inspired or motivated by the wearable equipment. In the second study, we focused more on the movements when participants interacted with the prototype and paid more attention to patch improvement. In this stage, there were eight participants who went through system-integration testings to test all the three scenarios. We handed out questionnaires to participants, requested them to scale their feelings of each scenario.

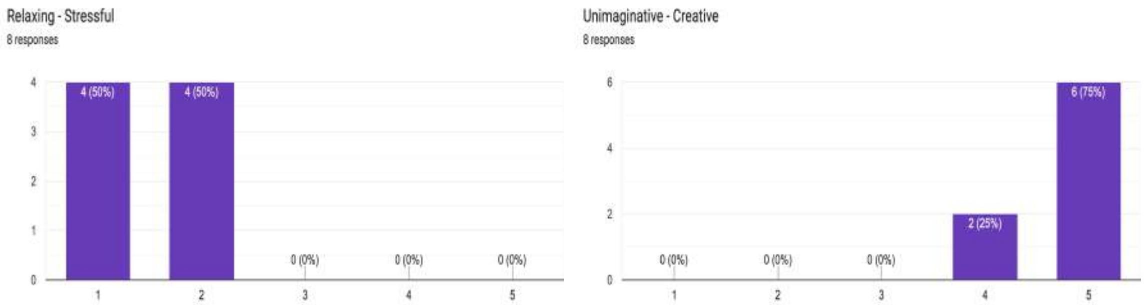
7.4.2.1 The first scenario

The first sonic interaction scenario is a theme inspired by the deep ocean. We added factors like whale sound, bubble sound, water flow and wind... In this group, we had several interesting findings. Some participants imagined they were in the ocean. Besides being themselves swimming in the sea, they mention their imagination that they were marine life or aquatic plants moving in the water. We observed the waves of seaweed, undulating movements like an octopus and flowing gestures like water flow. These observations were partly proved in the following Q&A section. One of our participants commented:

> *"I imagine myself as a jellyfish. Sometimes I sway in the water by leaning my body left and right. Sometimes I move my hands and arms, imitating the movement of the jellyfish's umbrella shape muscle, which contracts to squeeze out water for fast moving. At this moment, I was as free as a jellyfish to swim anywhere in the ocean."*

Four participants used the words "peaceful" and "relaxed" to describe their feelings when experimenting with the first interaction scenario. "Creative" was the most frequently occurring comment given by all the participants.

All participants believed that this scenario was relaxing to them. When mentioning their experience of the first scenario, they used the words "peaceful" and "relaxed" to describe their feelings, which also appeared as one result of the questionnaire (Figure 7.18a). "Creative" got highest score among all the features of the first scenario (Figure 7.18b) by all the participants.



(a) Relax-Stressful **(b)** Unimaginative-Creative

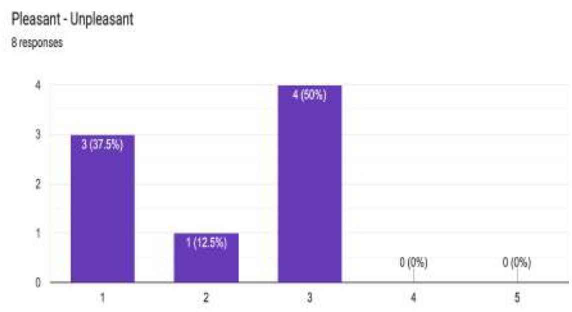
Figure 7.18: Scenario 1 results of questionnaire

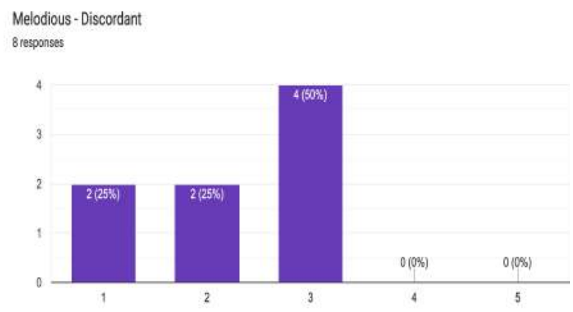
7.4.2.2 The second scenario

The second sonic interaction scenario includes many natural elements, melodies accompanying birdsong, running water and bubble sounds. To distinguish it from the first scenario, the second scenario aims to bring a cheerful feeling to users. Different heights of the arms' positions generated melodies with different pitches.

We observed that half of the participants spent more than two minutes slowly moving their arms and frequently stopped to listen to the sound for the corresponding position. Two participants commented that they had to spend more time learning the mechanism of this scenario than the first scenario.

We also got some feedback on the audio mix. Four participants thought it was not pleasant when sounds came together (see Figure 7.19a). Different gestures could generate different sonic interactions. While different melodies were playing simultaneously, they interrupted each other. Even though this scenario consists of four melodies, four of eight participants did not find these melodies harmonious (see Figure 7.19b).





(a) Pleasant-Unpleasant

(b) Melodious- Discordant

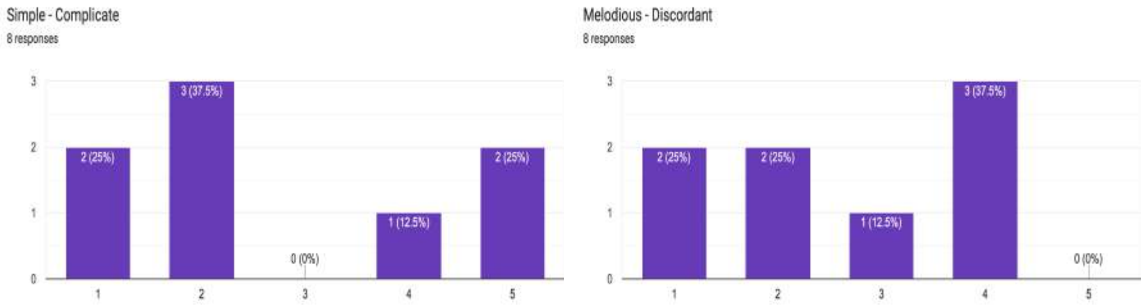
Figure 7.19: Questionnaire for the second scenario

7.4.2.3 The third scenario

The third scenario endued two arms with different pitches and timbres of the harp. Different from the other two scenarios, this interaction was relatively simple to control. By swinging arms, heptachords were generated with each arm.

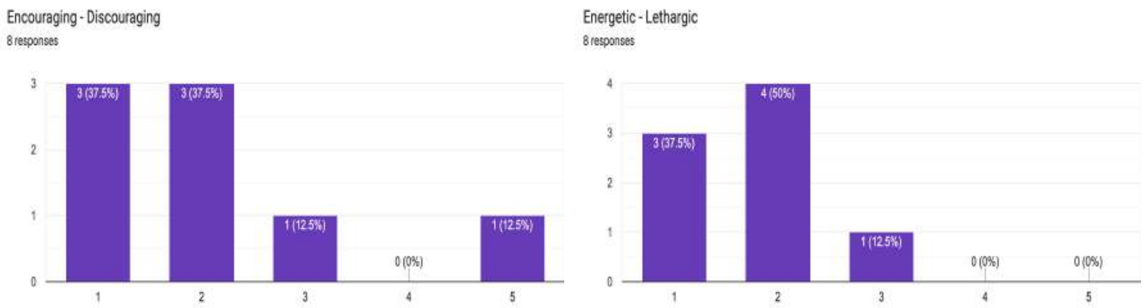
The most common movement in this scenario was raising arms and putting them down at different speeds. The feedback was polarised for this sonic interaction scenario, which meant the participants' feelings varied. The scale of 50% of the participants thought this sound could have been more melodious. There were some comments regarding sound fusion. One participant said it is sad that sounds interrupted with each other when moving both arms. We assigned each arm with a heptatonic scale, and created sound in the corresponding heights of arms. We assumed that users might enjoy that sounds were generated constantly, but ignored the possible interruptions when two arms moved simultaneously. It would be good if we gave indications in advance to explain the sound generation regulations.

Six participants believed that this scenario is encouraging, and seven of eight participants scaled it as an energetic interaction scenario. Two participants said it was their favourite sonic interaction scenario, whilst two participants who disliked it said it was noisy.



(a) Simple-Complicate **(b)** Melodious- Discordant

Figure 7.20: Scenario 3 results of questionnaire



(a) Encouraging- Discouraging **(b)** Energetic- Lethargic

Figure 7.21: Scenario 3 results of questionnaire

7.4.2.4 General reviews

After three questionnaires, we interviewed all participants to gain their general impression over our project. The followings are some comments, suggestions and discussions regarding the appearance, contents and general impression of our prototype. The feedback regarding appearance of prototype counted a lot in our evaluation result. The user cared about the aesthetic design of the cloth and its comfort when wearing the cloth. There were comments pointed that the design "did not look very appealing". And one participant suggested that "a less bulky" and "lightweight" garment could be designed. Also, one participant indicated that the sweater would be too warm for summer use, a more flexible and detachable design could replace a fixed design with knitted cloth.

For the content design, the participants were concerned about sound consistency and movement capture accuracy. The delay of sound response to movement could be annoying. At the same time, a scenario with more consistent sound generation would gain more favour from those who pursued consistency.

An easy-to-understand sonic interaction scenario would be attractive to users as well. Participants should be aware of *"what movements triggers what noises"* and *"how should it work properly"*.

Moreover, two participants mentioned that they would like space to create sound combinations. A sonic interaction scenario with more regularity elements could create a possibility for musical composition. Many participants also pointed out the disturbance when sounds mix together. It could be improved by revising the sound-activating mechanism. For instance, the generation of sound could base on the prediction of users' moving trajectory. By coding the sonic interaction corresponding to the possible movements of users, the design could avoid most interruptions of sound mixing together. The alternative could be a mechanism that assigns each gesture a specific sound. By giving instructions on how should the users trigger different sounds, the product could provide more space to users for musical composition. In addition, this mechanism can encourage users to perform specific movements with instructions to achieve the purpose of stretching out.

When inquiring about the overall perception of this type of product, six of eight participants said *"yes"* for the question below:

> *"Do you feel like you need this kind of product?"*

This proved the possibility of applying e-textile to our daily life. Three participants also mentioned that they might ignore the importance to take regular breaks during work, which gives more significance to this project.

