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Enhancing communication for people with voice disabilities

Design of a speech enhancement device that utilises existing components to improve communication for individuals with voice disabilities.

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Master Thesis Enhancing communication for people with voice disabilities

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EXECUTIVE SUMMARY

This master's thesis focuses on designing a speech enhancement device intended to improve face-to-face communication for individuals with voice disabilities. Conducted in collaboration with Whispp, a company specialising in assistive voice technology, the project builds upon Whispp's AI-powered app that converts whispered or impaired speech into clear, natural-sounding speech. The goal is to create a microphone that connects to the app, enabling seamless real-time communication in various social settings.

Voice disorders affect millions of people worldwide, significantly impacting their personal and professional lives. Current assistive devices often lack comfort, discretion, and usability, leaving room for innovation. This project follows the Double Diamond design methodology, starting with user research to identify needs and challenges. Interviews and surveys revealed that users prefer lightweight, discreet, and hands-free devices that can adapt to different environments.

Four concepts were developed: an extendable necklace, an around-the-ear boom, a ring, and a voice nosepiece. Following an evaluation involving weighted objectives and user feedback, the around-the-ear boom design was chosen for further development due to its comfort, effectiveness and discreet design. The final design features an ear hook with a flexible hinge for size adjustment, a compact body to house the internal components and a microphone wire. The device connects wirelessly to a phone via a dongle, transmitting the user's voice to the Whispp app for processing. Audio output options include phone speakers, a wireless speaker, or open-ear headphones. The estimated production cost of the complete set, including a carry case, microphone and open-ear headphones, is €75.61. The microphone alone costs €40.15, resulting in an anticipated retail price of approximately €200 for the full set and €100 for the microphone.

User testing confirmed the device's comfort, usability, and functionality. This thesis illustrates how thoughtfully designed assistive devices can seamlessly support everyday communication and enhance quality of life for people with voice disorders.

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CHAPTER 1 - INTRODUCTION

The ability to speak clearly plays an important role in both our personal and professional lives. According to Martins et al. (2014), around 6-15% of the population experiences voice disorders. A voice disorder is characterised by issues with how the voice sounds, such as changes in pitch, loudness or quality, that are not normal for a person's age or gender (Ad Hoc Committee on Service Delivery in the Schools, 1993).

Voice disorders can stem from a variety of risk factors and biological mechanisms. Such disorders can result in impaired physical and psychosocial functioning (Merrill et al., 2011). Some common voice disorders include: laryngitis, spasmodic dysphonia, polyps, precancerous and cancerous growths, and vocal cord paralysis or weakness (Mayo Clinic, 2022).

Individuals with voice issues, such as dysphonia, often experience emotional distress due to their condition and tend to have a lower quality of life (Krischke et al., 2005). The extent to which a voice disorder affects someone's day-to-day life depends on the severity of the disorder and how much the person uses their voice. It is not just about how hoarse someone sounds or what caused the problem; other factors such as the individual's voice needs and its impact on their physical, social and emotional well-being also matter (Murray et al., 2004). Therefore, even something as simple as hoarseness can have a significant impact depending on the situation.

For people who rely on their voice for work, such as teachers, singers, actors, customer service agents, lawyers, and religious leaders, the number of people affected by voice problems can go up to 50% (Oliveira et al., 2022; Martins et al., 2016). Since their jobs depend heavily on their voice, having a voice disorder can significantly impact their ability to work. Research from Roy et al. (2005) states voice disorders negatively impacted job performance and attendance, with 4.3% of participants indicating that their voice had limited or rendered them unable to do certain tasks in their job.

This demonstrates the significant impact that voice disorders can have on an individual's life. Depending on the cause, treatment may be possible. This may involve making lifestyle changes, undergoing speech therapy, taking medication, having injections or undergoing surgery (Johns Hopkins Medicine, n.d.). While this can be effective for some people, others still struggle with their voice disorder every day.

One way in which individuals with voice disorders can be supported is through the use of assistive technology. There are many devices that help people to speak and communicate when they are impaired in some way. While some people are impaired for life, others may need to use assistive devices temporarily during recovery from an accident, illness or operation. These devices and technologies improve the quality of life and safety of affected individuals (Malini & Rajkumar, 2020). Assistive technology for speech can take many forms, ranging from text-to-speech software to voice amplifiers and AI software that clarifies speech. Whispp is one of the companies dedicated to providing innovative solutions that empower individuals and transform their communication experience (Whispp, n.d.).

1.1 PROJECT

This project is carried out with the Dutch client company Whispp, which operates in the field of assistive voice technology. Whispp has developed language-independent AI technology and a voice app. The Whispp app enables individuals with voice impairments to express themselves again. Through their Assistive Voice Technology, Whispp renders whispered or rough esophageal speech clear. Currently, this technology is used in digital environments, such as phone or video calls. As part of their product roadmap, Whispp plans to expand the range of situations in which their technology can be used, with the aim of enabling its use in everyday life. With their idea for a wireless microphone connected to the Whispp app, individuals can be heard in noisy settings such as restaurants, which makes their disabilities less of an obstacle in their lives. This master's thesis builds upon this initial idea. The goal of this project is as follows:

> "Design a speech transmission device connected to speech improvement technology, enabling seamless face-to-face conversations for individuals with voice disabilities."

1.2 APPROACH

This project follows the double diamond method (Figure 1). Starting with the discovery- and definition phase, followed by the development- and delivery phases. This approach allows for an iterative design process.

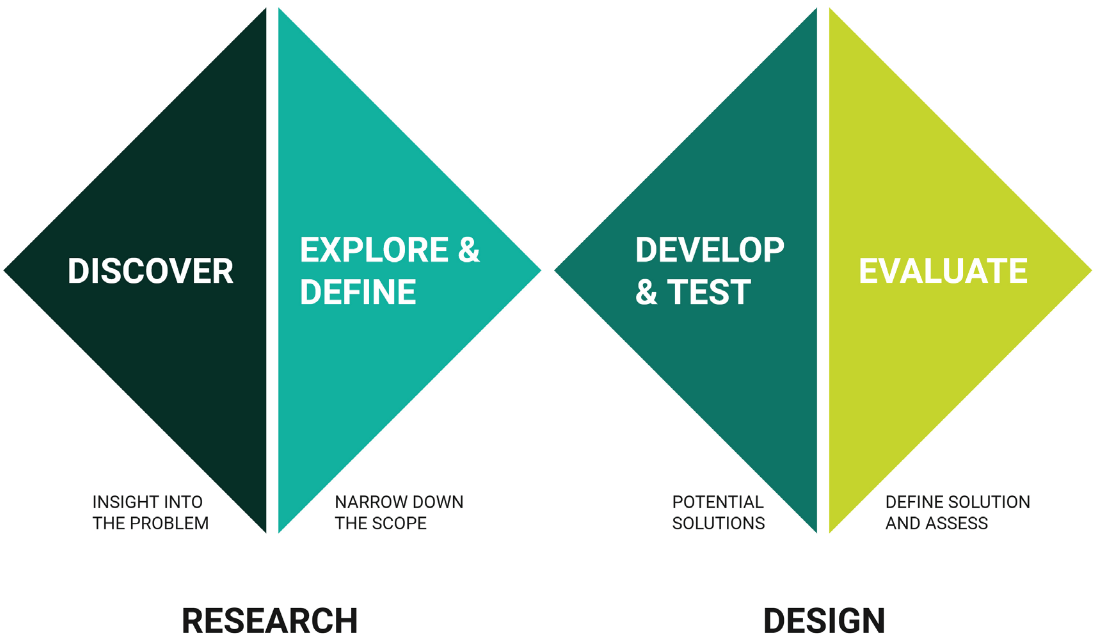


Figure 1: Double diamond used in the project (Design Council, n.d.)

The project starts with an analysis of the context, introducing Whispp and its target group. Next, the scope is further defined and design criteria are established. The design process then moves on to generating and testing concepts, concluding with the selection and evaluation of ideas.

1.3 DESIGN METHODOLOGY

As the user is at the heart of this design, the first step is to gain a deeper understanding of their needs and the challenges they face in their daily lives. This will be done through interviews, questionnaires and online research. These methods will help narrow down the project's scope, provide useful background information, and define the desired use case.

Once the context and user needs have been defined, several design methods from the Delft Design Guide will be used to generate and develop ideas. These methods include SCAMPER, WWWWWH and How-Tos. The ideas will then be developed into more concrete concepts through sketching and prototyping, and reviewed through user testing.

Alongside this, research into manufacturing possibilities and production costs will be conducted. This research will help evaluate the concept's desirability, feasibility and viability, ensuring the final design is both user-centred and realistic to produce and implement.

CHAPTER 2 - ANALYSIS

This chapter presents the context for the project. It provides a description of the client company and the identified target group, details of the research conducted and the resulting design requirements. These elements together form the basis for all design decisions made throughout the project.

2.1 WHISPP

Whispp is an assistive voice technology startup founded by Joris Castermans. Whispp's mission is to enable people with voice disabilities and severe stutters, to express themselves freely (Whispp.com, 2023). With an idea that originated in 2018, Whispp has developed assistive voice technology to aid these people. Their technology can render their whispered or rough esophageal speech voices to clearly understandable ones. People that have lost their voices due to illness, trauma or old age can use Whispp to transform their voices through a digital environment.

TECHNOLOGY

Whispp uses audio-to-audio-based AI to enable real-time voice conversion. Unlike traditional speech-to-text and text-to-speech systems, which typically introduce a latency of 2–3 seconds, Whispp's approach is language-independent and highly scalable. This makes it better suited to natural, flowing conversations.

While Whispp's voice technology does not directly address issues such as voice breaks or general disfluencies, it can benefit individuals who stutter or have voice disorders like spasmodic dysphonia. In these cases, deliberately adopting a whispered voice can result in more relaxed and fluent speech (Van De Vorst & Van Vugt, 2023).

Whispp offers both standard and personalised audio profiles. As a person's voice conveys not only information, but also emotion and identity, personalised profiles are designed to resemble the user's own healthy voice as closely as possible. These can be created using in-app recordings or by submitting past audio or video clips of the user's natural voice.

As of 2024, Whispp remains one of the few companies in the assistive technology sector to utilize audio-to-audio-based AI for phone calls and voice messages (Andersen, 2024).

TARGET GROUP

Whispp's current target group includes people with different types of voice disorders and speech impairments. These can be categorised as follows:

- **Voice disorders**: Laryngeal cancer, Vocal cord paralysis (trauma or surgery), Spasmodic Dysphonia, Muscle tension Dysphonia (MTD), Recurrent Respiratory Papillomatosis (RRP), Benign Voice disorders.
- **Disease based speech impairments**: ALS, MS, Parkinson's disease, Cerebral Palsy, Traumatic brain injury, Presbyphonia.
- **Severely stuttering people**

While people who stutter are included in Whispp's broader scope, research shows that whispering can reduce the frequency of stuttering by up to 85% (Ingham et al., 2009). As this significantly reduces the need for a speech enhancement tool, individuals with severe stuttering will be excluded from the focus of this project.

FUTURE PLANS

Whispp currently offers phone calls, video calls, and voice messages through its app. However, there are still many opportunities for growth. The product roadmap includes plans to expand into non-digital communication and to serve non-patient user groups, such as individuals seeking confidential phone and video calls. Whispp's long-term vision is to make its assistive voice technology available on every smartphone and laptop worldwide, thereby contributing to a more inclusive society. To achieve this, the company aims to collaborate with mobile network operators and major global technology companies.

STARTING IDEA

This project builds upon a new feature currently in development within the Whispp app: Live Conversation. This feature is designed to enhance real-time, in-person interactions by instantly converting whispered or vocal cord-impaired speech into clear, natural-sounding speech using Whispp's AI technology (Whispp, n.d.). The goal is to enable smooth, face-to-face communication without noticeable delay.

With this feature, the user speaks into their phone and the processed audio is played through a Bluetooth device so that conversation partners can hear it. While this setup is functional, it could be further developed to create a more comfortable and user-friendly experience. To support this, Whispp has explored various initial concepts for wearable devices to accompany the Live Conversation feature, including different types of wearable microphones (Figure 2).

Figure 2: Three initial idea sketches from Whispp

STAKEHOLDERS

The following stakeholders can be identified in relation to Whispp and the project:

- **Whispp**: The company's focus is on customer acquisition and retention, and it aims to deliver impactful solutions and foster long-term engagement.
- **Customers**: Individuals with speech impairments who require access to high-quality, user-friendly products and services.
- **Collaborators**: Potential partner companies whose interests align with Whispp and who may support product development, distribution or expansion.
- **Employees**: Whispp team members who are dedicated to delivering high-quality products and services.
- **Healthcare professionals**: Interested in innovations that support patient wellbeing.
- **Investors**: Seeking growth potential and a return on investment from Whispp's performance in the market.
- **Government**: Plays a role in setting and enforcing policies related to health, technology and public welfare.
- **Manufacturers and suppliers**: Companies interested in providing components or devices for product development.
- **Customer families**: Concerned with the health and wellbeing of their loved ones, they could influence product purchase and usage decisions.

- Media: Reporting on innovative developments and emerging technologies.
- Data privacy advocates: Focused on ensuring that personal information is handled responsibly and ethically.

As visualised in the stakeholder map (Figure 3), customers, Whispp and collaborators are identified as key stakeholders with high levels of both interest and influence. Close management of these groups is essential to ensure the success and sustainability of the project.

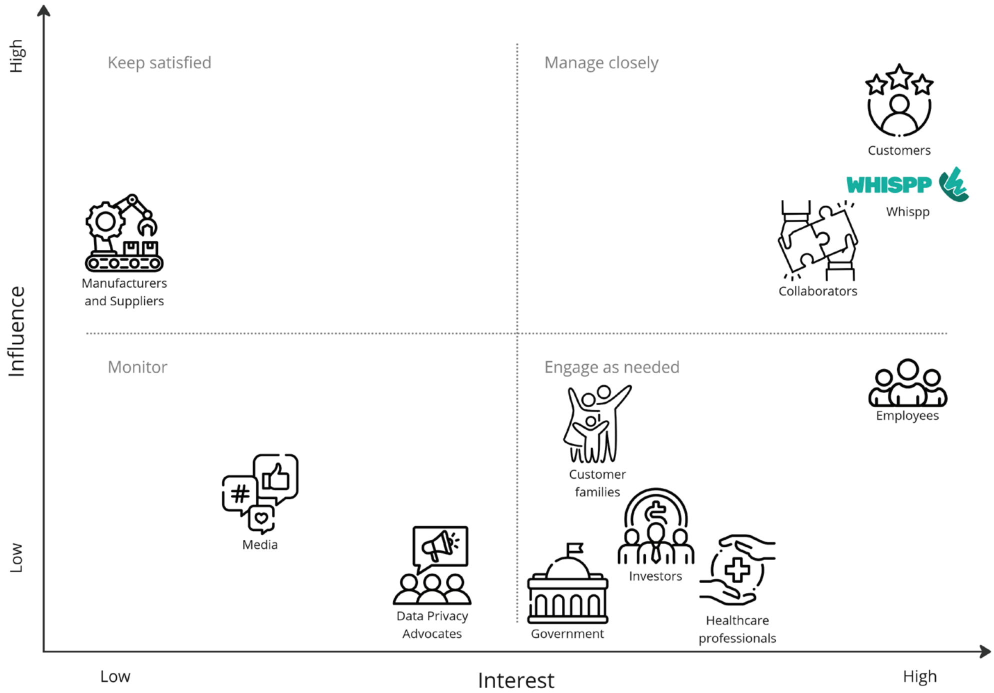


Figure 3: Stakeholder map of the project

2.2 VOICE DISORDERS

The voice is a critical part of communication and social interaction. Therefore, partial or total loss of voice can have a significant impact on quality of life and safety. Voice problems can also lead to severe functional and occupational impairment for professionals who rely heavily on vocalisation. Most people would be significantly affected by a major impairment in their speech (Naqvi & Gupta, 2020).