Two participants conveyed that they might reject consuming this kind of product. One of them said the sound scenarios were too simple to fulfil his/her demands. And another participant mentioned that this kind of prototype required bigger movement to interact with it that he/she would not do it during micro-breaks. Regarding these aspects, future work could include the development of more advanced sonic interaction scenarios, catering to a diverse range of user preferences. The range of sound options could be expanded to include a variety of music genres and sounds associated with the autonomous sensory meridian response (ASMR). Additionally, it would be useful to incorporate a personalized sound mode that allows users to incorporate their own preferred sounds into the interaction. And the range of motion could be adjusted as well. To increase accessibility, a mobile application could be introduced, offering the ability to select different sound modes and set up a schedule for a regular working style.

8

Design Phase IV :Final Refinement

After gathering general feedback from participants, we acquired a lot of constructive suggestions and opinions. Besides, we had a vision at the beginning to make this product washable and easy to assemble. Our next step was to improve the prototype based on our participants' suggestions and realize our detachable idea of making use of conductive e-textile materials.

During the construction of our first prototype, we utilized a knit vest combined with traditional electric wire to facilitate quick and easy testing. For the refined version of EaseFit, we decided to focus on improving the appearance of the design while also realizing the detachable function. To achieve this, we aimed to improve the selection of the basic clothing, electronic components, and their coverings. Some participants provided feedback that the sweater vest was not practical for daily wear, and the product appeared too bulky. As a result, we opted to replace the vest with a black basic jumper that would be more versatile in its appearance.

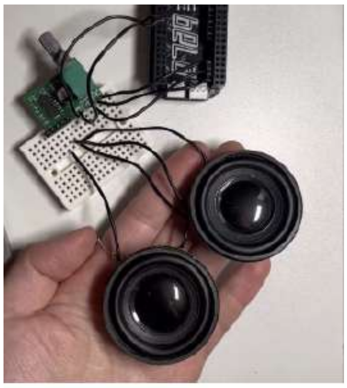
To make our e-textile product more approachable and customizable, we made a conscious effort to minimize the design's technical look. We opted for smaller and more flexible electronic components. We also considered the color and texture of the materials used, choosing ones that were visually appealing and warm to users.

8.1 Components Selection

After becoming familiar with the process of building the speaker kit, we set out to find lighter and smaller speakers and amplifiers with higher quality. Our previous speakers were assembled from the Kitronik Stereo Amplifier Kit, which contained two 66mm speakers (Figure 8.1a). This time, we opted to select the speakers and amplifier separately. We tested two different sizes of speakers: a pair of 3W 4Ohm speakers with a 32mm diameter (Figure 8.1b), and 2W 4Ohm speakers with a 45mm diameter (Figure 8.1c). We tested these speakers with various amplifiers (Figure 8.2), and after careful consideration, we determined that the smallest components produced the best sound quality. As a result, we decided to use them as the units for our next prototype.

(a) Speaker for the first prototype

(b) 3W 4Ohm 32mm speaker for testing



(c) 2W 4Ohm 45mm speakers for testing

Figure 8.1: Comparing different speakers

Figure 8.2: Selecting amplifiers

8.2 Realization of Detachability

One of the critical aspects of our design was to incorporate a detachable function, allowing for flexibility and ease of maintenance. In the initial stages of the design process, we brainstormed various methods to connect the different components of the product. After careful consideration, we decided to utilize pogo pins with magnets (as shown in Figure 8.3) as our preferred connecting method. Pogo pins, also known as spring-loaded pins, are commonly used in modern electronic applications for their efficient electrical connector mechanism [82]. They can provide stable connection and are easy to assemble.

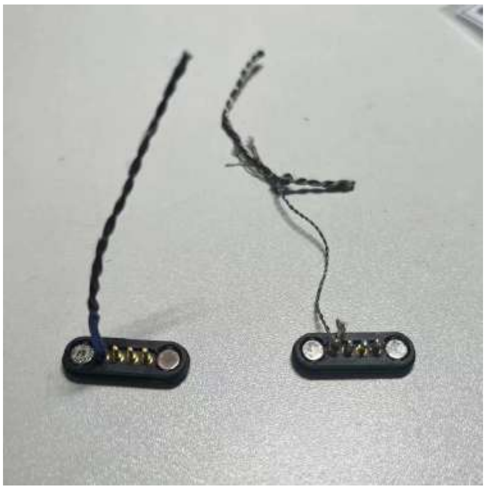
Figure 8.3: Different types of pogo pins

In addition, we tried out sewing conductive thread into the clothes and connecting it to the pogo pin. There are mainly two types of conductive thread in the market - silver-coated and stainless steel. The silver fiber conductive thread contains more than 18% silver, and the rest is nylon, which is a soft and easy-to-handle textile thread. But its resistance is higher. Stainless steel thread is a flexible thread made of single or multiple strands of stainless steel fibers twisted, with high strength, stable resistivity, high-temperature resistance and good electrical conductivity. Each type has various sub-specifications in different parameters. For each type, we chose the thickest one to experiment with. In Figure 8.4, the left one is stainless steel thread, and the right one is silver-coat thread. Then we started finding ways to connect them with pogo pins.

Figure 8.4: The conductive threads

We considered hiding the threaded part inside the clothes. Showing the thread pattern outside requires professional sewing skills and can potentially cause short-cut problems. The silver-coat thread is thin but with high resistance, so the thick stainless steel threads became our top choice. Our idea is to use thick stainless steel thread to go through circuits inside the clothes, and they can be fixed by normal threads. For the joining part, connecting the conductive thread with a small pin is a tricky problem. The stainless steel thread is too thick and tough to twine to the pin, we tried glue, twining by silver threads and then knotting them with stainless steel thread (Figure 8.5a). Using glue is not stable enough, and the thread connecting way is rather too complicated (Figure 8.5b). Our final solution was to make use of the interval of thread and solder it onto the pin, and then nail polish is used to insulate (Figure 8.6).

(a) Connecting pogo pin with silver-coat threads



(b) Comparing pogo pin connection methods

Figure 8.5: Testing connection methods between conductive threads and pogo pins

8.3 Prototype Building

8.3.1 Redesign the Shells

Our components have become smaller, requiring us to re-design our covering to accommodate them. In order to make assembly more convenient and streamlined, we opted to create the form of the covering as simple circles (see Figure 8.7).

The process of building the latest version of EaseFit involves two key elements: integrating circuits into the clothing and creating detachable components. We began by using tapes to map out the exact positions for each component as shown in Figure 8.8, which allowed us to determine where to place the pogo pins on the garment (see Figure 8.9). Once the positions were finalized, we affixed the pogo pins in place with glue and then sewed the conductive threads within the clothing. To ensure the threads were invisible and the jumper maintained a sleek and fashionable appearance, we used black normal threads to secure them. This aligns with our vision of creating a design that is functional and suitable for everyday use, rather than solely

Figure 8.6: Inside view of the prototype

(a) Inside view of 3D printed shells **(b)** Outside view of 3D printed shells

Figure 8.7: Pictures of refined shells

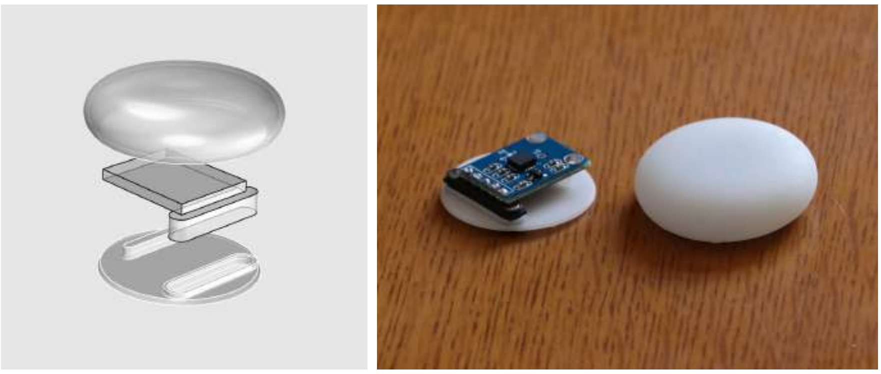
emphasizing the technological aspects.

Figure 8.8: Using tapes to fix components and set their positions

Figure 8.9: Pogos' position setting

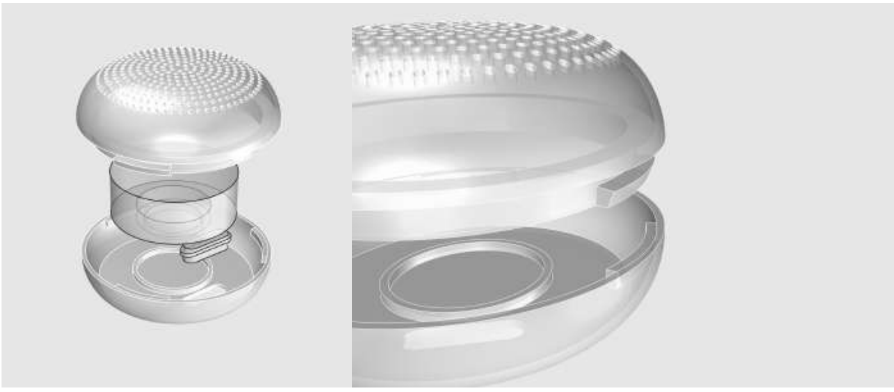
Each component of the cover is carefully arranged to fit inside, taking into consideration the location of the pogo pin hole and the way they connect. For the accelerometer sensor's shell (Figure 8.10), a support for the sensor is built in addition to the pogo pin hole. Once the sensors are secured, the upper and lower body of the shells are connected. In the case of the speaker shells (Figure 8.11), the upper shells are designed with array holes to enhance sound propagation, and the upper and lower parts can be connected using a buckle structure.

The arrangement of the core part (Figure 8.12) is critical. It is essential to power the Bela Mini using a battery with a minimum voltage of 4.5V to avoid the analog inputs from malfunctioning. As most Lipo batteries provide 3.7V power, a charger component that can also function as a booster is required. The core part comprises the Bela mini processor, a Lipo battery, a Lipo charger/booster component, an amplifier with volume adjustment, and a touch switch. Their arrangements are pre-determined using 3D building software, and locators are set accordingly.