Speech production requires airflow from the lungs to be vibrated through the vocal folds of the larynx (voice box) and amplified in the vocal cavities formed by the tongue, jaw, soft palate, lips, and other articulators. Any abnormality in the larynx that affects voicing during speech production is referred to as a voice disorder (Barche et al., 2020).

Voice disorders can be classified into several categories based on their underlying causes (University of Minnesota, n.d.):

- Organic voice disorders
  These arise from physiological abnormalities and are divided into two subtypes:
  - **Structural:** Caused by physical abnormalities in the larynx, such as tissue damage.
  - **Neurological:** Result from issues in the nervous system that affect its interaction with the larynx, such as vocal fold paralysis or spasmodic dysphonia.
- Functional voice disorders
  These are caused by inefficient or improper use of the vocal mechanism, often related to poor muscle coordination.
- Psychogenic voice disorders
  These disorders originate from psychological or emotional factors. In such cases, the voice is affected despite the absence of physical or neurological damage.

DEMOGRAPHIC

The term 'voice disorder' covers a wide range of conditions that can manifest in various ways, either individually or in combination. Voice disorders can affect people of all ages, but studies suggest that they are particularly prevalent among children and older adults (Stachler et al., 2018). Voice problems are among the most common medical issues affecting the elderly, with estimated prevalence rates in this group ranging from 12% to 35% (Çiyiltepe & Şenkal, 2017).

CAUSED ISSUES

Voice disorders affect voice quality, pitch and loudness (Barche et al., 2020). For instance, individuals with Parkinson's disease often experience voice-related problems such as reduced volume, a monotonous tone, and articulation difficulties (Suppa et al., 2022).

Such disorders can have a significant impact on quality of life. Consequences can include social isolation, depression, anxiety, missed work, loss of income and major lifestyle changes (Stachler et al., 2018).

2.3 RESEARCH

In order to gain a better understanding of the impact of voice disorders on individuals' daily lives, the following two research questions were formulated:

- In which social environment is an assistive device most desired?
- What are the user's wishes and requirements for such a product?

These questions aim to explore potential use cases and gain a better understanding of user preferences. To collect this information, the research uses both interviews and an online survey, with participants coming from Whispp's current user base. These approaches help to gather insights and build understanding during the design process (Van Boeijen et al., 2013).

INTERVIEWS

Semi-structured interviews were conducted with Dutch Whispp users to gain insight into their voice disorders, the challenges they face in conversation and their experiences and preferences regarding assistive products. Four participants, each affected by a voice disorder, were interviewed. The participants were aged over 50 and had conditions including spasmodic dysphonia, voice tremors and partial laryngectomy.

The semi-structured approach (Sahoo, 2022) allowed participants to speak openly about their experiences, providing valuable insights for the study. A full list of the interview questions is provided in Appendix B.

While the difficulties experienced varied between individuals, several common themes emerged:

- Their voice quality often fluctuated, influenced by nervousness or vocal strain.
- They often felt that they were too slow to respond during conversations and by the time they were ready to speak, the moment had already passed.
- They were often asked to repeat themselves.
- Conversations were described as tiring, and many users expressed a desire for a little extra support to make speaking easier.

Use contexts
Several scenarios in which users face particular difficulty were identified. The most frequently mentioned were:

- Noisy environments (e.g. bars and public spaces).
- Large group conversations (e.g. meetings).
- Spontaneous or informal conversations with friends or strangers.

While most participants mentioned difficulties, one noted that they had fully adapted to their voice disorder and did not feel limited by it in their daily life.

Experiences with assistive devices
Three of the four interviewees had experience using assistive devices, specifically voice amplifiers consisting of a microphone and speaker (Figure 4). Their experiences varied:

- Some found them helpful, especially in formal settings such as presentations.
- Others found them impractical or uncomfortable to use in everyday situations.

Figure 4: Echovoice voice amplifier (Echovoice ® EV7 TM Voice Amplifier NEW MODEL, n.d.)

The main reported drawbacks are:

- Size and weight: Devices were cumbersome and visually unappealing.
- Privacy: Conversations could be overheard when the microphone was on.
- Self-consciousness: Amplifying their impaired speech made users feel exposed in public.
- Audio feedback: Users heard their own voice while speaking, causing discomfort.

Product preferences

When asked about their preferences for future devices, users consistently mentioned the following:

- Lightweight and compact design
- Hands-free operation
- Adaptability to different contexts:
    - Earphones might work well for private, one-to-one conversations.
    - Speakers were preferred for group settings or noisy environments.

ONLINE SURVEY

To support the interviews and gather quantitative data, a survey was shared with Whispp users. The survey questions were similar to those used in the interviews, but focused on collecting measurable insights and identifying the main user demographic (Appendix C). A total of 31 users participated in the survey.

The results show that the Whispp user base spans a wide age range, although most respondents are over 60 years old. The most commonly reported voice disorders were total or partial laryngectomy (TLE) and spasmodic dysphonia (SD), although a variety of other conditions were also represented. The duration of voice impairment varied significantly. Some respondents had only recently developed a voice disorder, while others had lived with one for many years.

These disorders appear to significantly impact everyday life (Figure 5). Most respondents indicated that nearly all communication scenarios are affected (Figure 6). Common issues include having a soft or hoarse voice, which makes it difficult to speak clearly, especially in noisy environments.

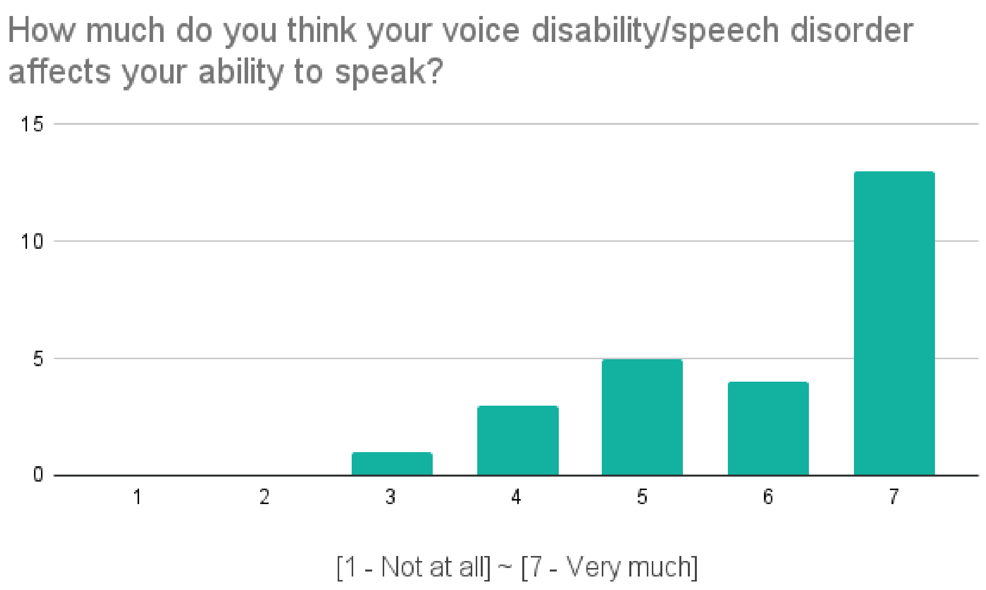


Figure 5: Degree of speech affected by voice disability

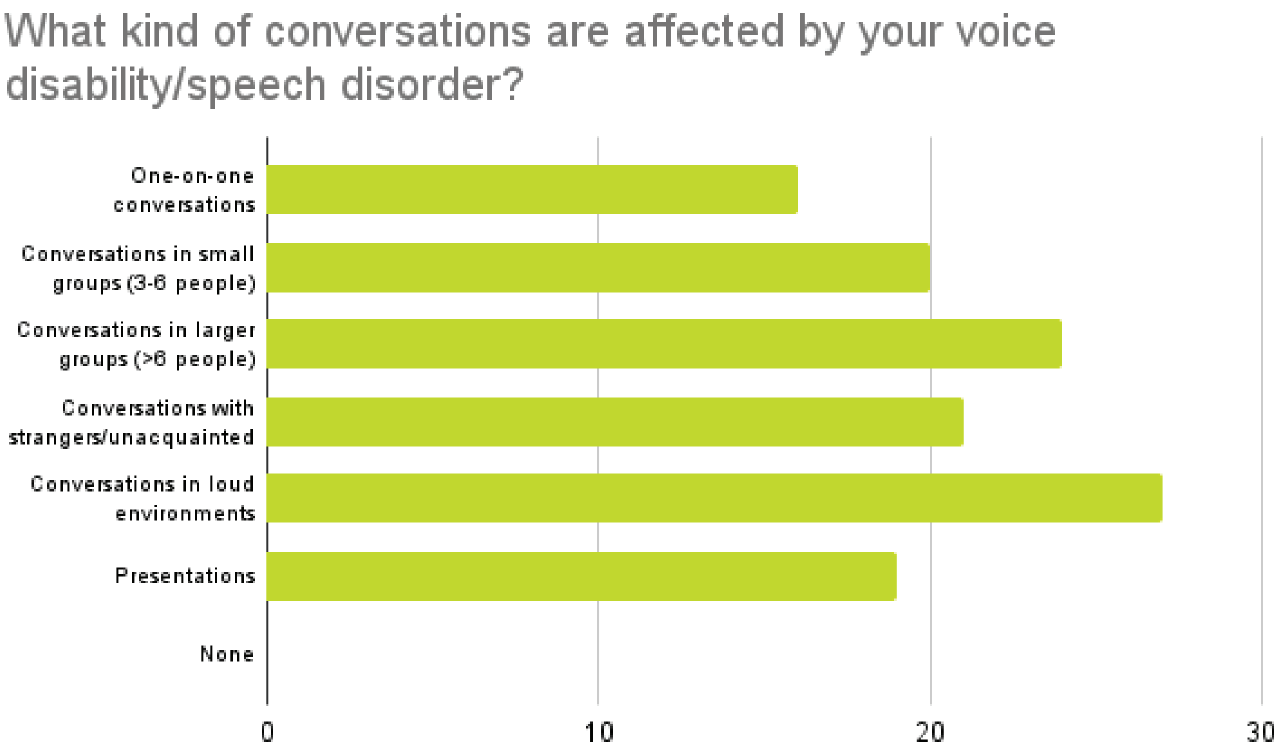


Figure 6: Affected conversation types by voice disorder

Whispp's Live Conversations feature could help address many of these challenges. The results show a clear desire to be able to engage in clear, effortless face-to-face conversations again. These findings suggest a promising opportunity for an assistive product that supports such interactions (Figure 7).

Figure 7: Importance for clear face-to-face conversations

PERSONA

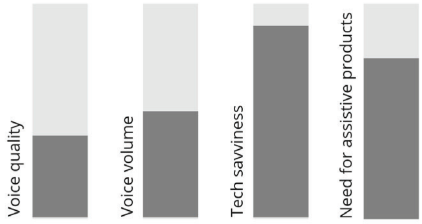
To summarise the general findings from both the interviews and the survey, two user personas were created (Figure 8). These personas represent the intended users and describe their behaviour, values and needs (Van Boeijen et al., 2013). They help to illustrate the diversity within the target group.

Name Arjan Dirksen
Age 52 years old
Occupation Marketing manager

Bio

Arjan is a marketing manager and excels in creating strategic campaigns. He has had Spasmodic dysphonia and experiences difficulties speaking and being heard. This causes difficulties in his personal and professional life. In his spare time he enjoys reading, hiking and watching football with friends.

> **" I have difficulty talking to other people in general, my voice is very low and people cannot understand me, especially when there are noises in the background. "**



Frustrations

- During meetings in larger groups he cannot be heard by everyone
- Often has to repeat what he said
- Some people do not have the patience to make an effort to want to understand him

Wants & needs

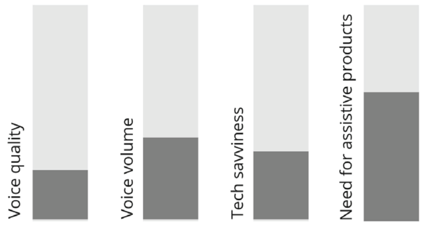
- To be heard by everyone
- Effective communication tools
- Present and introduce myself professionally

Name Mirjam van der Waal
Age 74 years old
Occupation Retired

Bio

Mirjam has been retired for a number of years and enjoys spending time with friends and family. She has partial laryngectomy and can only produce a low volume with her voice. This causes some difficulty in conversation, especially in larger groups where people can easily talk over her and she is difficult to hear.

> **" Whispp is like a safety net in my pocket all the time. "**



Frustrations

- People talk over me
- I am often too slow to say what I want in the moment
- Moving negatively affects the control of my vocal cords

Wants & needs

- To speak like I used to
- To not feel helpless
- Have an assistive device with me whenever I need it

Figure 8: Personas representing the intended users

As the target group includes people with a wide range of voice disorders, needs and preferences, using two distinct personas provides a more comprehensive overview. Personal and professional settings often involve different communication demands, which can affect how an assistive product is used.

For instance, despite having more severe issues with voice quality and volume, Marjam's overall need for an assistive device is lower than that of Arjan. She would only use it occasionally when additional support is required. In contrast, Arjan is more likely to use such a product regularly, particularly in professional situations where clear communication is essential.

These differences demonstrate that people within the same target group can have very different needs. Therefore, the design should be flexible enough to accommodate these different personas.

DEVICE PLACEMENT

As the research so far has shown, users prefer products that are discreet, lightweight and compact, and that allow for hands-free operation. The placement of the device is an important design consideration. Figure 9 shows several product placement options, along with their respective pros and cons.

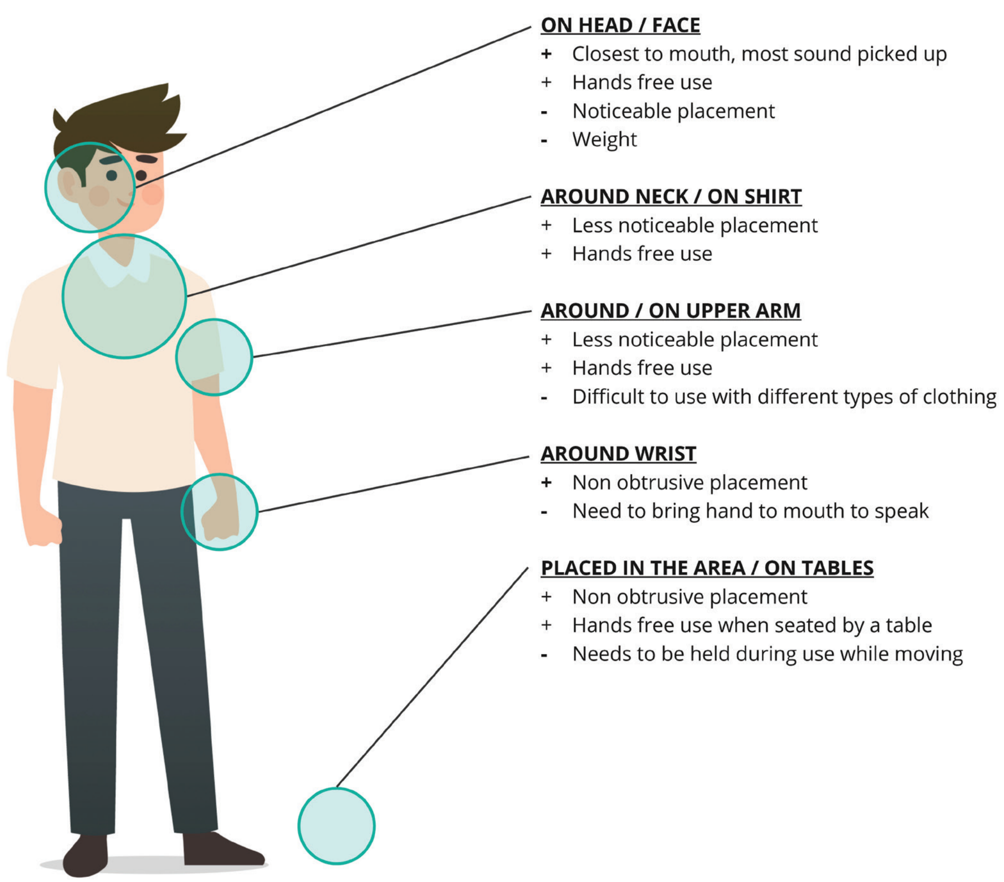


Figure 9: Device placement on person

2.4 AUDIO TECHNOLOGY

CURRENT ASSISTIVE PRODUCTS

Figure 10 presents a market analysis of assistive products and related technologies. It shows that speech assistive devices are much more limited than hearing assistive devices. Currently, speech assistive products mainly focus on amplifying the user's voice via a microphone and speaker setup. These devices typically take the form of a wired or wireless microphone worn near the mouth, or a handheld device held close to the mouth.

One of the products listed as a speech enhancer is a pair of earphones marketed as a speech enhancer that amplifies the user's voice. However, this enhancement is only audible to the person wearing the earphones, not to anyone else. Therefore, although it is marketed as a speech enhancer, it is not intended for the same target group as this project.
This analysis shows that there are currently no products on the market that fully meet the users' needs.

Figure 10: Market analysis

TECHNOLOGY ELEMENTS

In order to design a speech enhancement device, all of its components need to be examined. The communication device has three main components that need to be studied. The first is the input source, which is a microphone that records the user's voice. Next, this audio signal needs to be transmitted to the user's phone. Once received, the Whispp app can convert the voice. Finally, the converted signal is sent to an output device (Figure 11).

The output can take various forms, including phone speakers, earphones, portable speakers, or hearing aids. The preferred output device can vary depending on the location, the people involved in the conversation, and the surrounding noise levels. For this reason, it is beneficial to allow users to select their preferred output option.

Based on the research in Chapter 2.3, the four main output options are:

- **Phone speaker**: Useful for quick- or over the counter conversations.
- **Small portable speaker** : Ideal for larger groups, such as meetings, where a speaker can be placed centrally so everyone can hear the user clearly.
- **Earphones**: Suitable for conversations with acquaintances or in smaller groups, providing a more private listening experience.
- **Hearing aids**: When speaking to people who wear hearing aids, the converted voice can be transmitted directly to their devices.

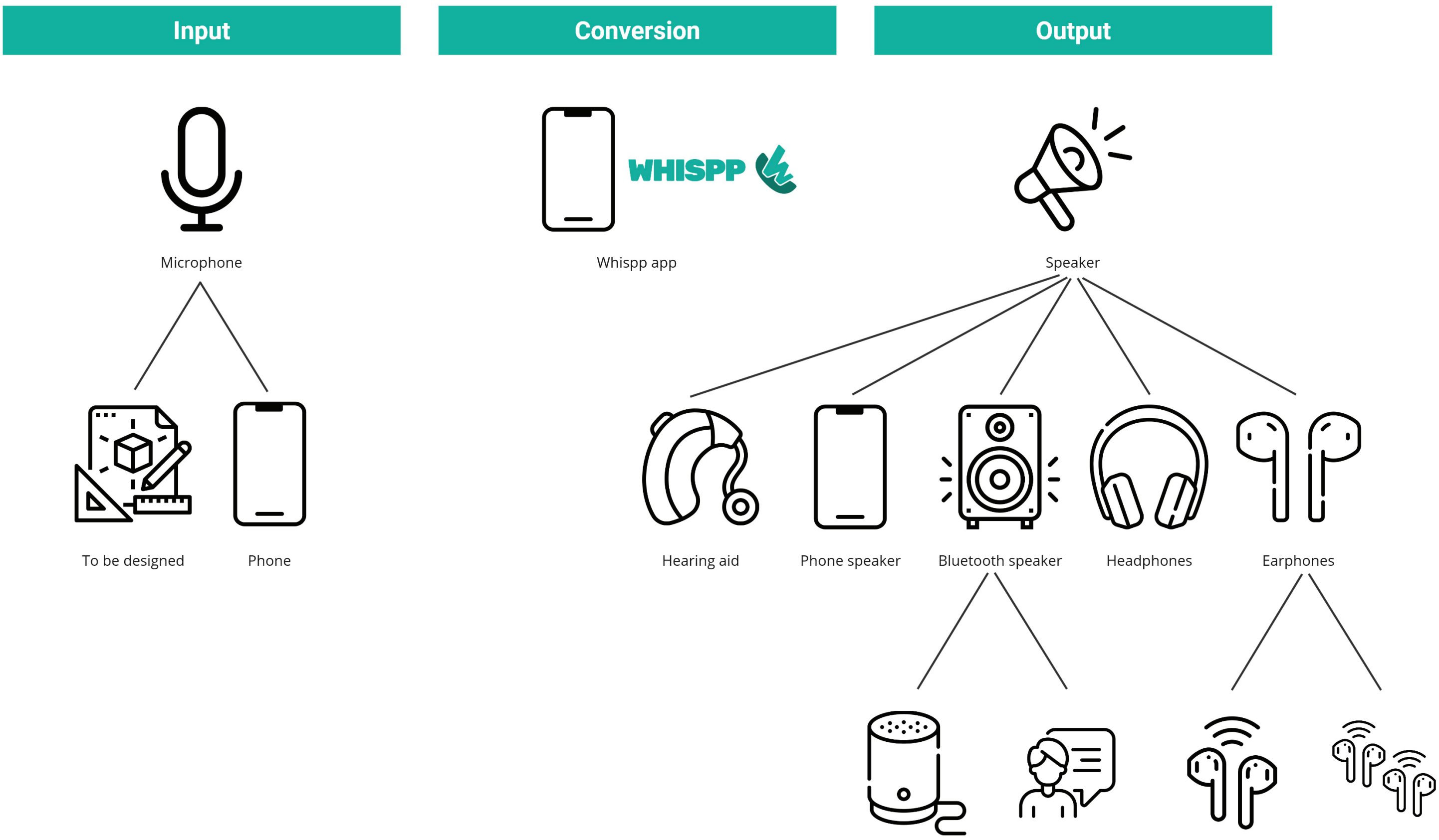


Figure 11: Input, conversion, output

CONNECTION METHODS

To pair the microphone to the aforementioned outputs, a connection method is required. There are several methods available, each with its own specific use cases, advantages and disadvantages (see Appendix E). The following connection methods were analysed:

- Wired connection
- Bluetooth
- DECT (Digital Enhanced Cordless Telecommunications)
- FM (Frequency Modulation)
- RF (Radio Frequency)

To reduce hassle for users and avoid restricting movement, a wireless connection is preferred. Wireless technologies enable devices to exchange data over short distances using radio waves. The most widely used of these is Bluetooth, with over 7 billion Bluetooth-enabled devices in use today (Sharma & Shrivastava, 2024).

One of the challenges of using Bluetooth as a connection method is maintaining low latency. Latency refers to the delay or time it takes for data to travel from one point to another in a system. Lower latency means faster communication, while higher latency means a longer delay. Latency is particularly important in real-time applications such as voice or video calls. High latency disrupts the natural flow of conversation, making it difficult for users to understand each other (Paolini & Senza Fili, 2018).

Bluetooth LE Audio supports LC3 (Low Complexity Communication Codec) to provide high quality audio with much lower latency than Bluetooth Classic. Typically, the latency is around 20 to 30 milliseconds, compared to 100 to 200 milliseconds with Bluetooth Classic (Ceva, 2023).

Another option for achieving low latency is to use RF technology, such as a 2.4 GHz digital wireless microphone system. For example, a USB-C dongle wireless receiver (Figure 12) can connect a wireless microphone to a smartphone via the USB-C port. This setup enables the direct transmission of high-quality, low-latency audio into the phone.

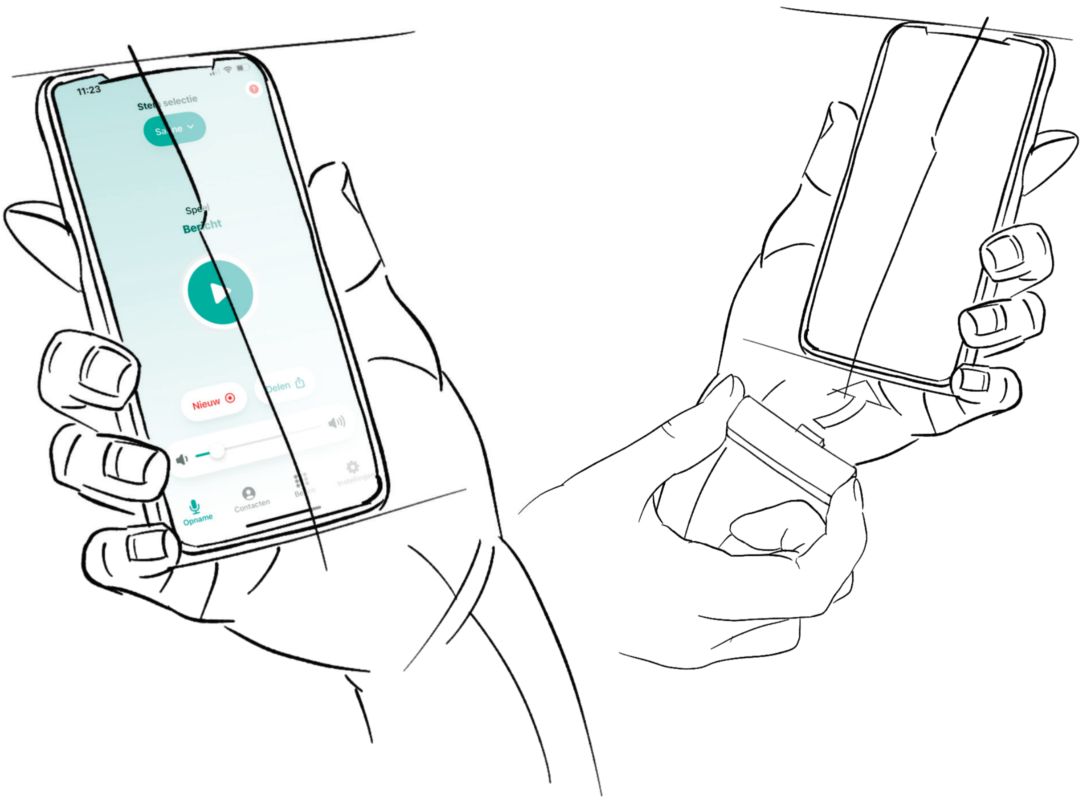


Figure 12: Phone with the Whispp app and a connectable dongle for wireless transmission

This plug-and-play setup simplifies the installation and eliminates the need for users, who may not be technologically skilled, to adjust their phone settings. This makes the solution more accessible and user-friendly for the target demographic.

In some cases, it may be desirable to output audio to multiple devices at the same time. For example, this could be useful if you want to connect multiple earphones for a few people. Achieving this requires additional configuration.

One solution is Auracast, a new Bluetooth LE Audio feature that allows a single device to broadcast audio to multiple receivers (e.g. earphones or speakers) at the same time. Another solution is to use an RF transmitter. Adding an RF transmitter to a phone dongle allows connection to multiple receivers at once. However, the connected devices also need to have an RF receiver.

Given the critical importance of low latency for real-time communication, RF is selected as the primary connection method for the microphone. To connect to audio output devices, users can either connect via the phone's Bluetooth connection, which allows connection with all Bluetooth devices they might already own. To achieve lower latency, it is preferable to a use compatible output device containing an RF receiver. Figure 13 shows an overview of the setup.