(a) 3D model of accelerometer sensor setting **(b)** Accelerometer sensor and its shell

Figure 8.10: Pictures of accelerometer sensor and the shell



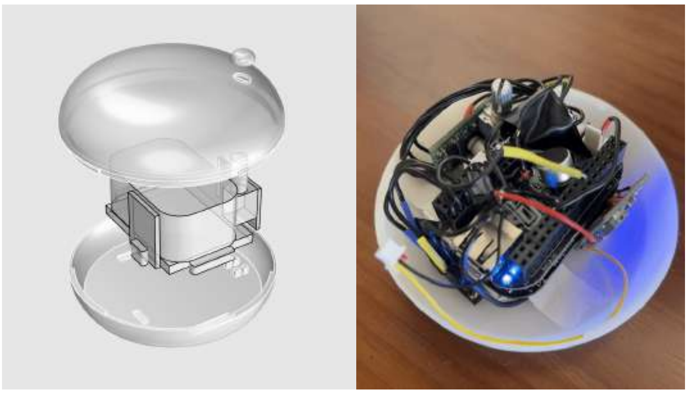
(a) 3D model of speakers setting

(b) 3D model of shell connecting structures

(c) Speaker and its shell

(d) Detail of connection between speaker and pogo pin

Figure 8.11: Pictures of speaker and the shell



(a) 3D model of core part setting **(b)** Core part and its shell

Figure 8.12: Pictures of core part and the shell

Figure 8.13: Result of placing the components

8.3.2 Covering Material Experiments

In this phase, testing of different covering materials for the 3D shells was necessary. The material had to be resistant to dirt and wear, soft, and compatible with clothing. After considering these factors, we selected DuPont Tyvek paper[1], leather, and fur (see Figure 8.14). Two types of Dupont paper were used, a white one and a colorful one. We attached the materials to the 3D casing using easy-to-tear, double-sided tape and tested the effect on clothing (see Figure 8.15).

[1] `https://www.dupont.com/brands/tyvek.html`

(a) Selected covering materials

(b) Testing different materials on the shells

(c) Effect of leather covering

(d) Effect of colorful DuPont paper covering

(e) Effect of white DuPont paper covering

(f) Effect of fur covering

Figure 8.14: Details of various covering materials tests

Figure 8.15: Comparing different kinds of materials on clothes

9
Result

9.1 Final Concept - EaseFit

The plush material and cotton jumper resulted in a harmonious and interesting effect, leading to the final selection of the plush material. After these determinations, a final version of prototype is finished (see Figure 9.1). A website, EaseFit[1], was built to exhibit our prototype.

Our prototype serves as the cornerstone of our final product concept, enabling us to test its feasibility and gather further inspirations. With this attempt, introducing EaseFit, our innovative product that leverages technology to foster a healthy rest hobby and deliver a relaxing sensory experience. The EaseFit system comprises several components, including a jumper, a charge and container module, two sensor modules, and two speaker modules. To enjoy the benefits of EaseFit, users simply need to don the clothing and attach the different components to their respective positions.The core components of EaseFit consist of the switch and volume adjustor, which house a rechargeable battery and a powerful core processor.

The jumper forms the foundation of the system, providing a comfortable and snug fit for the user. It is crafted with soft materials and loose shape that enhance overall comfort during using. The two sensor modules are strategically placed within the jumper, designed to monitor and respond to the user's bodily movements and physiological signals. These sensors enable the system to adapt and personalize the sensory experience according to the user's needs. Whether it's tracking motion patterns or detecting stretching levels, the sensors play a vital role in tailoring the experience for optimal relaxation and rejuvenation.

Enhancing the immersive experience further, the two speaker modules provide high-quality audio output. These modules are carefully positioned within the jumper to deliver soothing sounds, ambient music, or guided meditation, enhancing the overall sensory experience. Users can customize their preferred audio content or choose from a range of pre-programmed options, allowing for a truly personalized and immersive relaxation session.

Each of the components in the EaseFit system is seamlessly connected to the clothing using magnets, ensuring easy attachment and detachment. This magnetic connec-

[1] `https://slimtoto.github.io/EaseFit`

(a) A view of final prototype

(b) A view of final prototype

Figure 9.1: Final prototype

tion allows users to effortlessly affix and remove the modules as needed, enhancing the overall convenience and usability of the product. Once all the components are securely attached, the user can simply press the touch switch located on the main body part to power on the product, initiating the immersive sensory experience.

In our ideal scenario, we envision a user-friendly interface that allows users to control the sound modes and customize their preferred routines through a mobile app. With the app, users can easily switch between different sound modes and tailor their relaxation experience according to their current mood and preferences. For instance, users can choose to receive regular reminders for relaxation sessions, and then customize their desired soundscapes to match their desired ambiance. In an underwater theme, for example, the user can select a sea sound that transports them to a serene underwater world, enabling them to immerse themselves in an enjoyable undersea journey.

One of the key objectives of EaseFit is to encourage individuals to detach from screens during their leisure time and instead focus on exploring and reconnecting with their own bodies. By providing a multisensory experience that engages the auditory and tactile senses, the product aims to foster relaxation, mindfulness, and a sense of self-awareness. Users can truly unwind and engage in self-reflection, creating a space for rejuvenation and self-discovery.

To ensure durability and protection for the delicate sensors and components, solid shells are used to safeguard them from potential damage. This design consideration gives users peace of mind, eliminating concerns about accidental impact or wear and tear during everyday use. With the robust protection provided by the solid shells, users can confidently enjoy their relaxation sessions without worry.

EaseFit aims to revolutionize the way individuals approach rest and relaxation by combining cutting-edge technology with comfortable apparel to create a personalized and immersive sensory experience. The integration with a mobile app enables users to personalize their sound modes and routines according to their preferences. The wearable nature of the system ensures that users can enjoy its benefits anywhere and at any time, whether it's at home, during travel, or even at the office.

9.2 E-textile

Throughout the development of e-textiles, careful selection of elements is essential to meet specific usage requirements. In this study, our focus was on gesture-detection, making the selection of appropriate sensors crucial. The accelerometer sensors proved to be a suitable choice due to their compact size and ability to provide abundant and reliable data. These sensors enabled accurate tracking of movements, allowing for seamless interaction with the sonic interactive garment. Additionally, we explored other sensor options, including the trill sensor series, which demonstrated intriguing capabilities for touch-related interactions. These interactive sensors opened up possibilities for incorporating tactile and responsive elements into the garment, enhancing the overall user experience. By considering various sensor options and their unique features, our research provides insights into optimizing sensor selection for specific interaction modalities in e-textile applications.

Testing the circuits frequently is a crucial practical tip that should not be overlooked during the design process. Circuit connections can often be delicate, and even a small error can cause a malfunction in the system. Therefore, it is essential to test the circuits regularly to ensure they are connected correctly and to identify and fix any potential issues as soon as possible. One effective way to do this is to use a multimeter, which can help to check the continuity of the circuits and detect any open or short circuits. Additionally, using a breadboard can also help with testing the circuits before permanently soldering them in place, allowing for easier modifications and adjustments. By implementing these testing practices, you can save time and effort in the long run and increase the reliability and functionality of your design.

The results of this study demonstrate the efficacy of utilizing pogo pins and magnets as media for circuit connections within the sonic interactive garment. The integration of pogo pins offered a robust and reliable connection interface, ensuring consistent electrical conductivity throughout repeated use. Additionally, magnets provided a secure and detachable method for linking different components, allowing for flexibility and ease of maintenance. They also ensure that the signal is transmitted reliably, which is critical for the proper functioning of the circuit. With this type of connection, components can be easily attached and removed without the need for special tools or equipment. They are also small and lightweight.

When considering thread selection for e-textile applications, both silver-coated thread and stainless steel thread possess unique strengths and weaknesses. Silver-coated thread is generally easier to work with, but it exhibits higher resistance, making it more suitable for trigger functions rather than efficient signal transfer. On the other hand, stainless steel threads are more challenging to knot and equipped with magnetic properties. However, it offers improved durability and mechanical strength compared to silver-coated thread. It is important to note that both types of threads have various specifications, including different twine patterns, processing methods, and thicknesses. Consequently, careful consideration and selection are necessary, taking into account specific needs and requirements of the project at hand. By carefully assessing these factors, designers can ensure the optimal choice of thread that aligns with the desired functionality and performance of the sonic interactive garment.

Furthermore, the implementation of strict isolation techniques was found to be crucial for ensuring the safety and functionality of the garment. Insulating fabrics, conformal coatings, and encapsulation methods effectively prevented electrical shorts and reduced electromagnetic interference, thus ensuring the long-term reliability of the electronic components integrated into the fabric.

9.3 Design Phase

An entire product design cycle was conducted for our e-textile product, which combined the sonic interaction technology. Concluded from the evaluation results, the choice of sound aesthetics varied by the user. The participants said they would like to include their DIY(Do it yourself) sound scenario. Users also care about the appearance of the product. They explained that a barely designed garment or a formulaic garment would lack attractiveness to them. A topic that repeatedly occurred in the interviews is personalisation. It could be a meaningful study direction to emphasise personality expression during product design.

Throughout our product design cycle, which integrated e-textile and sonic interaction technology, we obtained valuable insights from our evaluation results. User preferences for sound aesthetics varied, with some expressing a strong interest in creating their own sound scenarios. The appearance of the product also played a significant role, with a majority of participants favoring unique and distinctive designs over standardized ones. Notably, personalization emerged as a recurring theme during interviews, indicating the importance of allowing users to express their individuality through the product's design.

Our project shows the immense potential of combining e-textile technology with sonic interaction, enabling the creation of products that enhance sensory experiences while providing opportunities for personal expression and customization. As the field of e-textiles continues to evolve, our findings underscore the significance of incorporating user preferences and personalization into the design process to create appealing and successful products.

9.3.1 Interaction Design

During the design phase, a crucial question arose regarding the interaction between the prototype and the user's movements. We deliberated on two main approaches: one involving instructing and driving the user's movements to achieve precise and controlled sound generation, and the other focused on predicting the user's movement trajectory to enable spontaneous and unpredictable sound generation. Each approach offered distinct advantages and considerations. Ultimately, we opted for a hybrid approach that combined guidance and spontaneity, aiming to strike a balance between control and freedom in the user experience.

Establishing the interaction mechanism was a pivotal step after identifying and defining the desired functionalities of the product. We explored two mechanisms: one based on predicting user movements and the other involving assigning specific sounds to different body positions. These mechanisms allowed for a combination of guided instructions and user creativity, enabling users to engage in planned movements while also having the freedom to explore and create spontaneous musical compositions.

During the development of our interactive sonic product, we found the integration of Pure Data and Bela to be highly effective for audio programming. Pure Data provided a versatile audio synthesis tool, facilitating the creation of a wide range of sounds and effects. Its user-friendly interface streamlined our workflow. Moreover, Bela offered exceptional capabilities for ultra-low latency audio and sensor processing, making it an ideal platform for our project. The seamless integration of Pure Data and Bela enabled us to design and implement sonic interactions with efficiency and precision. Looking ahead, as audio programming technology continues to advance, it holds tremendous potential for further innovation and development in the e-textile and sonic interaction domain.

Our project has yielded valuable insights into user preferences, the significance of personalization in product design, and the establishment of effective interaction mechanisms for e-textile-based sonic interactive products. The successful integration of Pure Data and Bela exemplifies the possibilities and advantages of audio programming technology in this context. These findings contribute to the advancement of e-textiles and sonic interaction, paving the way for future research and innovation in this exciting field.

10
Discussion

In this thesis, we investigated the feasibility of using e-textile combined with sonic interaction to provide a playful experience. In this section, we will discuss the results and other findings throughout the duration of this project. Zimmerman, Forlizzi, and Evenson [83] suggested four lenses for assessing an interaction design research contribution: process, invention, relevance, and extensibility. We will first illustrate the reflections of this research, and will extend the text referring to these four aspects.

10.1 Process

10.1.1 Product Development and Iterative Design

The development of our e-textile prototype followed Hassenzahl's [20] *Why*, *What*, *How* module. We started with the "*Why*" stage by defining the problem we aimed to solve, which was to promote physical and mental health in the workplace. We then moved to the "*What*" stage, where we identified the functions our e-textile product needed to have, such as detecting body position and providing relaxation prompts through sound. Finally, we arrived at the "*How*" stage, where we determined the technical requirements and design considerations for our prototype, such as using acceleromter sensors for data collection and integrating Pure Data and Bela for audio programming. By following this module, we ensured that our e-textile product met the needs of our target users and fulfilled its intended purpose.

We conducted a product development method as our process. The knowledge gained through the design process is frequently considered rich and diversified but also incomplete, open, and ambiguous [57]. So what type of knowledge is gained through RtD? In the RtD process, knowledge is gained via the act of making. Through RtD, the prototype can be a provocation, not only about the artefact but also around the part of people's lives that it addresses [55]. Within our process of building the prototype, we have been exploring various possibilities of integrated sensors into clothes.

The development of SID is in line with the trends of the third wave of human-computer interaction, which includes culture, emotion, and experience in interactions rather than just function and efficiency [5]. Referring to this book: *The Sonification Handbook* [5], how should designers evaluate the characteristics of a complex sound in interaction is one of the biggest challenges in SID. In our project, we conducted some evaluation methods used in the UX design and product design field. These methods help us better understand our products and provide valuable suggestions for improvement.

10.1.2 Discoveries from Building E-Textile Products

Pogo pins are a popular choice for connecting circuits in electronic devices for their reliability and easy-to-use. In addition, pogo pins with magnets offer an effective way to attach different components and connect circuits. The magnets provide a strong connection between the pins and the components, which helps to prevent accidental disconnections.
Another practical tip we learned from our experience building e-textile prototypes is that conductive yarn is not always necessary. When we were building our first prototype, we used traditional electronic wires as a quick solution instead of conductive thread. We found that the data transmitted by the traditional wire was more stable and accurate due to its low resistance and rubber insulation protection. In contrast, the performance of the conductive thread can be affected by body movement and external pressure, which can cause disturbance in the data. It is important to ensure proper insulation and prevent short circuits regardless of the material used. While conductive yarn can be useful for specific design purposes, it is not always the most practical choice for building functional e-textile products.

Insulation is indeed crucial when building an e-textile product as it ensures that the conductive materials do not come into contact with each other and cause a short circuit. This is especially important when working with wearable technology that comes into direct contact with the human body. The insulation not only protects the user from electrical shock but also protects the delicate electronic components from damage due to moisture or sweat. There are various types of insulating materials available, such as rubber, plastic, or fabric coatings, and it is important to choose the appropriate type for the specific application. In addition, proper insulation also improves the overall durability and longevity of the product, ensuring that it remains functional for an extended period.

10.2 Invention

It is a challenging work to build an interactive electronic product from scratch. For product development, it is beneficial to try different materials out through hands-on exploration. Although selecting and testing different electronic components are time-consuming and excruciating, these experiments help us build a basic understanding of how various electronic components work and which one fits with what kind of situations.

From our design vision, we created this project as a integration of product and art, but more focused on the product design perspective. Our desire was to take advantage of e-textile to design a product that could promote desk workers to have regular breaks during work, and efficiently relax their body during the break with sonic interaction. At the same time, we hoped to decrease users' screen time by using a body-controlled device without using eyes. The smartphone has become a dependent product in our daily life, and our vision to help people relax through a less electronic design so we can decrease the usage of electronic screens.

It's important to note that the congruence and incongruence of a product design can have a significant impact on the user experience [22]. In the case of our e-textile product, we have intentionally designed it to be incongruent with traditional "smart clothes" by using different materials and construction techniques. This incongruence can be seen as a positive feature, as it can bring a sense of novelty and surprise to the user.

We intentionally made the design trace less obvious, which allows for more room for personalization and customization. Users can add their own embellishments or modify the product to their liking without disrupting the overall design. This approach not only makes the product more appealing to a wider audience, but also encourages creativity and individuality.

On the other hand, the sound mapping aspect of the design is more under the congruence structure, as it is a more common feature in wearable technology. By making this aspect of the design congruent with user expectations, we can ensure that users feel comfortable and familiar with how to interact with the product. Balancing congruence and incongruence in design can be a delicate process, but it can lead to a more engaging and enjoyable user experience.

10.3 Relevance

Our research spans across several fields, including soma design, sonic interaction design, product design, and wearable electronics. As we developed our design, we observed users engaging with it, particularly when motion sensors were incorporated into the garment. We found that people were delighted to make various movements to explore the changes in sound that resulted from their actions. In designing the sonic interactions, we emphasized the importance of the action-perception loop [5]. To study the effectiveness of different sound scenarios, we created three interactive modes for users to compare. We discovered that a soft, soothing sound was an effective way to guide users into slow stretches. However, in the mode that was intended to elicit swaying movements, we observed a gap between the designers' intention and the users' actual usage. Some users struggled to operate the mode as intended, which affected their ability to enjoy the sound. Furthermore, we found that users preferred more complex modes that required them to master the corresponding operation methods and control objects. Timely feedback was crucial, as users were left with a negative impression if they took action but did not receive sound feedback.

Sonic interaction design related to two crucial parts: first is sound design; the other is the interaction design which refers to mapping design. How to design the sound itself is an open question, balancing pleasantness versus annoyance, artistic expression or the capacity to comprehend the message delivered by sounds, as in the case of interactive sonification [5]. In designing the sound for our product, we faced the challenge of accommodating diverse user preferences while maintaining a focus on natural and ambient sounds that resonate with most people. However, given our goal of providing both entertainment and relaxation, we recognized the need for greater flexibility in our sound design. The interaction design aspect of our project also required extensive research and experimentation. While we initially employed simple interactive mapping approaches related to our topic, the possibilities for exploration in this area remain endless.

10.4 Extensibility

10.4.1 Wearable Technology as a Design Medium

As a subdivision in wearable technology, e-textiles have unique challenges and opportunities. The integration of electronic components into textile materials requires a deep understanding of both fields, as well as knowledge in areas such as circuit design and power management.

Building an e-textile product involves a significant amount of manual work, such as stitching and soldering. Unlike traditional electronics, e-textiles require special techniques to integrate electronic components into fabric or clothing. The process usually involves hand-sewing conductive threads onto the fabric, attaching electronic components with conductive adhesive or soldering, and carefully routing wires and components to prevent short circuits. These manual processes require a high level of skill and attention to detail, making e-textile product making a time-consuming and labor-intensive process. This can also be a main reason that it doesn't fit in vast market now.

While the manual labor required to build e-textile products can be a challenge, it is not the only reason why these products may not yet have achieved mass market appeal. Other factors such as cost, durability, washability, and ease of use also play important roles. Ensuring the durability and washability of e-textile products can be challenging, particularly as they need to be able to withstand repeated bending, stretching, and washing.

However, from a wearable technology point of view, clothes can be an ideal medium to collect our body data. The "smart" clothes can know our gesture, motion, heartbeats, and even moods. Which manifestly provides a lot of design possibilities. As technology advances and more user-friendly materials and techniques become available, the potential for e-textile products to become more widely adopted may increase. With continued innovation and development, e-textile products may in the future become a common and accessible part of everyday life. As the technology continues to advance, e-textiles have the potential to transform the way we interact with our clothing and accessories, making them not just functional, but also fashionable and personalized.

10.4.2 Sounds as a Design Medium

Sounds can be a powerful design medium, capable of evoking emotions, creating a sense of atmosphere, and conveying information. For a product, sounds can enhance user engagement and immersion. By placing more emphasis on sound design, designers can create experiences that are more memorable and engaging for users. In sonic interaction design, designers carefully craft sounds to communicate with users and create a more engaging and immersive experience. However, designing effective sounds can be a challenge. Balancing the aesthetic qualities of sounds with their functionality is a delicate process. Sound design can also be subjective, as individuals have different preferences and interpretations of sound. Furthermore, the context in which sounds are used can greatly impact their effectiveness. For example, sounds that are pleasant in one situation may be irritating or distracting in another. With careful consideration and experimentation, designers can leverage the power of sound to create more impactful and engaging designs.

10.4.3 Future Work

After the design processes and the evaluation studies, we found that three interaction scenarios were not enough for daily use purposes. More complicated interaction could create more engagement and be provided in future. Some participants also mentioned that the range of the sound types could be broadened, such as different music genres and sounds which evoke autonomous sensory meridian responses (ASMR), etc. To be packed, a mobile application could be introduced. Such software would include choosing different sound modes and a timer function to set up a working schedule.

Referring to the feedback on the appearance of our prototype, customized design is very important for some users. The future product could provide space for users' design freedom, such as selecting electronic components to realize different functions or selecting different base clothing and decoration to satisfy users' personalised aesthetics.

Meanwhile, we pursued to design a product that could promote a working style with regular breaks to increase the working efficiency. This vision needs to be further developed with revisions and validation verification to study if it could increase working efficiency.

Moreover, we would like to address the problem of short-term engagement with our prototype by exploring multi-functionality. For example, health detection is an popular function of the current wearable equipment. For our future product, it will have the ability to detect body position and remind users of incorrect sitting positions like forward neck, hunchback and scoliosis. The product could also have the function to maintain a comfortable body temperature by warming and cooling the garment. A timer which can remind users to take breaks is included in future work as well. Since the working styles vary by person, a breaking schedule will be given as a recommendation, and users can change the rate and time for each break.