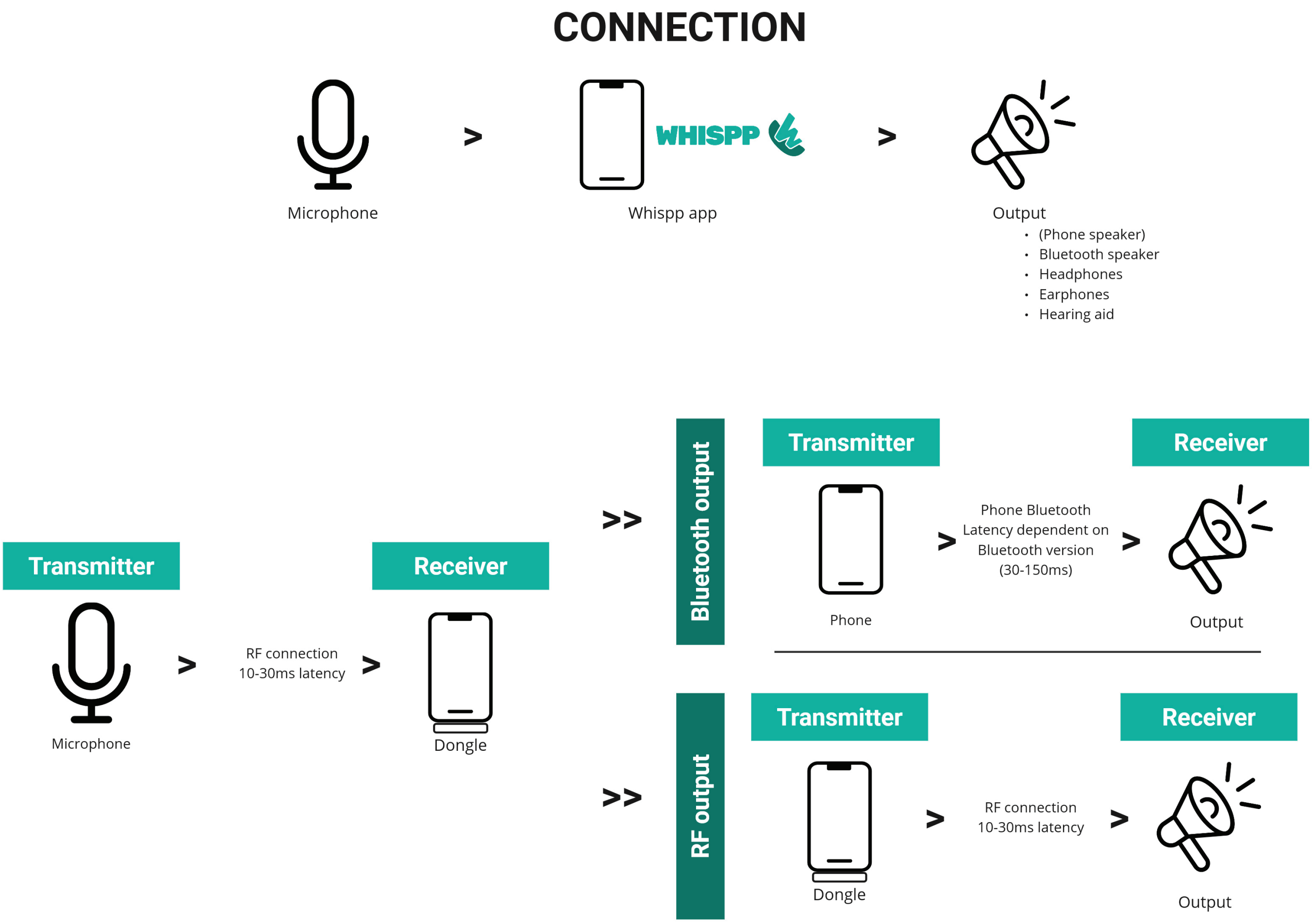


Figure 13: Connection setup

MICROPHONE TYPES

There are several types of microphones to consider for the device's input, each suited to different environments and offering varying audio quality. Figure 14 illustrates the three most common microphone types.

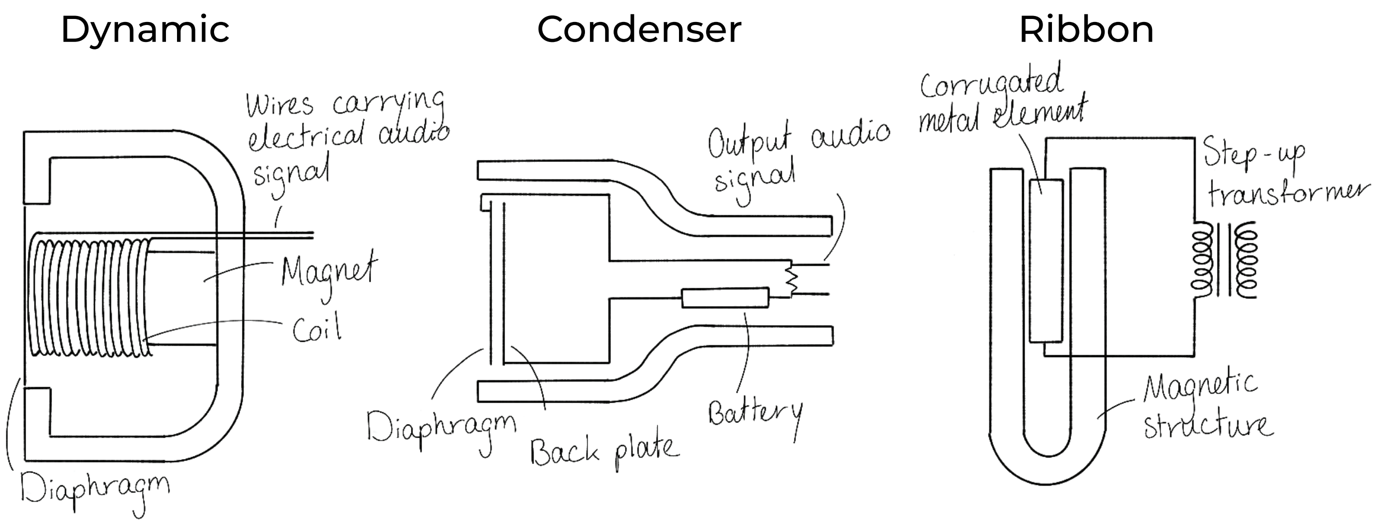


Figure 14: Three most common microphone types: dynamic, condenser, and ribbon

Dynamic microphones are commonly used for loud sound sources, such as live performances. They are frequently found on music stages, in radio studios, and in podcasting or live streaming setups, where durability and the ability to handle high volumes are essential.

Condenser microphones are the preferred choice for voiceover work and television or film productions. Their main advantage over dynamic microphones is their ability to capture the nuances and tone of voices and instruments due to their higher sensitivity.

Ribbon microphones are typically used in professional studios to achieve a warm, vintage sound. High-quality ribbon microphones provide one of the most accurate representations of voices and instruments among all microphone types, making them ideal for detailed studio recordings.

Based on the users and intended applications, a condenser microphone is the ideal choice, as its high sensitivity can capture softer speech and subtle sounds accurately.

In addition to the type of microphone, the polar pattern also plays a crucial role in sound quality. Polar patterns describe a microphone's sensitivity to sound from different directions (An Artist's Guide to Microphone Polar Patterns, 2023). They indicate which areas around the microphone pick up sound most effectively and which areas reject it (Figure 15).

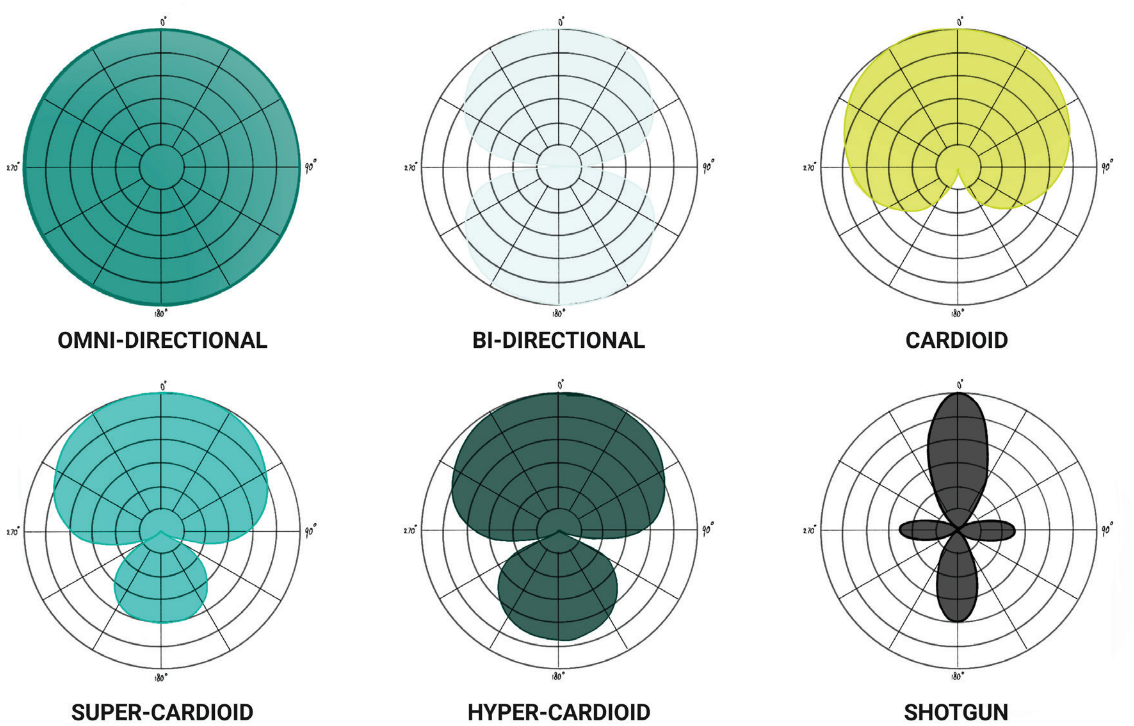


Figure 15: Polar patterns of microphones and the areas in which they pick up sound most effectively

The choice of microphone polar pattern depends largely on the product design. The shape and placement of the device can significantly influence the final selection. For this reason, the polar pattern will be chosen later in the development process, once the product design is more defined.

AUDIO TESTING

To gain a better understanding of the capabilities of the current Whispp app, an audio test was conducted. The test evaluated the app's performance when processing voices with various speech impairments and decibel levels. This test used voice recordings of people with total laryngectomy, spasmodic dysphonia, vocal cord paralysis and healthy voices. These recordings were played at various sound levels to test how well the Whispp app could pick up their voices. Each recording consisted of 50 words and was played at a whisper level (20-30 dB) and at soft-to-loud speech levels (40-50 dB, 50-60 dB and 60-70 dB). See Appendix F for a detailed description of the test setup.

Table 1: Whispp app output

Measured decibel	Sound level	Accurately converted speech by the Whispp app
60-70 dB	Louder speech	99%
50-60 dB	Regular speech	97.5%
40-50 dB	Softer speech	93%
20-30 dB	Whisper	4.5%

Table 1 shows the results of the test. The test revealed no significant differences between the types of voice. However, speech volume and pronunciation were important factors. The Whispp app does not register very soft voices (below 30 decibels) clearly. It also became evident that the louder the input sound, the better the app could convert voices.

As the microphone is intended for use in noisy environments, the effect of background noise on audibility should be considered. Research shows that, on average, noise levels in restaurants have been measured at below 77 dB over the past two years (Sand et al., 2024), which is typically the level at which one would need to raise their voice. For people with voice disabilities, this level of background noise will have a significant impact.

Another test was conducted to assess the impact of background noise on Whispp's performance (see Appendix G). These tests were conducted using two types of background noise. One involved 'restaurant noise', comprising unintelligible conversations and sounds of movement, and the other involved 'conversation noise', comprising intelligible conversations. Figures 16 and 17 show how background noise affects the app's output. In a noisy restaurant, for example, the app often fails to detect soft voices. Even speech at normal levels of 50-60 dB can be drowned out by ambient noise, which makes communication particularly challenging for individuals with voice disorders.