For hardware optimization, we can use more accelerometers on different positions to create more attractive and complex interactions. We can also collect more data from one accelerometer sensor, we only used the y direction for now, but there can be more. Different sensors can work as different modules and can be added in a detachable way for customers to customize their "work suits". Meanwhile, more emerging sensors can be used in e-textile with the development of technology.

As technology advances, there is a possibility that the interaction mechanism of e-textile products could be further enhanced. One potential direction is to incorporate machine learning or other advanced technologies to improve the accuracy and sensitivity of gesture recognition. This would enable the product to recognize more complex movements and respond accordingly, providing a more intuitive and seamless user experience.

10.5 Limitations

Some of our initial patches cannot be played properly in the speakers, especially when it comes to low-frequency sounds. We tried some sound effects, such as a heartbeat sound or an ambient diving sound; however, these layers would disappear when we used the speaker we assembled to test. Hence, we modified our patches to ensure that they only generate sounds with frequencies which could be generated by the speakers.

E-textile is a developing technology needing more studies and practices to advance to the next stage. Many e-textile applications are still in their infant phase. Since the components are embedded in our garment, such as fabric sensors; they should be washable, non-toxic, and resistant to surface shear [33], it is not easy to find a reliable commercial product satisfying those requirements.

For sonic interaction design, sonic aesthetics is a big challenge. The designers of sonification should either be literate or skilled in aesthetic thinking and practice [84]. Through design phase, we iteratively refined our patches referring to the feedback from both evaluation participants and designers ourselves.

There are also some evaluation limitations. We hope this product can be used in people's daily life. An ideal scenario would be that our evaluation participants use the prototype during their work time for a long period and then give us some feedback about their experience. We would also be interested in the feedback on using EaseFit in a relatively long-term duration. This would enable us to get insight into if EaseFit helps improve work efficiency and if users would get bored easily after a while. In this work, we only assessed their experience with different patches in a relatively short interaction duration.

Another aspect is the sustainability of our product. As our final product, the garment was equipped with electronic components that involve safe, biodegradability and deposition of electronic materials [14]. For instance, the textile battery is applied in our product which has some potentially hazardous materials. We have properly sorted the waste of the design and production process.

10.6 Process Bias

Since the time and material are limited, we preferred to utilize the existing resources like accelerometer, heart-beat sensor and speaker kit that could be accessed easily. In addition, the same type of electronic components from different producers were not compared. For a similar reason, it restricted iterative design that the prototype would be complicated and time-consuming to refine. For instance, to revise the wiring sometimes should overthrow the old one and start over, which would spend piles of time and energy.

Given that our prototype is not a mass-produced commodity, components can not be customized to our design. We mainly tested and assembled the existing commodity like Bluetooth speakers and power banks to our prototype. They might have a satisfactory performance during the testing, but the shape, size or volume was not adapted to our design. They were eliminated for design concessions.

10.7 Evaluation Bias

There were researcher and participant biases during the evaluation studies [85]. The study participants were mostly university students or students who just graduated since they were the most accessible to us. The evaluation results might vary by different types of work or participant demographics. Regarding the evaluation process, we hoped to conduct an evaluation study that would involve longer usage periods, such as a week or a month, in order to gather feedback from users on the longer-term effectiveness. However, we did not conduct a follow-up evaluation due to time and resources limitations, which might cause bias in evaluation results.

11

Conclusion

This thesis is purposed on investigating the question:

> *How can e-textile and sonic interaction be used to provide a playful and relaxing experience for desk-workers at home?*

The aim is to create an interactive sonic design product in combination with e-textile, designed for desk workers at home. A product that provides a playful experience involving different interactions with users. Our project highlights the potential of e-textiles and sonic interaction for improving human sensory experience. By combining these two emerging trends, we were able to create a product that provides a playful and relaxing experience for desk-workers at home.

The result showed that this kind of product could provide a playful experience for desk workers at home. We designed a product named EaseFit, then completed and tested our prototype, an intelligent garment, which realized the sonic interaction using e-textile technology. The prototype's concept is to capture users' body movements and generate sounds corresponding to the movements. The prototype verified the feasibility of providing a playful experience using e-textile combined with sonic interaction. The evaluation results also showed high acceptance of this kind of product.

Our initial idea is to take advantage of e-textile and sonic interaction technologies to design a product that could be used in people's daily lives. From an idea to an implementable concept, it experienced quite a number of developments and screenings. The concept of the final prototype was determined after quantitative literature reviews and several implementations of conceptualization methodologies. The exploration of conceptualization included several brainstorming sessions, travelogue mappings, concept development and elimination tools to convert the research ideas into a common-meaning concept.

Furthermore, we completed the prototype through design iterations, prototyping, and evaluation studies. The prototype verified that e-textile products could be designed as entertainment equipment and a tracksuit at home. Evaluation results showed the feasibility and potential of developing wearable equipment to remind people to have regular micro-break when working from home.

Throughout our iterative design process, we encountered challenges and learned valuable lessons about the importance of user-centered design and rapid prototyping. We also gained insights into the potential market opportunities for e-textile and sonic interaction products, particularly in the realm of wearable technology and home-based sensory experiences.

11.1 E-textile

The emergence of e-textiles has revolutionized the fashion industry by enabling the creation of garments that can interact with the surrounding environment. E-textiles are mainly utilised in the medical and art areas. However, our research focuses on developing a piece of daily entertainment equipment in combination with sonic interaction used at home. Through prototyping, we embedded electronic components, including different sensors, speakers and a microprocessor, in a piece of ordinary clothing. The feasibility of this daily use concept was proved after completing our prototype, and the possibility got positive feedback from the evaluation results.

In the field of electronic textiles, one of the major challenges is ensuring that the wearable garments are washable without causing damage to the electronic components. During our research and development process, we recognized the importance of finding a solution to this issue, and through experimentation and testing, we came up with an effective solution. Our approach involved the use of pogo pins, which allowed for the electronic components to be detachable from the fabric of the garment. Additionally, we designed and 3D printed shells to protect those subtle components. We demonstrated that our approach was feasible and effective, offering a promising solution to the challenge of washability in electronic textiles.

11.2 Product Design

Through our product design cycle, which integrated e-textile and sonic interaction technology, we gained valuable insights from our evaluation results. We found that users have varying preferences for sound aesthetics, with some expressing a desire for DIY sound scenarios. Furthermore, users also placed importance on the appearance of the product, with many stating that they preferred a unique design rather than a formulaic one. During the interviews, the topic of personalisation repeatedly arose, suggesting that emphasising personality expression during product design could be a meaningful study direction.

Overall, our project highlights the potential for combining e-textile technology with sonic interaction to create products that not only enhance human sensory experiences but also provide opportunities for individual expression and personalisation. As the field of e-textiles continues to develop, our findings suggest that incorporating user preferences and personalisation into the design process will be essential for creating successful and appealing products.

During the design phase, a fundamental question arose about the interaction between the prototype and the user's movements. Specifically, we had to decide whether the prototype should drive the body to move with instructions or predict the user's movement trajectory to generate sound with spontaneous movements. This question required careful consideration and a thorough understanding of the potential user's needs and preferences.

On one hand, driving the body to move with instructions would allow for more precise and controlled sound generation. However, this approach could limit the user's creativity and spontaneous expression, potentially hindering the overall user experience. On the other hand, predicting the user's movement trajectory could lead to more unpredictable and diverse sound generation. This approach could offer users more freedom and creativity in their movements, resulting in a more engaging and enjoyable experience.

A compromise method is to take a hybrid approach that would combine both of these methods. This approach involved providing some guidance to the user in the form of suggested movements or sound scenarios, while still allowing for spontaneous movement and sound generation. By doing so, we aimed to strike a balance between control and freedom, resulting in a product that would be both enjoyable and satisfying for the user.

We recognized the importance of establishing the interaction mechanism after identifying and defining the product's desired functionalities. For example, the mechanism of interaction could be designed by predictions that the designers predict the movements that users may do. This mechanism can avoid most interruptions of sound by coding the possible movements of users. The random movements of users should be collected and learned by designers or machines. Another mechanism should assign each body part's position a particular sound. This mechanism can encourage users to perform specific movements with instructions to reach the stretching-out purpose. Instructions on how to trigger the sound should be provided, while also allowing for user creativity in free musical compositions.

During the development of our interactive sonic product, we found that the combination of Pure Data and Bela was particularly useful for audio programming. Pure Data is a powerful tool for audio synthesis that allowed us to create a wide variety of sounds and effects. Additionally, its user-friendly interface made it relatively easy for us to work with.

Furthermore, Bela is a powerful platform that provides ultra-low latency audio and sensor processing capabilities, making it an ideal choice for our project. By integrating Pure Data with Bela, we were able to create a seamless and efficient workflow for designing the sonic interactions. As audio programming technology continues to evolve, it is exciting to consider the possibilities for further innovation and development in this field.

11.3 Process Design

Testing the interaction unit iteratively is a crucial step in the design process to ensure that the product meets user needs and expectations. Rapid Iterative Testing & Evaluation (RITE) is a methodology that can be particularly useful for testing and refining prototypes in the early stages of development.

In our project, we used RITE to evaluate our design repeatedly and make quick refinements. We combined RITE with soma design, a framework for designing and evaluating interactive systems, to get instant feedback from both designers and participants. This allowed us to improve the usability, functionality, and overall user experience of our product.

By testing and refining our design through multiple iterations, we were able to address issues and make improvements to the interaction unit. This iterative approach ultimately helped us create a more effective and user-friendly product that better meets the needs of our target group.

During the evaluation phase, it is essential to gather feedback that can be used to inform product development. To achieve this, we utilized a questionnaire designed to connect and compare our patches both horizontally and vertically. This approach allowed us to evaluate each patch's features separately, scale their effectiveness, and compare them with one another to gain a better understanding of user preferences. By utilizing this methodology, we were able to gather crucial insights that informed the refinement of our prototypes and ultimately led to a refined design.

11.4 Future

More complex sonic interaction scenarios would be provided for future work to satisfy different user groups. The sound types could be broadened, such as different music genres and sounds which arise from the autonomous sensory meridian response (ASMR). It could be beneficial to introduce a personalized sound mode to utilize the user's endorsed sounds in interaction. To be packed, a mobile application could be launched. The application would include choosing different sound modes and a timer function to set up a working schedule.

For the aesthetic aspect, the future product could provide space for users' design freedom, such as selecting electronic components to realize different functions or selecting different base clothing and decoration to satisfy users' aesthetics.

Moreover, we plan to add features to our prototype to address the issue of short-term engagement by enhancing its multi-functionality. In particular, we believe that incorporating health detection capabilities could be an important step forward in this regard, given the current limitations of many existing wearable devices. By detecting the user's body position, for example, our prototype could provide valuable reminders about incorrect sitting positions, such as forward neck, hunchback, and scoliosis. This added functionality would not only make our product more attractive and useful to potential users, but would also help to promote healthier habits and improve overall wellbeing.

In addition, there is an evaluation expectation for future work. We hope to conduct a long-term evaluation in the future. In that case, we could receive users' feedback on having it relatively long term, like a week or a month. This would enable us to get insight into if it helps improve work efficiency and if users would get bored easily after a while.

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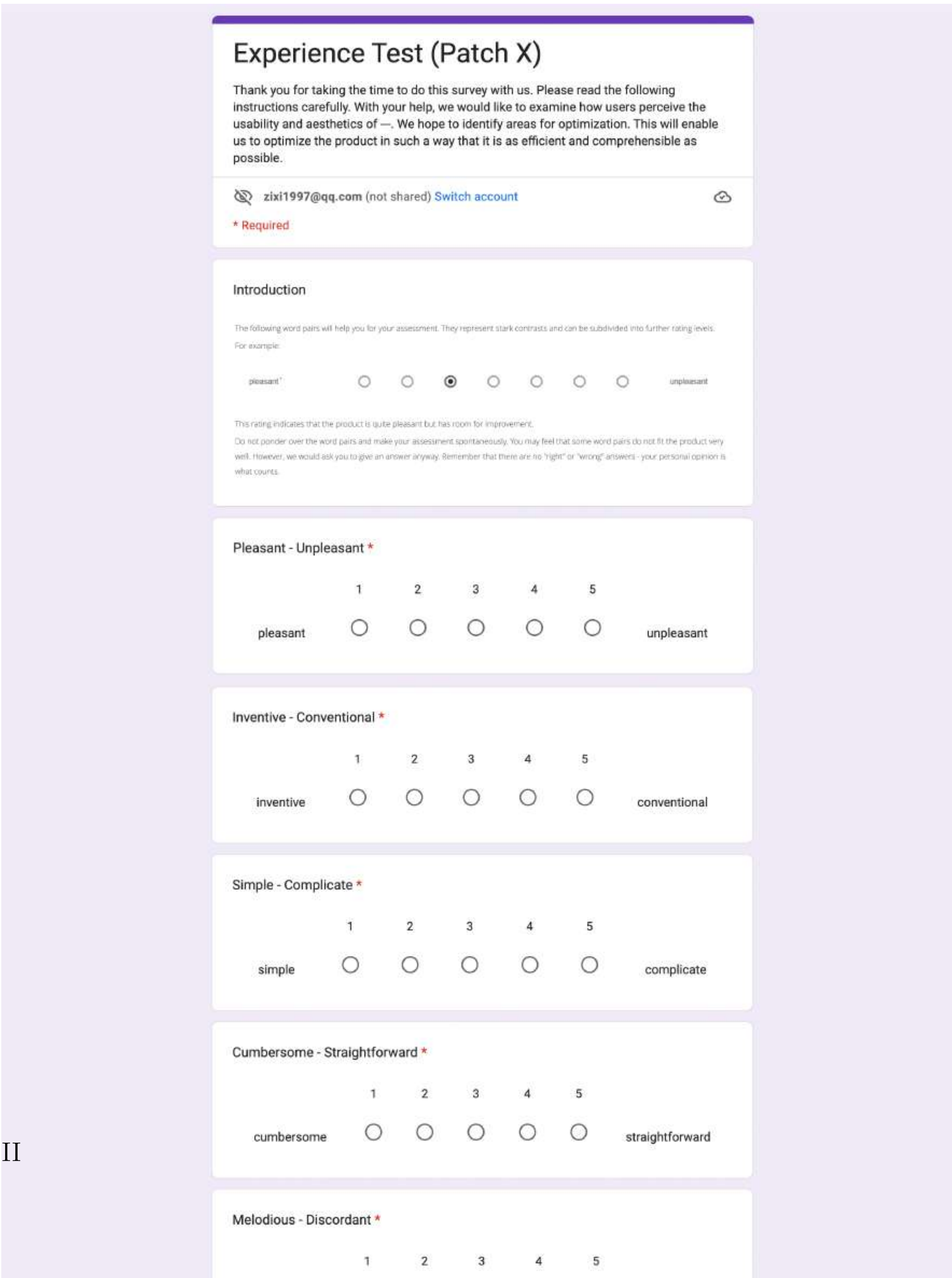
A

Appendix 1

A.1 Questionnaire



Experience Test (Patch X)

Thank you for taking the time to do this survey with us. Please read the following instructions carefully. With your help, we would like to examine how users perceive the usability and aesthetics of —. We hope to identify areas for optimization. This will enable us to optimize the product in such a way that it is as efficient and comprehensible as possible.

zixi1997@qq.com (not shared) Switch account

* Required

Introduction

The following word pairs will help you for your assessment. They represent stark contrasts and can be subdivided into further rating levels.

For example:

pleasant* ○ ○ ◉ ○ ○ ○ ○ unpleasant

This rating indicates that the product is quite pleasant but has room for improvement.

Do not ponder over the word pairs and make your assessment spontaneously. You may feel that some word pairs do not fit the product very well. However, we would ask you to give an answer anyway. Remember that there are no "right" or "wrong" answers - your personal opinion is what counts.