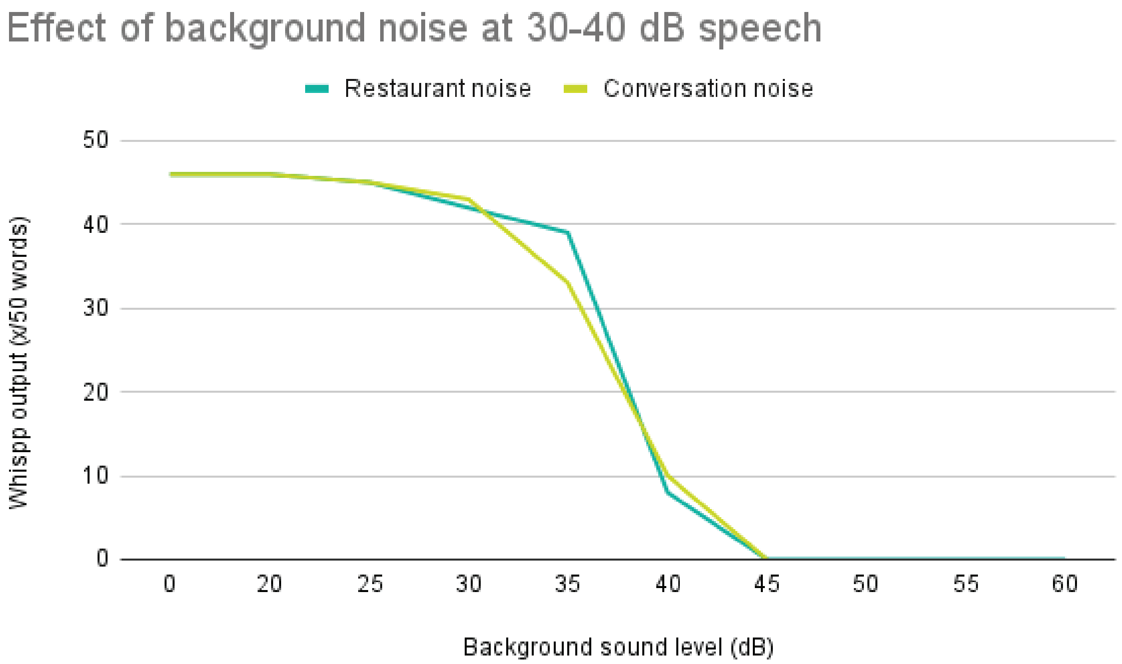


Figure 16: Voice audibility at 30-40 dB with background noise

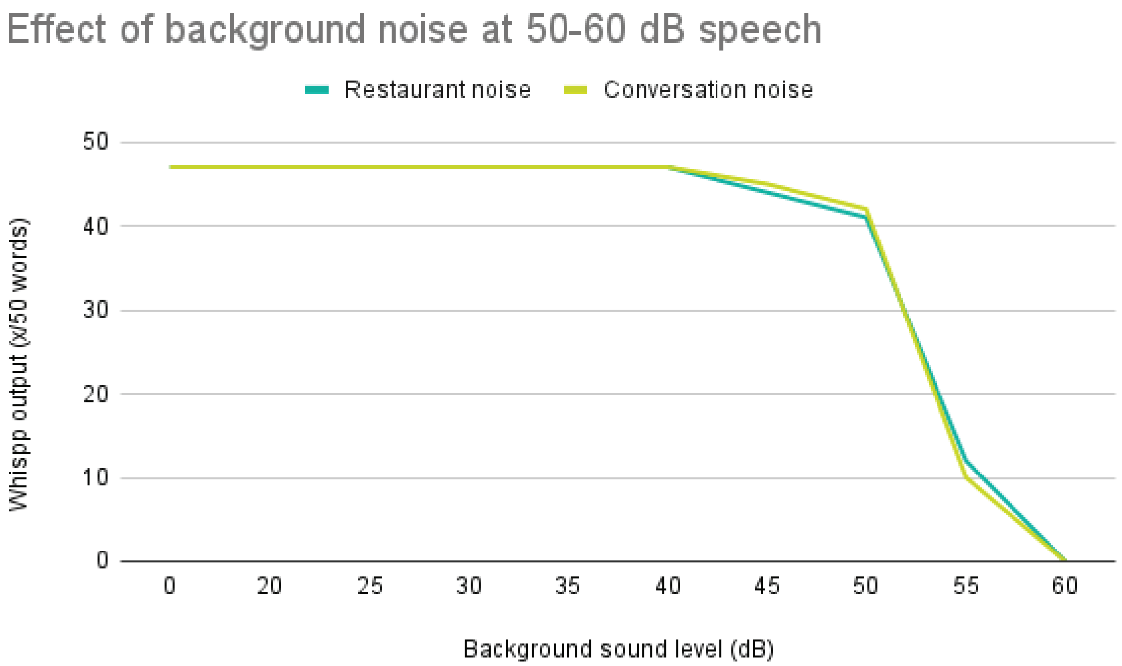


Figure 17: Voice audibility at 50-60 dB with background noise

Microphone placement is critical in ensuring sufficient voice capture. Another test examined the impact of microphone positioning on the upper body and face (see Appendix H). This test involved playing an audio file through a speaker positioned inside the mouth to ensure consistent sound levels. A decibel meter was used at four locations on the upper body and face: the ear, the cheek, the upper chest, and the lower chest. Figure 18 shows the sound levels played from the mouth on the x-axis and the sound picked up at the four locations on the y-axis. When tested at three sound levels, the results showed that almost a third of the sound volume is lost when the microphone is positioned further from the mouth. Therefore, it is preferable to place the microphone as close to the mouth as possible, particularly in loud environments where capturing voices is more difficult.

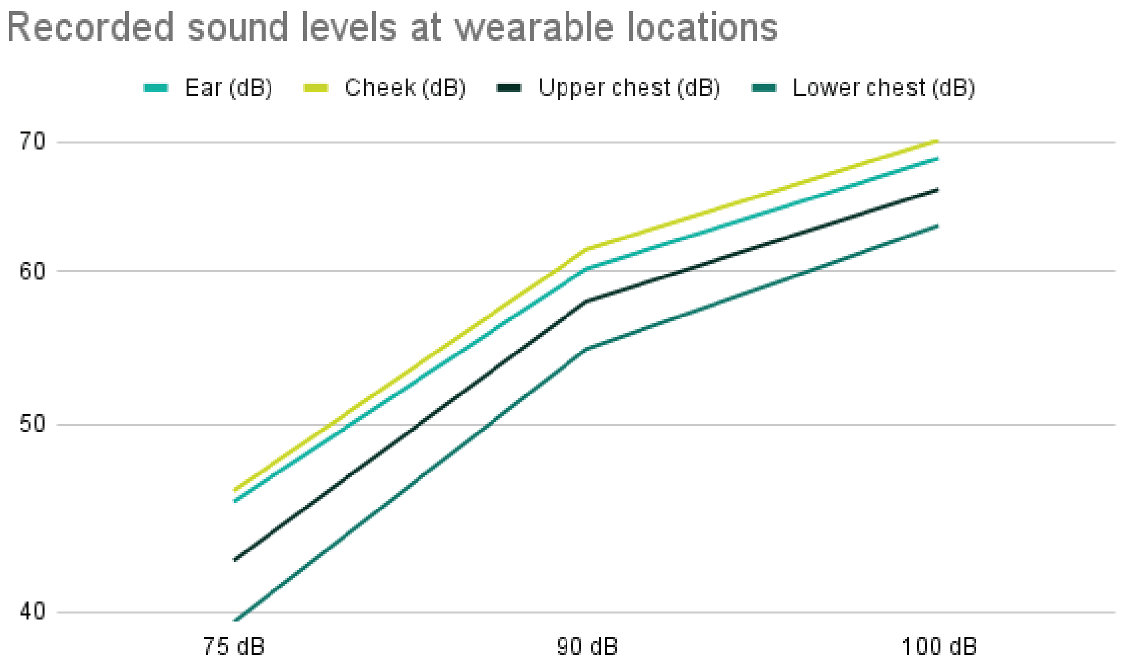


Figure 18: Recorded sound levels at wearable locations

An additional test was conducted to determine the optimal placement of the microphone on the face (see Appendix I). Similar to the previous test, this one was carried out in seven different locations: the side of the mouth, the tip of the nose, the chin, between the eyebrows, the underside of the glasses, the forehead, and the middle of the cheek. The results showed that the closer the microphone was to the mouth, the higher the recorded volume (Table 2). Interestingly, despite being physically close, the cheek recorded the least sound since it lies behind the forward-projected sound waves, resulting in more volume loss. Figure 19 shows the optimal placement based on these results: ideally, the microphone should be positioned as close to the mouth as possible.

Table 2: Volume picked up at points on the face

	1	2	3	4	5	6	7
Source (mouth)	Side mouth	Tip of nose	Chin	Between eyebrows	Underside glasses	Forehead	Middle cheek
66.1 dB	61.1 dB	60.4 dB	60.3 dB	59.6 dB	59.1 dB	58.2 dB	54.7 dB

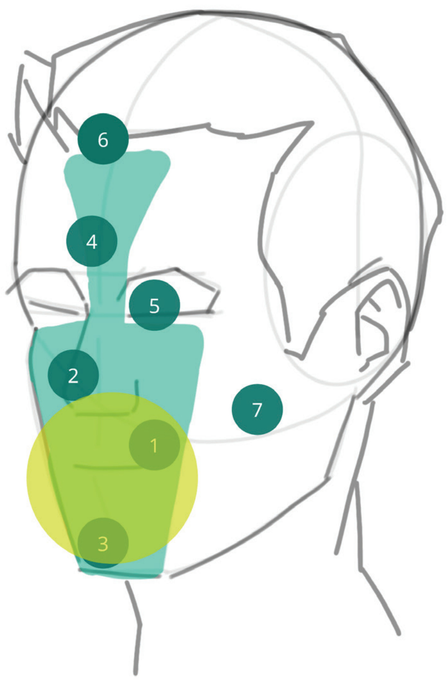


Figure 19: The best microphone placement on the face for picking up sound

Since discretion is important to users, the possibility of placing the microphone inside the mouth was also investigated (see Appendix J). This location would be as close as possible to the sound source and highly discreet. However, while the raw audio recorded in this way was intelligible, significant noise was introduced by the microphone rubbing against the teeth. Furthermore, once processed by the app, the vocal sounds were almost completely lost. Therefore, while this method is not currently viable, it could hold promise as both microphone technology and the Whispp app improve.

Finally, consideration was given to the output source. As discussed earlier, there are several options for the output, but the volume of the phone speaker is a concern as it might limit usability in noisy settings. A test was set up using a converted voice recording in the Whispp app alongside a speaker playing background noise at 70 dB (see Appendix K). Both audio files were played simultaneously. At a distance of 20 cm, it was determined whether the voice could be heard over the background noise. Figure 20 shows that, at this close distance, the phone speaker can project the user's voice clearly enough. However, for settings involving longer distances or groups, using a phone speaker as the Whispp app output might not be sufficient.

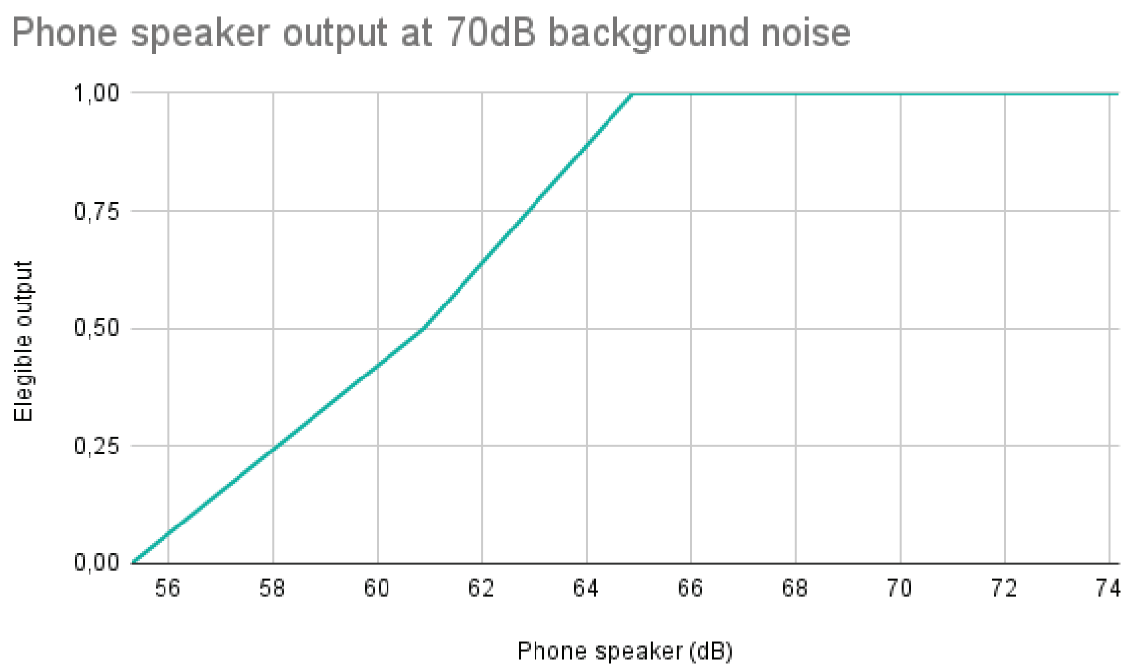


Figure 20: Phone speaker audibility with 70 dB background noise

2.5 REQUIREMENTS

The information gathered was used to create a list of requirements. This list outlines the important characteristics that the design must meet in order to be successful (Van Boeijen et al., 2013).

User interaction

1. The product can be used by people of all ages and physical abilities
2. The product is comfortable enough to use all day
3. The product can be used hands-free

Technical aspects

4. The product is wireless
5. The product is rechargeable
6. At least 4 hours of use per charge
7. The product's microphone can pick up the user's voice well enough to be understood
8. Multiple devices can be connected at once
9. Latency limit of 100ms
10. The product adheres to all rules and regulations for consumer electronics
11. Cross-platform compatibility

Device casing

12. Lower weight than current amplifiers on the market (205.5g - Echovoice ® EV7 ™ Voice Amplifier)
13. Durability of at least 5 years
14. Rechargeability
15. Drop resistant from 2m
16. Water resistant

Production

17. The product costs less than €100

Wishes:

- Easy to learn how to use
- Usable for most conversation types
- Discreet design
- Aesthetics fits most users
- Minimal latency
- Minimal set up time
- Easy access to components for maintenance

CHAPTER 3 - SYNTHESIS

This chapter focuses on generating and exploring ideas through sketches and prototypes, with the aim of articulating and simulating design proposals (Van Boeijen et al., 2013). Different forms and concepts are analysed to evaluate their usability and feasibility. The most promising ideas are then selected for further development.

3.1 IDEATION

With the list of requirements established, the ideation phase began with the creation of initial idea sketches (Figure 21).

Figure 21: Visual exploration of alternative concepts in the early design stage

FORM ANALYSIS

During the ideation sketching phase, the size of the product was a recurring consideration. A few of the ideas in Figure 21 consist of a necklace-type microphone. Since discretion is important to users, both the size and shape play a key role in the product's appearance and usability. To explore this further, a form analysis was conducted using clay models to study the impact of the volume and shape of a wearable microphone's body (Figure 22). The models vary in shape, texture and size to determine whether the visual impact would be significant if, for example, the microphone were worn as a necklace.

Key findings from the form analysis include:

- Thicker models tend to draw more attention than thinner ones.
- Shape variations can create visual interest, but texture also contributes significantly to this effect.
- In order to maintain discretion, the product should be kept as small and thin as possible.

Figure 22: Clay models exploring the visual impact of wearable devices

3.2 SELECTION

The idea sketches shown in Figure 21 can be categorised. These numbered sketches are placed in the C-Box, which helps organise and evaluate large numbers of ideas (Van Boeijen et al., 2013). The ideas are mapped along two axes: 'usability' and 'feasibility'. 'Usability' describes how easy and pleasant the product is to use, while 'feasibility' refers to how practical and realistic its development is (Figure 23).