Pleasant - Unpleasant *

	1	2	3	4	5	
pleasant	○	○	○	○	○	unpleasant

Inventive - Conventional *

	1	2	3	4	5	
inventive	○	○	○	○	○	conventional

Simple - Complicate *

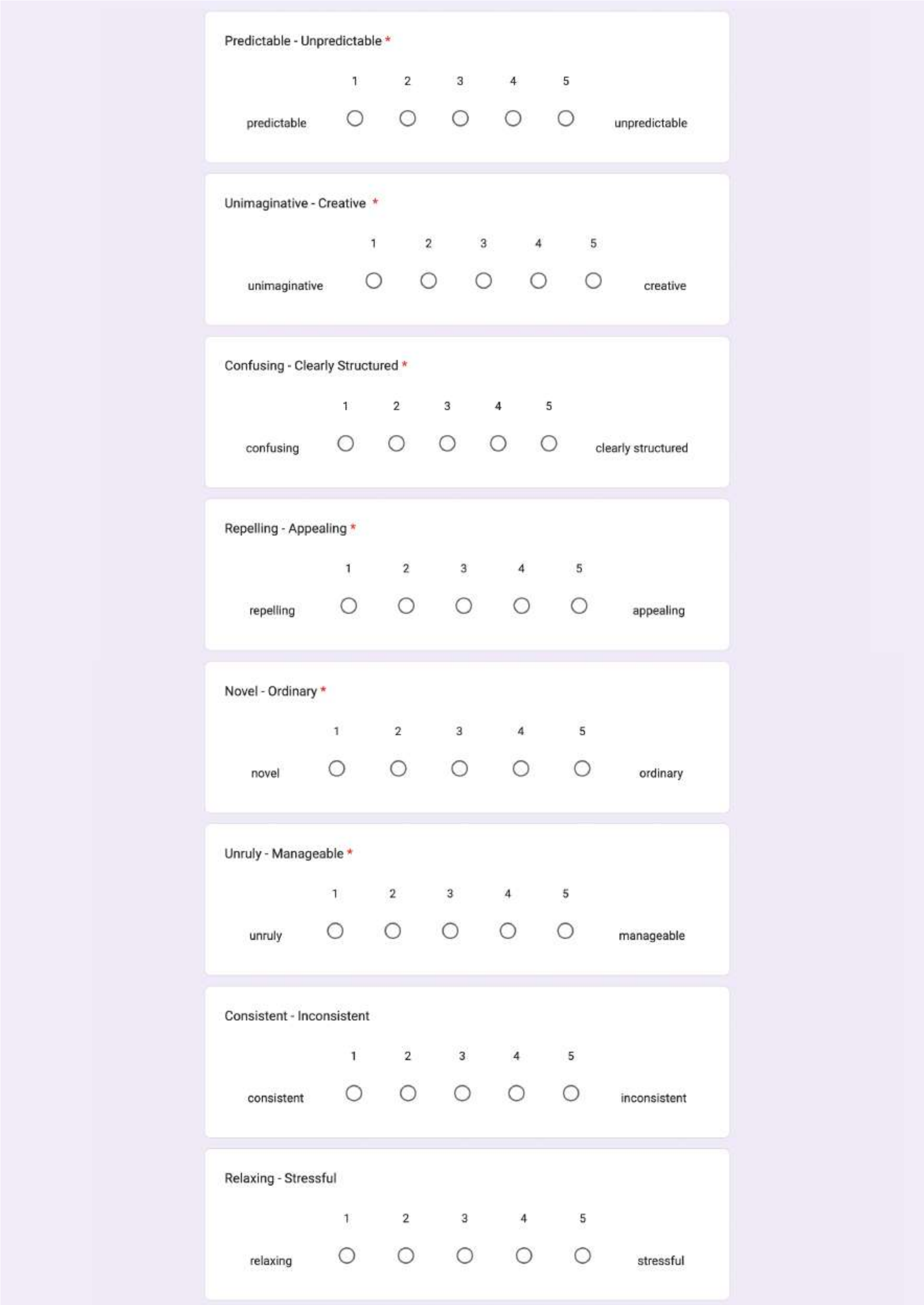
	1	2	3	4	5	
simple	○	○	○	○	○	complicate

Cumbersome - Straightforward *

	1	2	3	4	5	
cumbersome	○	○	○	○	○	straightforward

Melodious - Discordant *

1 2 3 4 5



Predictable - Unpredictable *

	1	2	3	4	5	
predictable	○	○	○	○	○	unpredictable

Unimaginative - Creative *

	1	2	3	4	5	
unimaginative	○	○	○	○	○	creative

Confusing - Clearly Structured *

	1	2	3	4	5	
confusing	○	○	○	○	○	clearly structured

Repelling - Appealing *

	1	2	3	4	5	
repelling	○	○	○	○	○	appealing

Novel - Ordinary *

	1	2	3	4	5	
novel	○	○	○	○	○	ordinary

Unruly - Manageable *

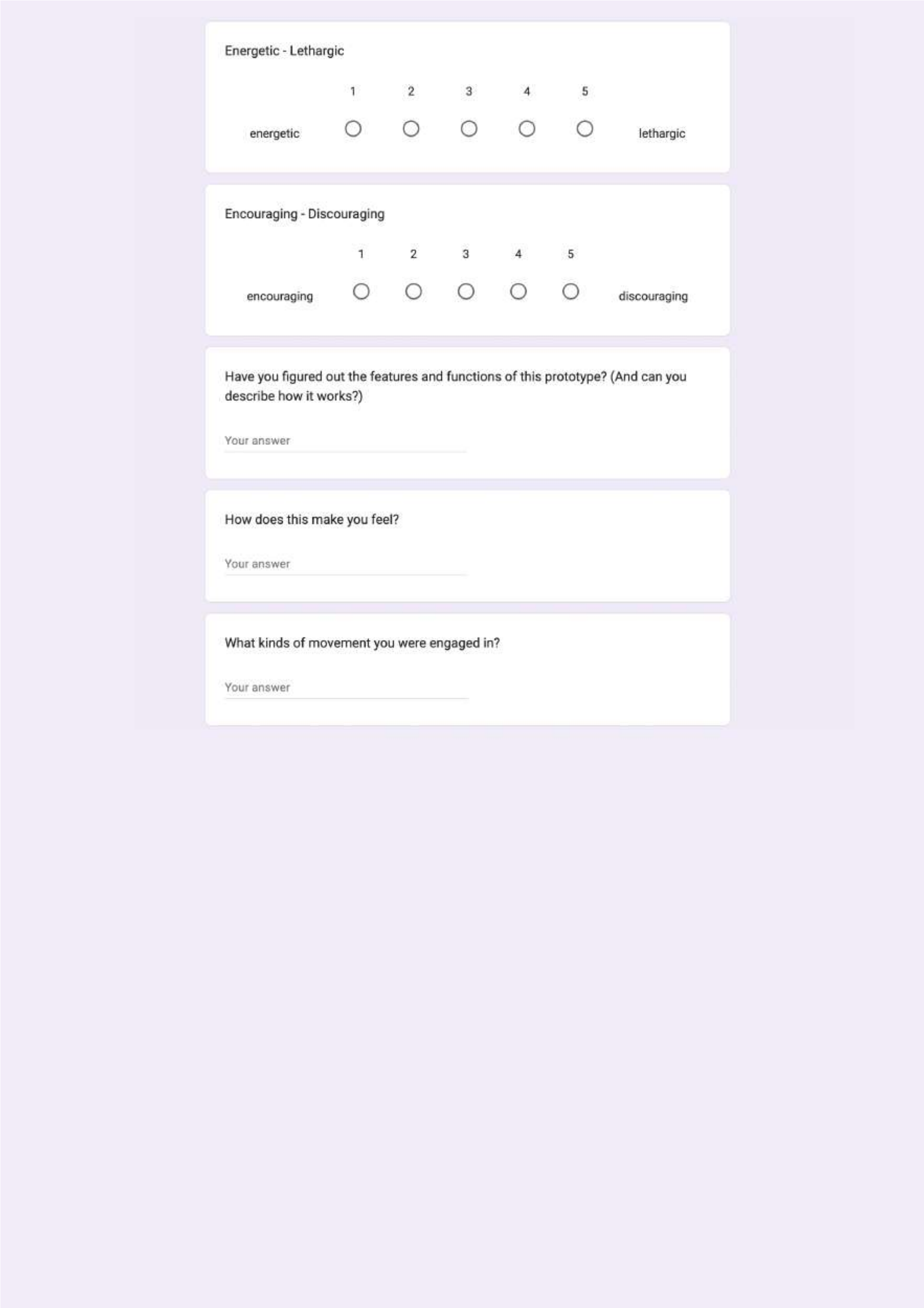
	1	2	3	4	5	
unruly	○	○	○	○	○	manageable

Consistent - Inconsistent

	1	2	3	4	5	
consistent	○	○	○	○	○	inconsistent

Relaxing - Stressful

	1	2	3	4	5	
relaxing	○	○	○	○	○	stressful



Energetic - Lethargic

	1	2	3	4	5	
energetic	○	○	○	○	○	lethargic

Encouraging - Discouraging

	1	2	3	4	5	
encouraging	○	○	○	○	○	discouraging

Have you figured out the features and functions of this prototype? (And can you describe how it works?)

Your answer

How does this make you feel?

Your answer

What kinds of movement you were engaged in?