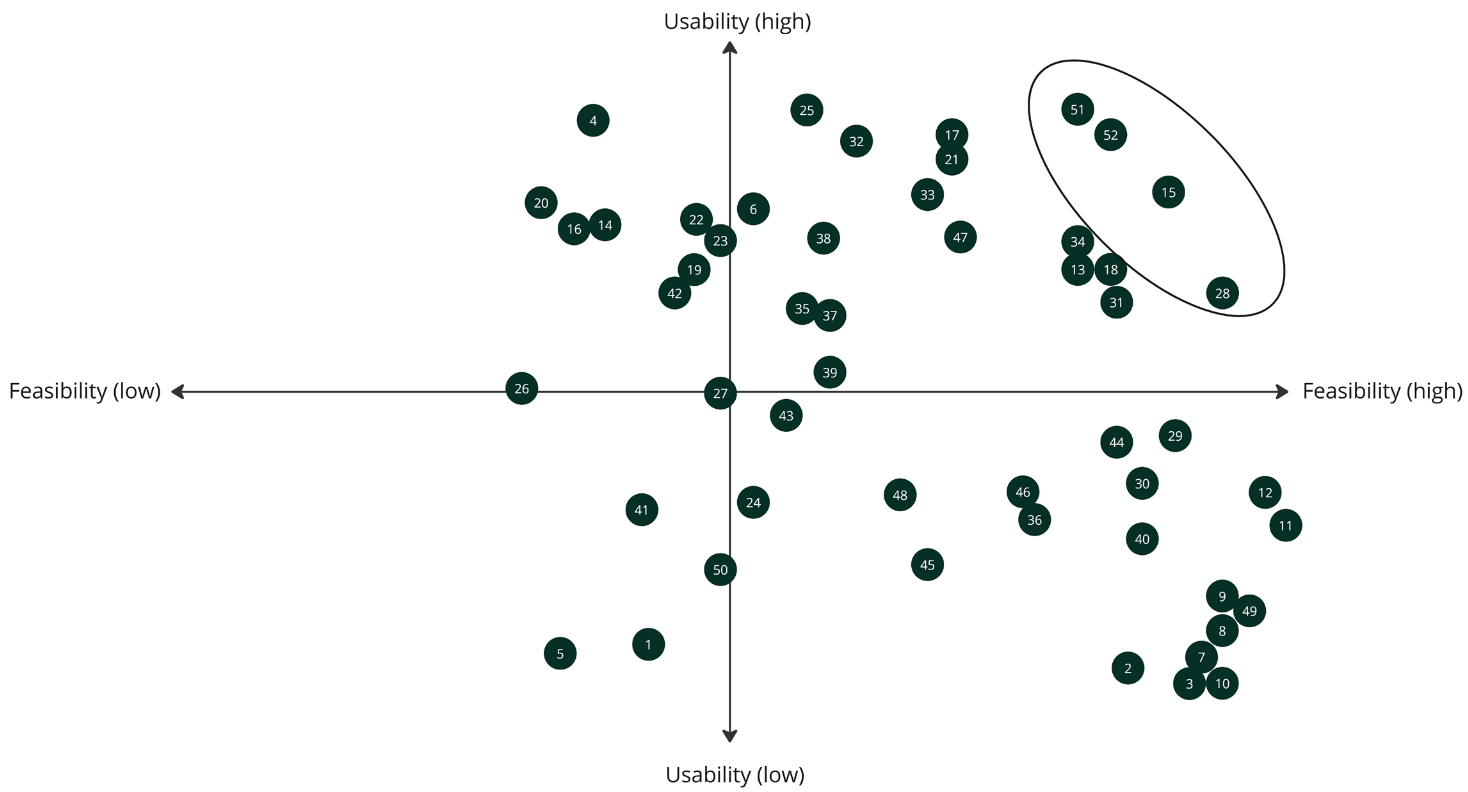
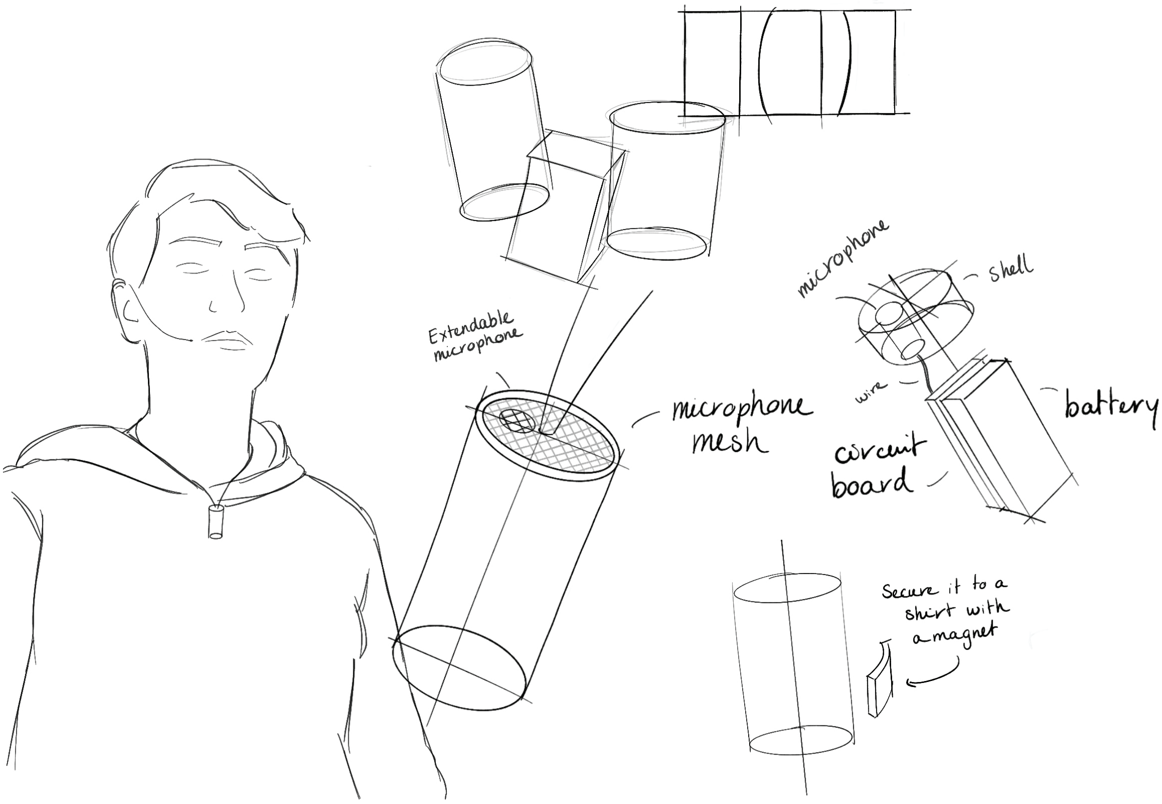


Figure 23: C-box Feasibility-Innovativeness

Four ideas from the C-box scored best in terms of usability and feasibility. These ideas have been developed into the following four concepts:

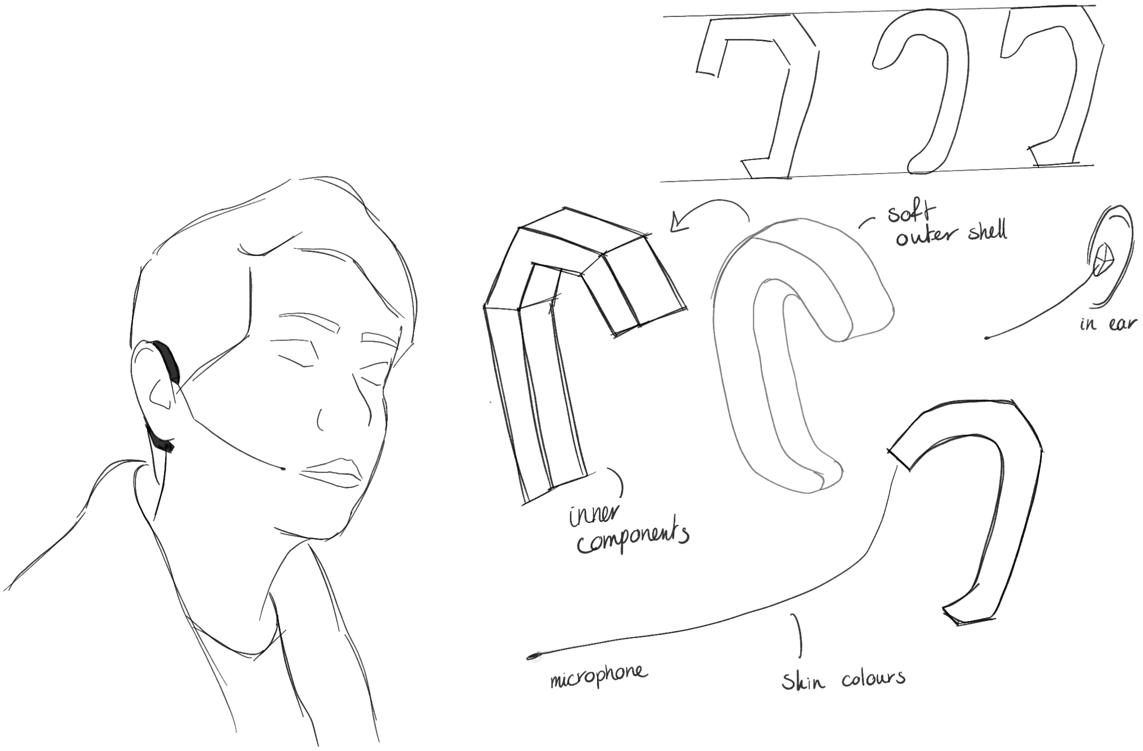
1. Concept 1: Extendable necklace
2. Concept 2: Around-the-ear boom
3. Concept 3: Ring
4. Concept 4: Voice nosepiece



Concept 1

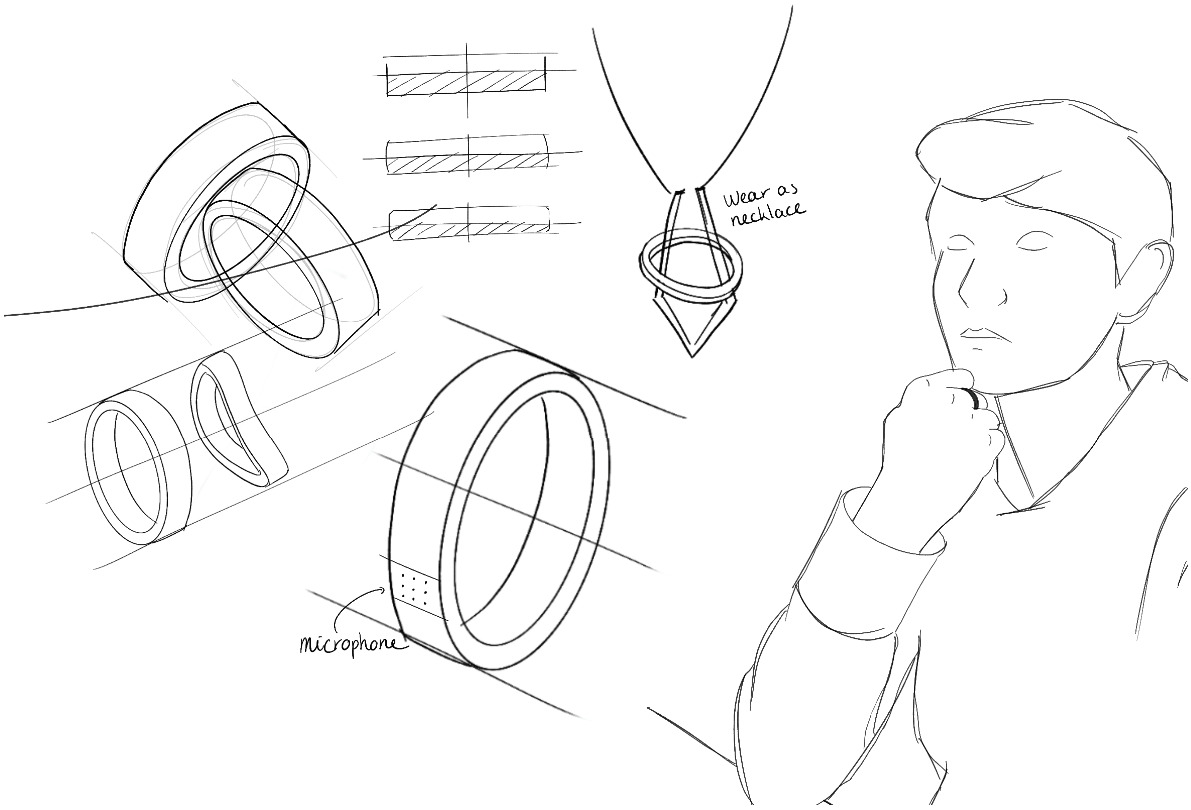
Extendable necklace

This necklace has a built-in microphone that can easily be extended closer to your mouth for better sound pickup. Simply pull the microphone along the cord or hook it around your ear to optimise audio pickup. When not in use, it can be worn as a sleek, stylish necklace, providing a hands-free solution for clear communication.



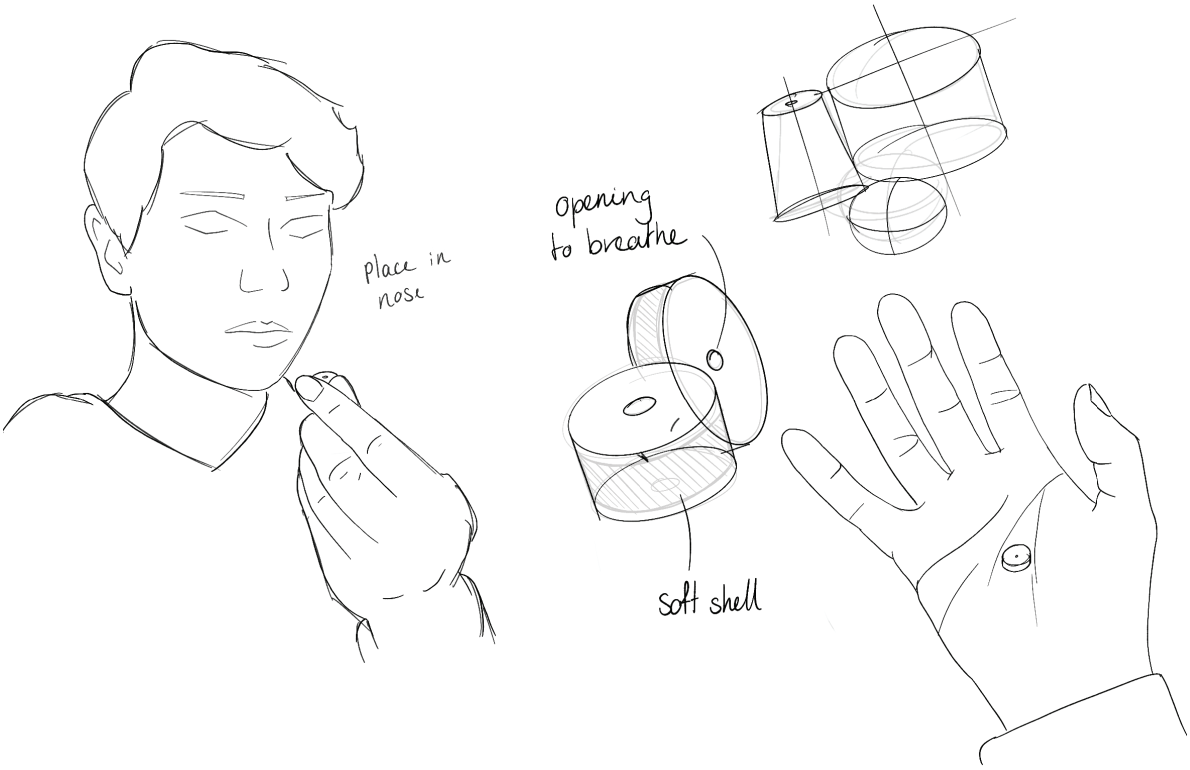
Concept 2
Around-the-ear boom

This product features a discreet hook that wraps around the ear with a small, skin-coloured microphone attached for minimal visibility. The design ensures a secure and comfortable fit, providing a hands-free solution.