Your answer

Figure A.1: Evaluation questionnaire

A.2 Timeline

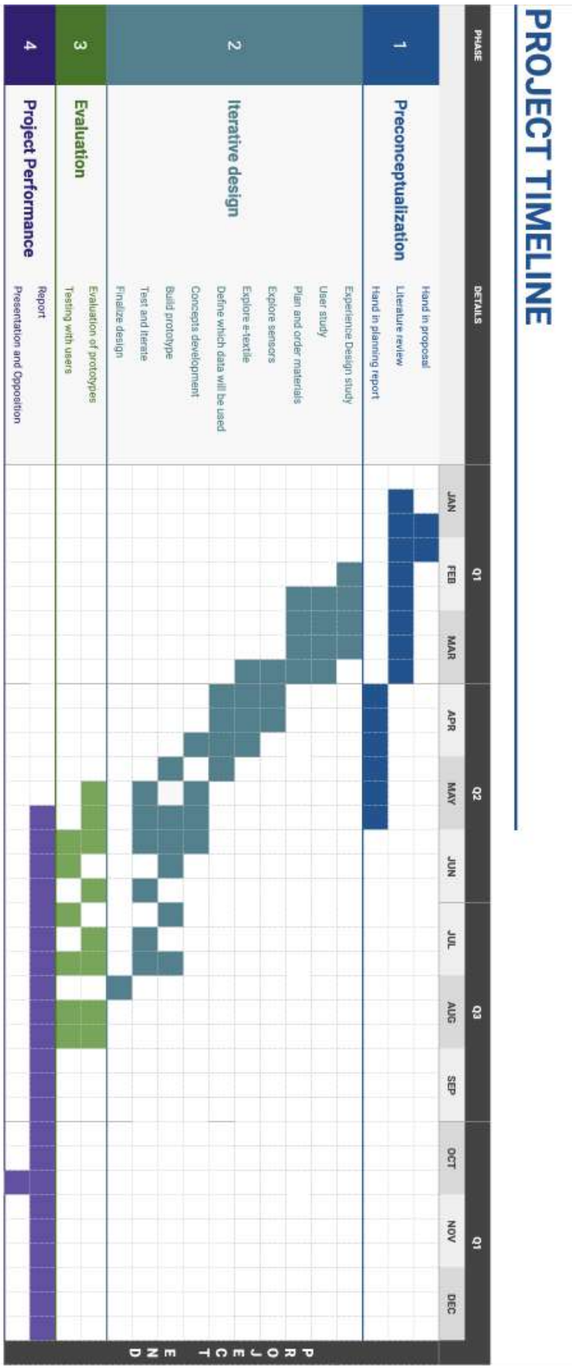


Table A.1: Timeline of the project

A.3 Interactive patches

A.3.1 Patch 1

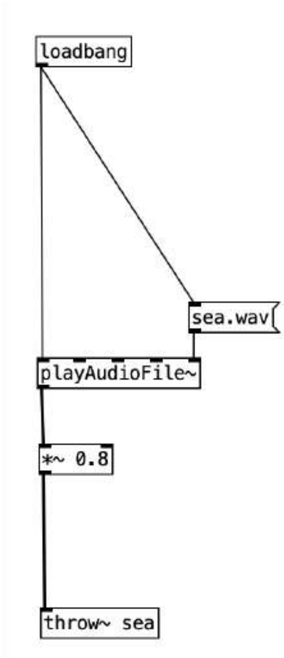


Figure A.2: Background patch

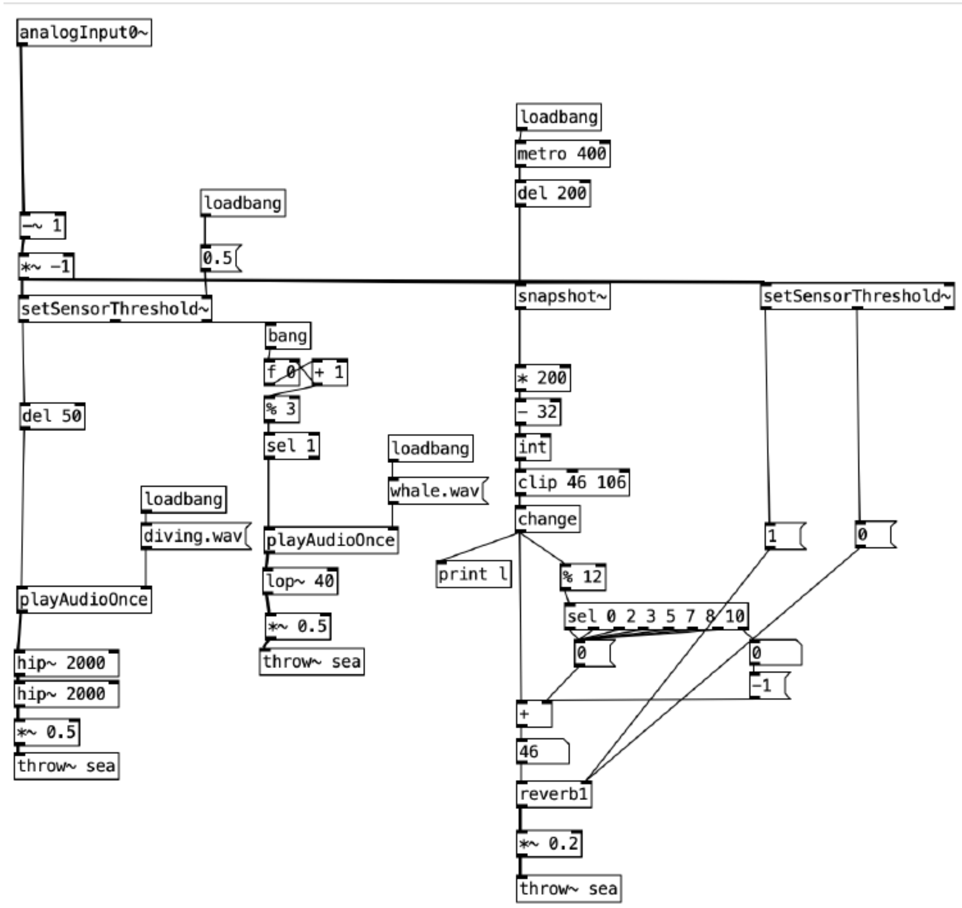


Figure A.3: Interaction patch

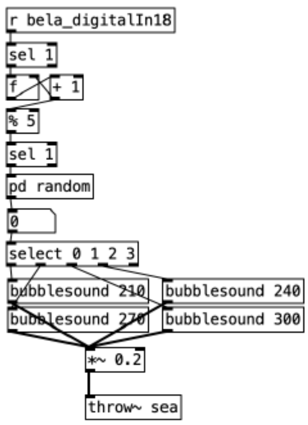


Figure A.4: Several bubble patch

A.3.2 Patch 2

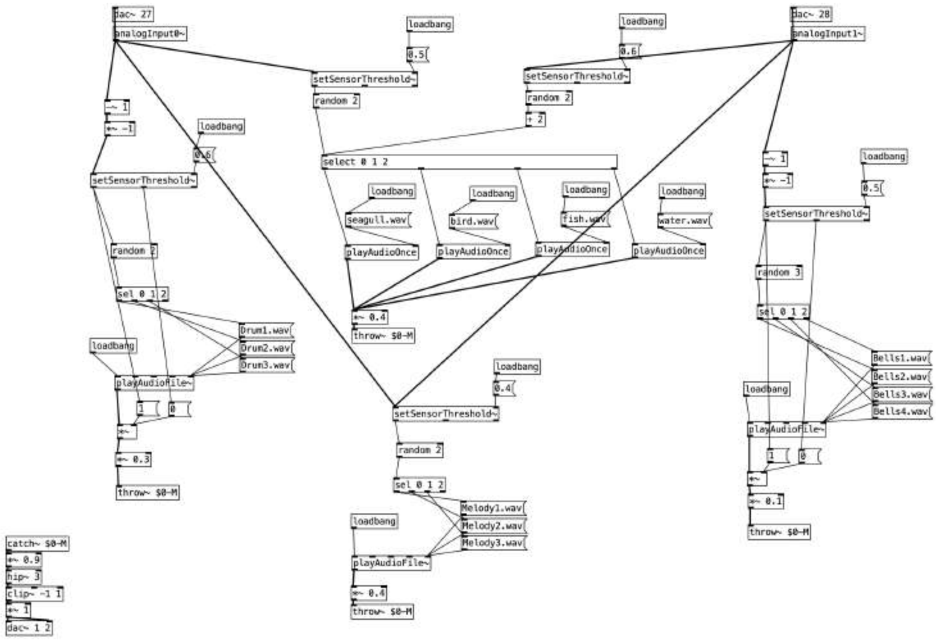


Figure A.5: The holistic patch of nature theme

A.3.3 Patch 3

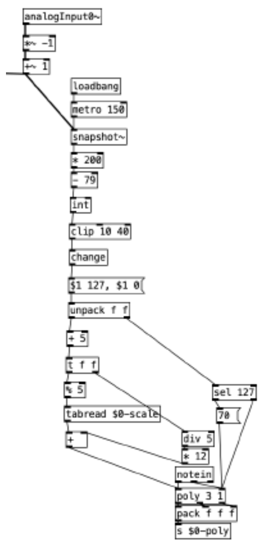


Figure A.6: The control setting part of harp theme

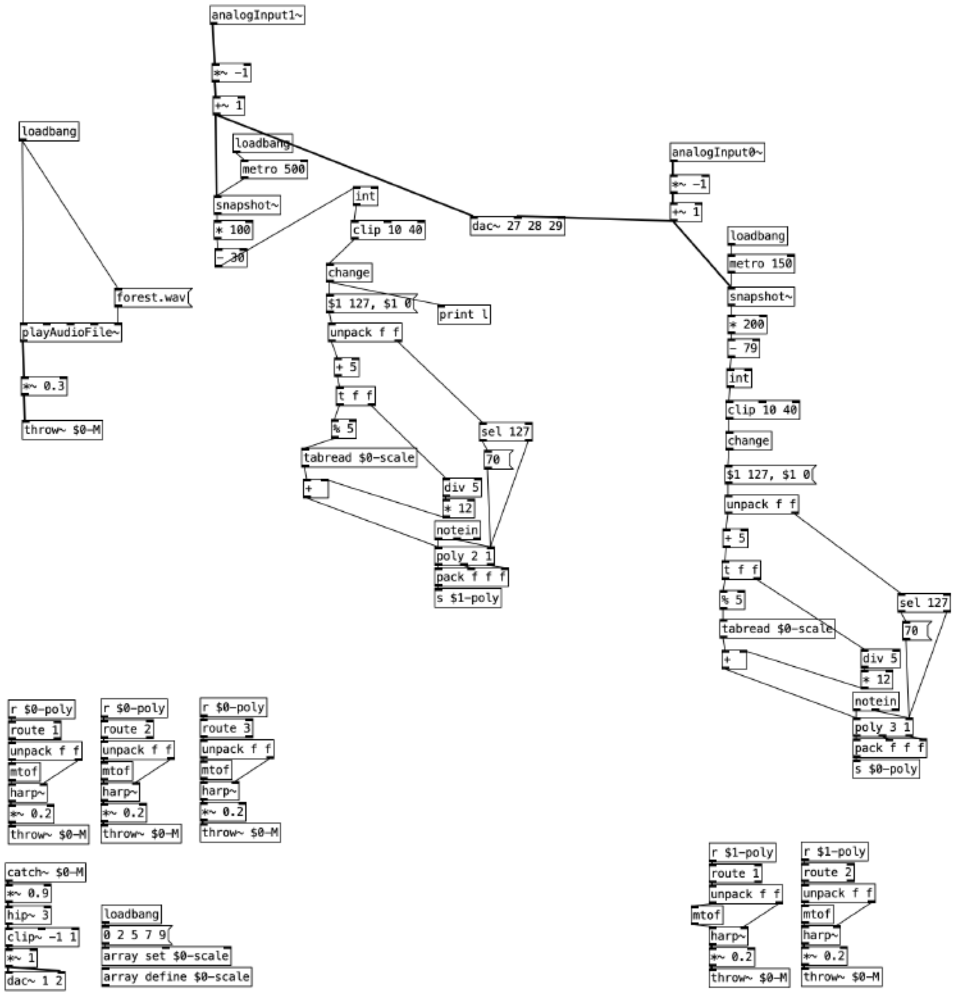


Figure A.7: The holistic patch of harp theme

A.4 Sound lists

Sea background sound: `https://freesound.org/s/213914/`
Whale sound: `https://freesound.org/s/88449/`
Stroke sound: `https://freesound.org/s/474624/`
Forest background sound: `https://freesound.org/s/607116/`

B

Appendix 2

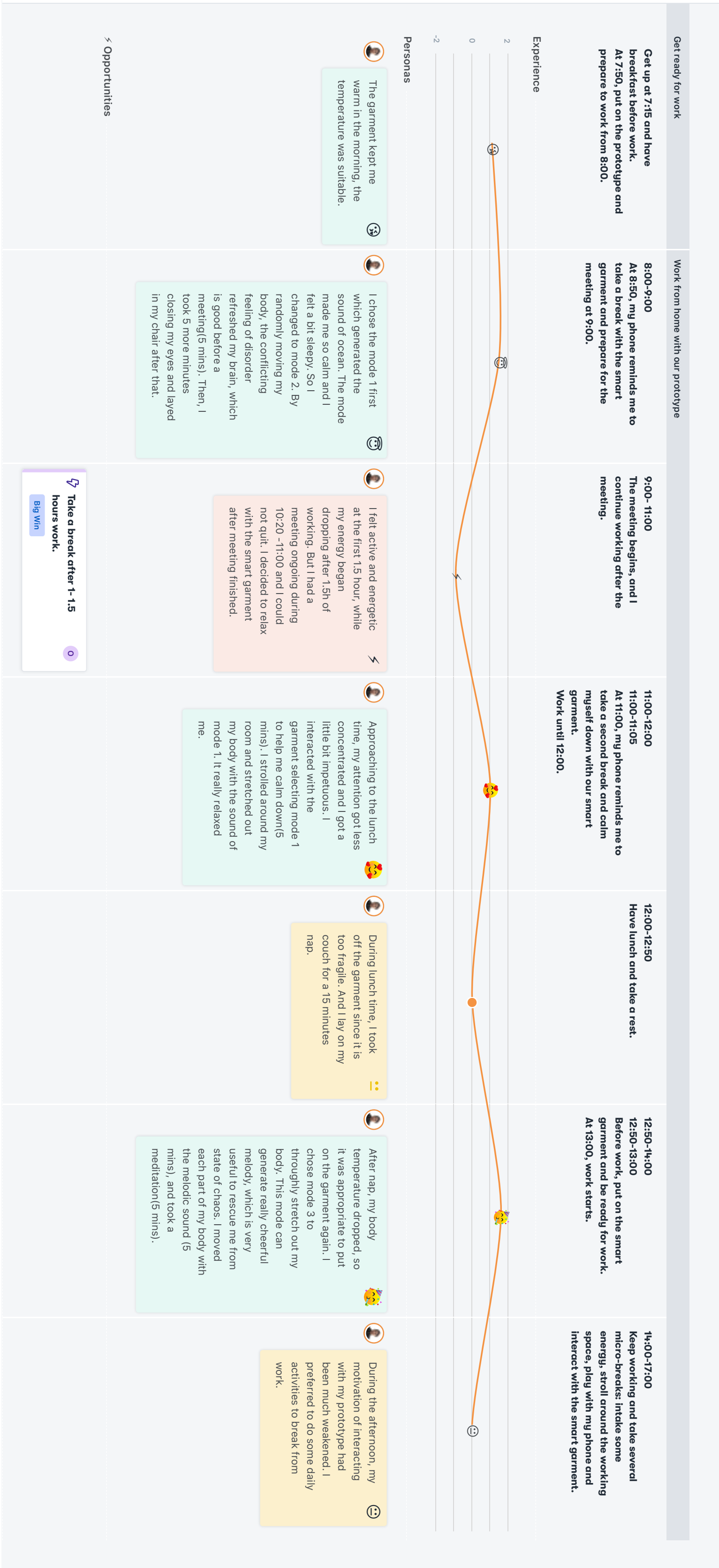


Figure B.1: The first person perspective study