Concept 3
Ring

This ring has a built-in microphone that clearly picks up your voice when you hold your hand near your mouth. In quieter environments, where your voice can be heard from further away, the ring can also be worn as a necklace, so there is no need to hold your hand near your mouth.



Concept 4
Voice nose-piece

This compact, comfortable device has a built-in microphone and fits discreetly inside the nose. Its soft outer shell and breathable design ensure comfort during extended wear, and the small breathing hole allows natural airflow.

3.2 CONCEPT PROTOTYPES

To further evaluate the four concepts, physical prototypes were created for each one (Figures 24-27). These prototypes enabled hands-on testing and improved understanding of how each concept would function in the real world.

Figure 24: Concept 1: Extendable necklace prototype

Figure 25: Concept 2: Around-the-ear boom prototype

Figure 26: Concept 3: Ring prototype

Figure 27: Concept 4: Voice nosepiece prototype

CHAPTER 4 - EVALUATION

This chapter focuses on evaluating and selecting the developed concepts. To ensure that the chosen concept aligns with user needs, it was evaluated using weighted objectives and assessed based on user feedback. The most suitable concept was chosen based on these findings for further refinement and development.

4.1 CONCEPT SELECTION

Once the quick prototypes had been completed, the next step was to select the most suitable concept. The weighted objectives method was used to support this decision. This method compares design concepts based on their overall value (Van Boeijen et al., 2013). The evaluation criteria are derived from the previously established list of requirements. The criteria used in this assessment are presented in Table 3.

Table 3: Weighted objectives criteria for selecting the preferred concept

	Criteria	Weight
1.	Effectiveness This assesses how well the device captures the user's voice based on its placement.	25
2.	User comfort This evaluates how comfortable the device is to wear and use throughout a typical day.	20
3.	Aesthetics fits most users This measures how visually appealing the device is to a broad range of users.	15
4.	Usable for most conversation types This determines whether the device functions across different types of conversation settings.	15
5.	Discreet design This measures how unobtrusive and subtle the device appears when worn.	10
6.	Set up time This looks at how quickly and easily the device can be put on and made ready for use.	10
7.	Weight This considers how the weight of the device affects comfort, especially in relation to where it is placed on the body.	5
	Total score	100

The evaluation carried out by the designer is based on personal judgement, informed by insights collected during earlier stages of the study, including interviews and questionnaires. The results of this evaluation are summarised in Table 4.

Table 4: Weighted objectives

Criteria	Concept 1 Extendable necklace		Concept 2 Around-the-ear boom		Concept 3 Ring		Concept 4 Voice nose-piece	
	Score	Total	Score	Total	Score	Total	Score	Total
1.	5	1225	10	250	9	225	9	225
2.	10	200	8	160	7	140	3	60
3.	9	135	8	120	9	135	8	120
4.	7	105	10	150	7	105	10	150
5.	10	100	8	80	10	100	8	80
6.	9	90	9	90	10	100	8	80
7.	9	45	9	45	10	50	8	40
Total		800		895		855		755

Each criterion is assigned a weight according to its importance. The scores indicate how well each concept meets a criterion, and are given a value from 1 to 10. The overall score for each concept is calculated by adding together the scores for each criterion. The concept with the highest overall score is the preferred concept (Van Boeijen et al., 2013). Based on this method of weighted objectives, the around-ear boom design (Concept 2) emerges as the most promising option.

USER EVALUATION

To further evaluate the concepts, Whispp users were asked to share their personal opinions and preferences regarding each design. The key questions were:

- What are your thoughts on each concept?
- Which concepts would you consider using?
- What changes would you suggest to improve them?

A questionnaire was distributed to Whispp users to collect answers to these questions (see Appendix L). Six participants rated the concepts based on their likelihood of use and provided comments on what they liked and disliked about each concept.

Due to the small sample size, additional input was sought from user representatives to supplement the evaluation. Ten participants, who were unfamiliar with the design process and the project, were introduced to the project and its challenges. They were then asked to represent the target user group. They were asked to respond to the same set of questions, providing insights into the potential usability and acceptance of each concept. The combined results are presented in Table 5.

Table 5: Concept ranking

Concept		Whispp users (n=6)	User representatives (n=10)
Concept 1	Extendable necklace	2nd	3rd
Concept 2	Around-ear-boom	1st	1st
Concept 3	Ring	3rd	2nd
Concept 4	Voice nosepiece	4th	4th

The around-ear boom (Concept 2) was the highest-rated option in both user evaluations. It also achieved the top score in the weighted objectives analysis. Based on these results, Concept 2 has been chosen for further development.

CHAPTER 5 - MODEL

This chapter outlines the key stages involved in developing the final product. It begins with a market analysis to understand existing solutions and compare form and design. Based on these insights, the chosen direction was refined through concept development and iterative design. Attention is then given to the audio output system while reviewing user input. User testing was employed to validate design decisions and improve functionality. The chapter concludes with an overview of the final production steps, translating the refined concept into a product that is ready to use.

5.1 MARKET ANALYSIS

Figure 28: Wired and wireless headset microphones currently available on the market

Analysis of existing products on the market reveals a variety of headset microphones, available in wired and wireless versions (Figure 28). The two main styles are single-ear and dual-ear hooks that wrap around the back of the neck. Wired models range from thin, discreet cables to thicker, more robust ones that offer increased durability.

Two wired headset microphones were tested, one featuring a single ear hook and the other a double ear hook. Testing these models revealed the following key findings:

- The thin wire models, both single and dual ear hooks, are lightweight and comfortable, even with prolonged use.
- The single ear hook version is difficult to position correctly and tends to shift out of place.
- Managing the wire and connecting the microphone to a smartphone was time-consuming and impractical for everyday use.

Figure 29 shows the design analysis of products with a similar shape, such as open-ear headphones and hearing aids. These products are usually worn for long periods of time, especially hearing aids, which are designed with long-term comfort in mind. This focus on user comfort is also highly relevant to microphone design. Figure 30 provides a closer examination of the design features of behind-the-ear hearing aids to gain further insight.

Figure 29: Design and shape analysis of open-ear headphones and hearing aids

Figure 30: Hearing aid (BTE)

A slight variation of the traditional BTE (Behind-The-Ear) hearing aid is the open-fit BTE. These are more compact versions of standard BTE models (Bradshaw, 2025). Open-fit hearing aids are often preferred by people who wear glasses because their smaller size leaves more space behind the ear, allowing the frames to sit comfortably without interference (Ear Solutions, 2023).

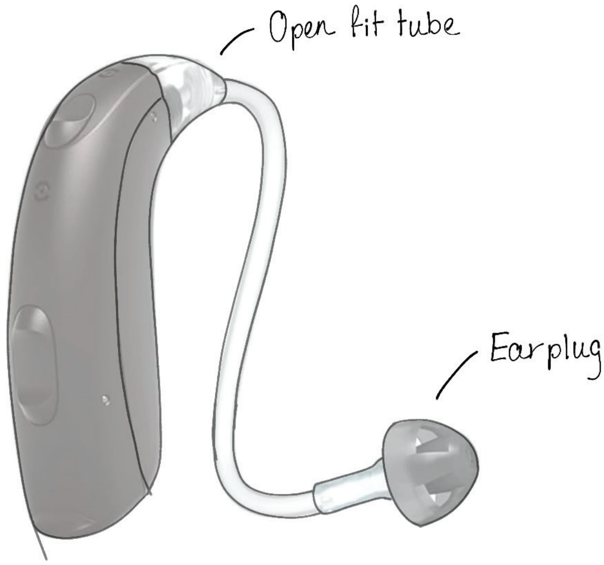


Figure 31: Open fit hearing aid

When it comes to hearing aids and earphones, size is one of the most important considerations. Ear shapes and sizes can vary significantly from person to person, yet most of these products are only available in one size. The same issue was encountered with the first prototype microphone developed in Chapter 3. While it fit one user well, it did not fit others. The first prototype microphone (Figure 32) was made from hard plastic, which limited its adaptability as it closely followed the contour of the ear.

Figure 32: The first prototype microphone, as depicted in Figure 25

A comparison of open-ear headphones and hearing aids reveals two key differences in their design approach:

- Form: some designs, especially headphones and certain hearing aids, do not fully wrap around the ear. This partial contact allows for a less restrictive fit.
- Material flexibility: most headphones use soft, flexible materials. Even if the product follows the shape of the ear more closely, this flexibility allows it to comfortably accommodate a variety of ear sizes.

5.2 CONCEPT DEVELOPMENT

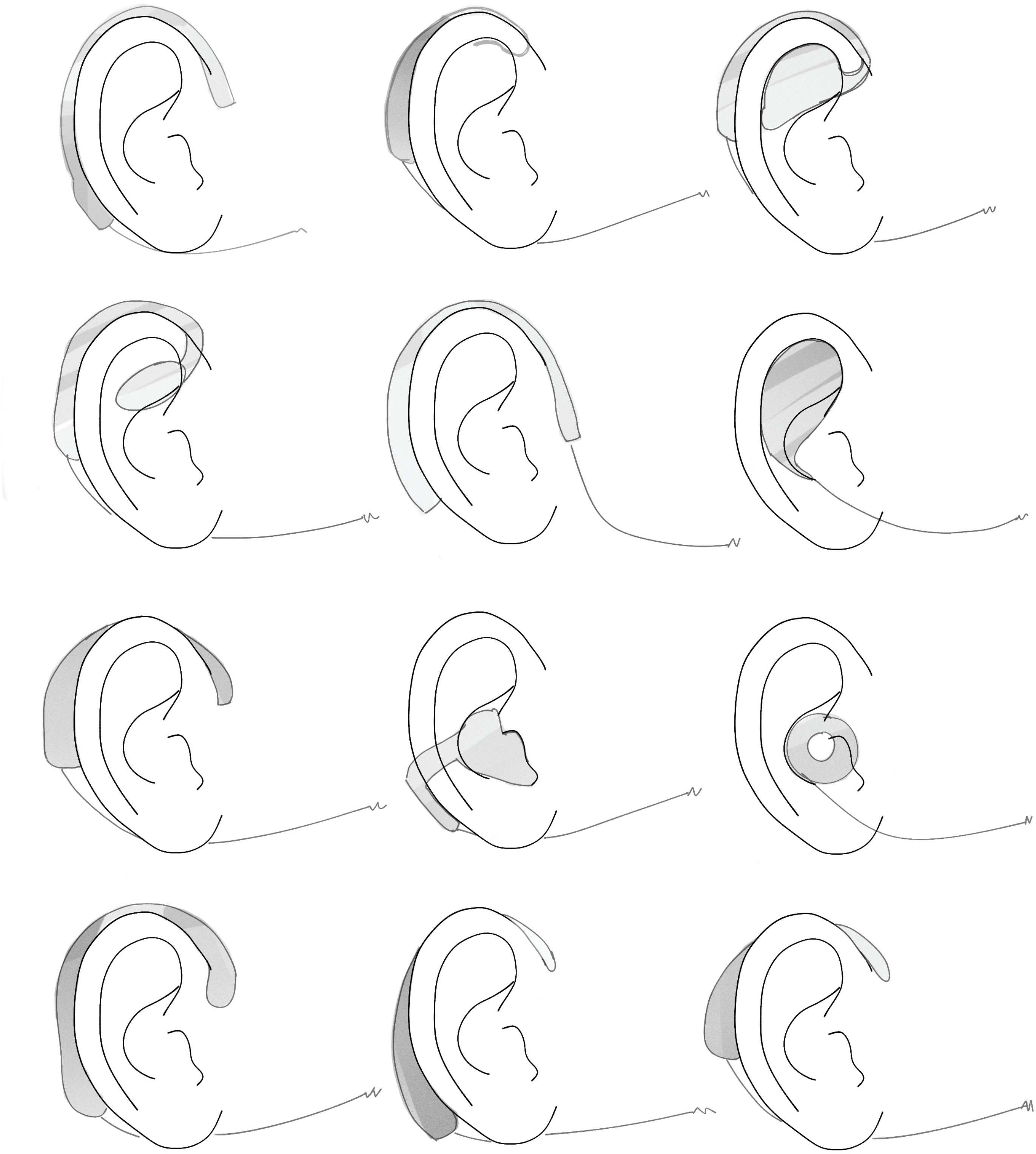


Figure 33: Visual exploration of alternative product forms in the early concept development process

Based on the analysis in Chapter 5.1, a series of design sketches were created to explore potential shapes for the earpiece (Figure 33). These ideas were then developed further using physical models created with clay (Figure 34).

Figure 34: Various clay models exploring methods of securing the microphone body to the ear

These models revealed five key insights:
- Rounded, organic shapes fit the shape of the ear well.
- A thinner top section allows the design to be comfortably worn with glasses.
- Hooking the end into the ear provides extra support but increases visibility.
- Stiffer shapes do not fit all ear sizes equally well.
- Flexible hooks help to secure the earpiece more comfortably and adapt to different ear shapes.

SIZING
The shape and size of the human head vary slightly from person to person. To ensure a comfortable and optimal fit for all users, these anatomical differences must be taken into account when designing the product. The most relevant variations are external ear size and the distance from the ear to the mouth (Figure 35).

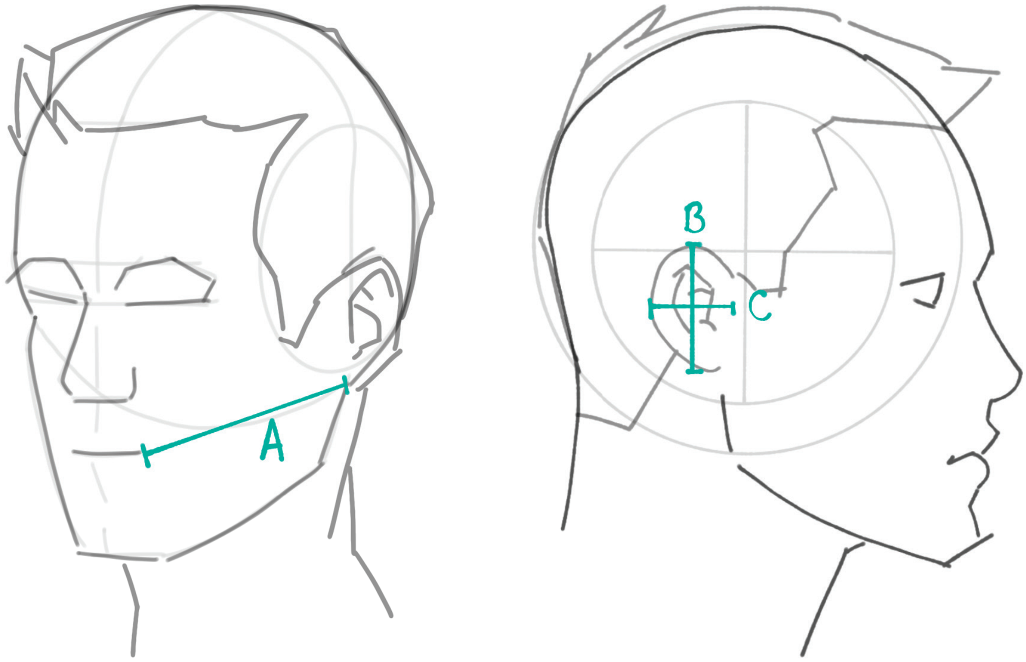


Figure 35: Relevant head sizes (A: Distance from the corner of the mouth to the mandibular angle, B: Total ear height, C: Ear width)

The first key size is the distance from the ear to the mouth, which determines the necessary length of the microphone wire. Research by Mangar et al. (2013) measured the distance from the corner of the mouth to the mandibular angle, which can be used as an approximation for the microphone wire length. Their findings revealed an average distance of 7.7 ± 0.9 cm for women and 8.3 ± 0.8 cm for men, showing a difference of almost 2 cm between the lower and upper limit of the two groups. Since accurate microphone placement is essential for optimal voice recording, as discussed in Chapter 2.4, this variation is too large to be accommodated by a one-size-fits-all solution. Therefore, the microphone length must be adjustable or offered in multiple sizes.

The second important size is external ear size. According to an anthropometric study by Prasetyo and Putri (2021), ear dimensions differ significantly between males and females. Although this product is placed behind the ear, these external measurements, used alongside 3D models of human ears, serve as useful indicators of size for design development.

Existing products like open-ear headphones use flexible ear hooks to adapt to varying ear sizes (Figure 36). These are typically made from a soft, silicone-like outer material with a Nitinol wire core, which provides comfort and spring-like flexibility to allow the hook to fit different ear shapes.

Figure 36: Open ear headphones with a flexible hook

Another approach to account for user differences is personalisation through manual moulding. This involves replacing the springy Nitinol wire with a more moldable metal wire, allowing the user to adjust the ear hook to fit their ear more precisely. Figure 37 shows a prototype with a TPU (Thermoplastic PolyUrethane) ear hook reinforced with a moldable metal wire.

Figure 37: Prototypes of a moldable ear hook reinforced with a metal wire to change the shape

3D MODEL

This development stage resulted in the first 3D prototypes of the product (Figure 38). These models were made using TPU, PLA (Polylactic Acid), metal wire and a microphone.

Figure 38: Prototype featuring a moldable ear hook and hard casing with microphone wire.

The prototype consists of two main parts. The top section uses the moldable ear hook design from Figure 37. A moldable metal wire embedded within the TPU allows users to shape the hook to their ear. The bottom section is a rigid PLA shell designed to house the Printed Circuit Board (PCB) and other internal components.

Upon reviewing this prototype, it was found that the adjustable hook was effective in adapting to different ear shapes. However, the connection point between the hook and the main body was found to be a weak spot. Therefore, later models were adjusted to strengthen this joint (Figure 39). The hook now connects more securely to the body via an extended cover that also serves as a removable outer shell, making assembly and maintenance easier.

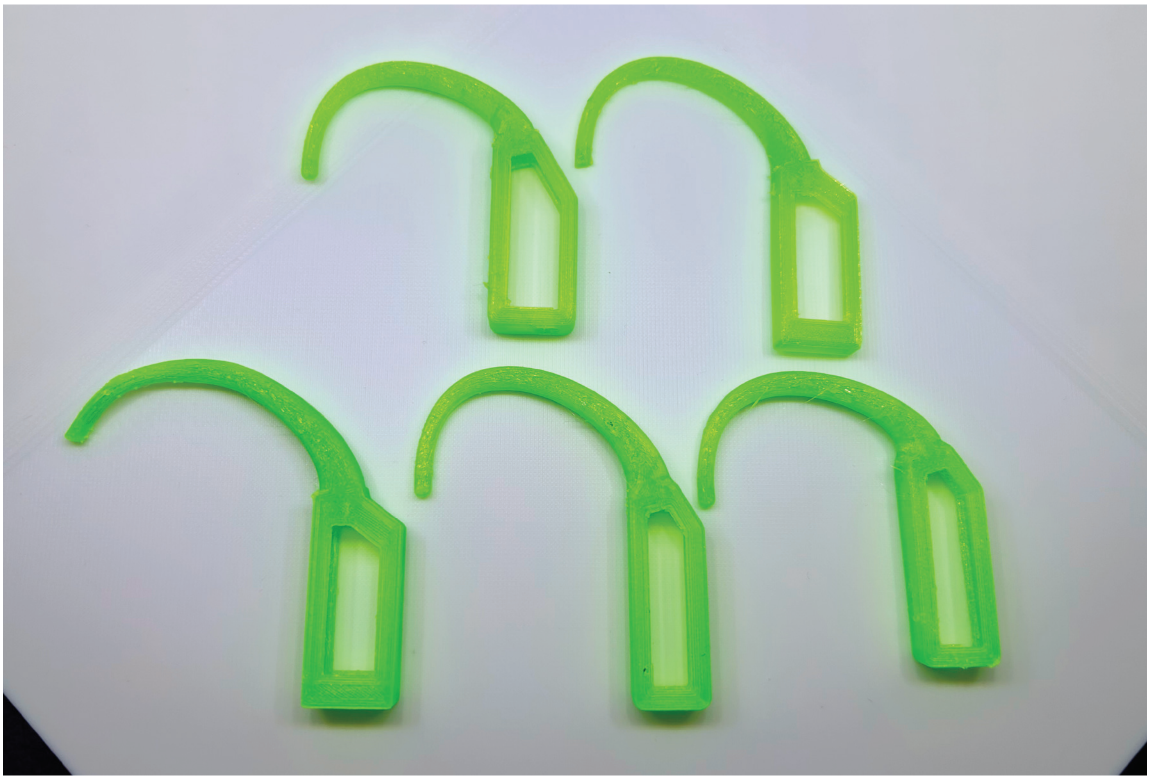


Figure 39: Model iteration to improve the joint connection between the hook and the body

These early prototypes serve two purposes: testing the flexibility and fit of the ear hook and evaluating the product's overall size and weight when worn.

COMPONENTS

Although the first prototypes were complete, several technical aspects of the device were still not defined. In order to make the device fully operational, a PCB must be included. The PCB connects and supports all the internal components that are essential for the microphone to record the user's voice and transmit it to their phone, where it is processed by the Whispp app.

Key components of the PCB:

- ADC (analogue-to-digital converter)
- Battery
- Capacitors and resistors
- Charging IC and connector
- LED
- MCU (Microcontroller Unit)
- Microphone
- RF transmitter and antenna
- Power button
- Preamplifier
- Voltage regulator

The MCU serves as the device's control centre. It contains processor cores, memory and programmable input/output interfaces (Idris et al., 2023) and is responsible for managing the flow of data between components.

The device is powered by a battery, which connects to:

- A voltage regulator to ensure consistent power delivery.
- Capacitors and resistors, which stabilise the circuit, filter fluctuations and enable accurate signal processing.
- A charging IC, which controls the charging process to ensure it is safe and efficient.
- A charging connector, which provides the physical connection for recharging.

A power button allows the user to switch the device on or off, and an LED provides a visual indication of the battery status.

- Green: >20% remaining
- Amber: 10–20% remaining
- Red: <10% remaining

On the audio side, the microphone records the user's voice and converts sound into electrical signals. Since analogue microphones output analogue signals, an ADC is needed to digitise the sound so it can be processed by the MCU.

A preamplifier boosts the microphone's weak signals before they are sent to the ADC, ensuring clear sound and preventing distortion.

The processed voice signal is then transmitted wirelessly using an RF transmitter and antenna to a USB-C dongle that is connected to the user's phone. This dongle contains an RF transceiver that collects the signal and passes it to the Whispp app. The app then processes the voice and sends the output to either the phone's speaker or another connected output device.

PCB

All the components come together when they are placed on the PCB. Figures 40 and 41 show the initial PCB layout and the chosen microphone components, detailing their size, weight and cost. See Appendix M for the complete list of components.

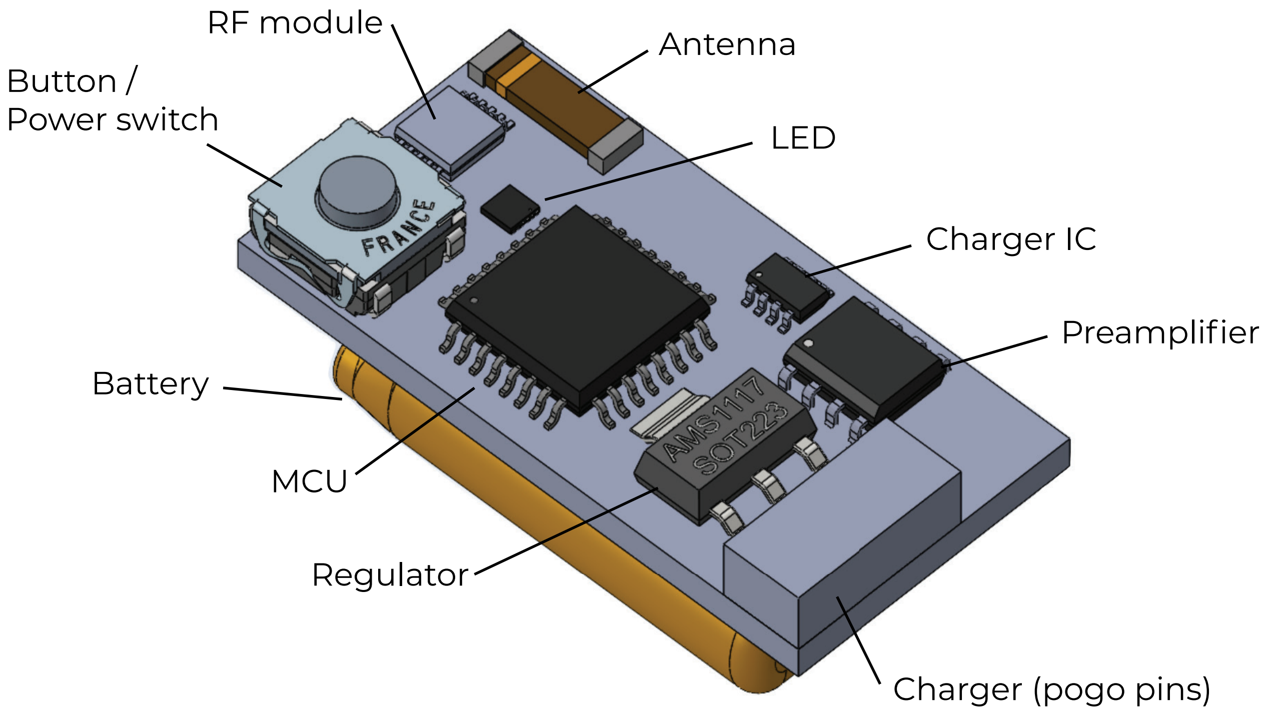


Figure 40: PCB components

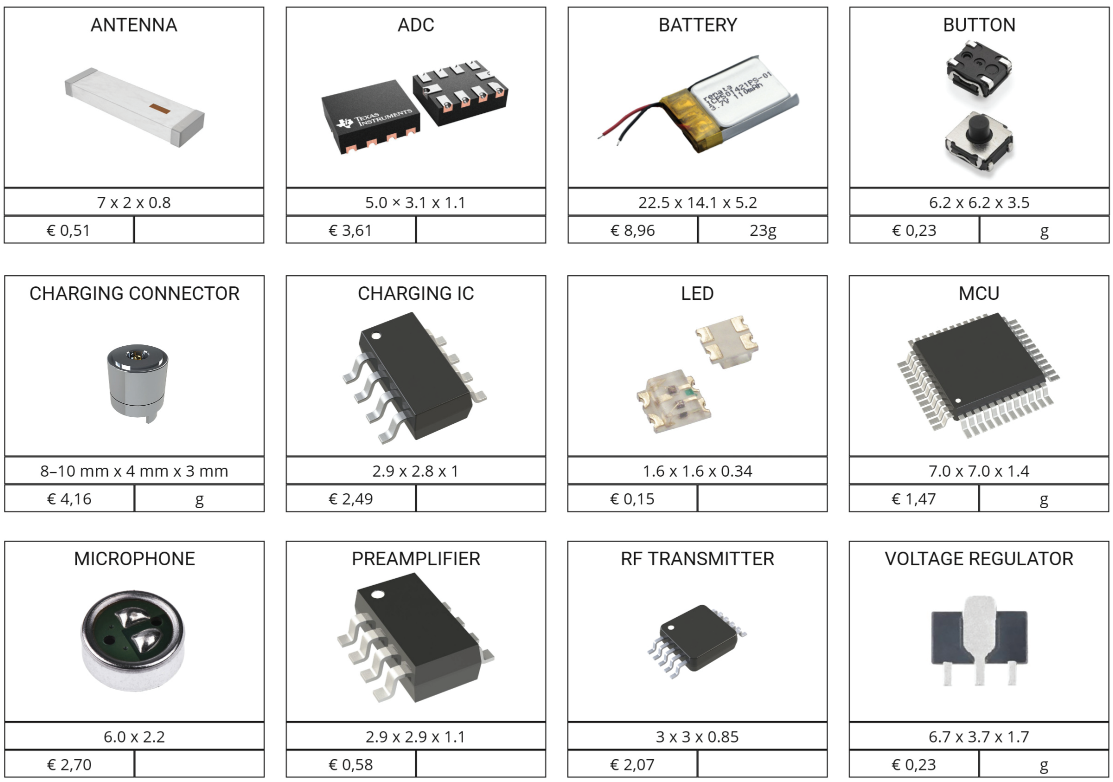


Figure 41: Device components

The battery was identified as a key component, with its capacity, weight and form factor acting as the primary design parameters influencing the product's operating time, weight and layout, respectively. Capacity directly affects the device's weight and operating time. Therefore, the capacity must be chosen carefully to balance weight and functionality. Table 5 provides an estimate of the device's power usage based on the components that require the most power during use.

Table 5: Battery capacity based on component power usage

Battery capacity	
Microphone	<1mA
Preamplifier and ADC	40μA + 150μA
MCU	3.2mA
RF (during transmission)	18mA
	= 21.39mA

In order to achieve a usage duration of four hours, the battery must provide a capacity of at least 85.56 mAh. The current model uses a 115 mAh battery weighing approximately 23 grams.

To compare the battery size to existing products on the market (Figure 42), Figures 43 and 44 illustrate a comparison of weight and usage duration across various product types. See Appendix N for a detailed overview.

Figure 42: Various products on the market

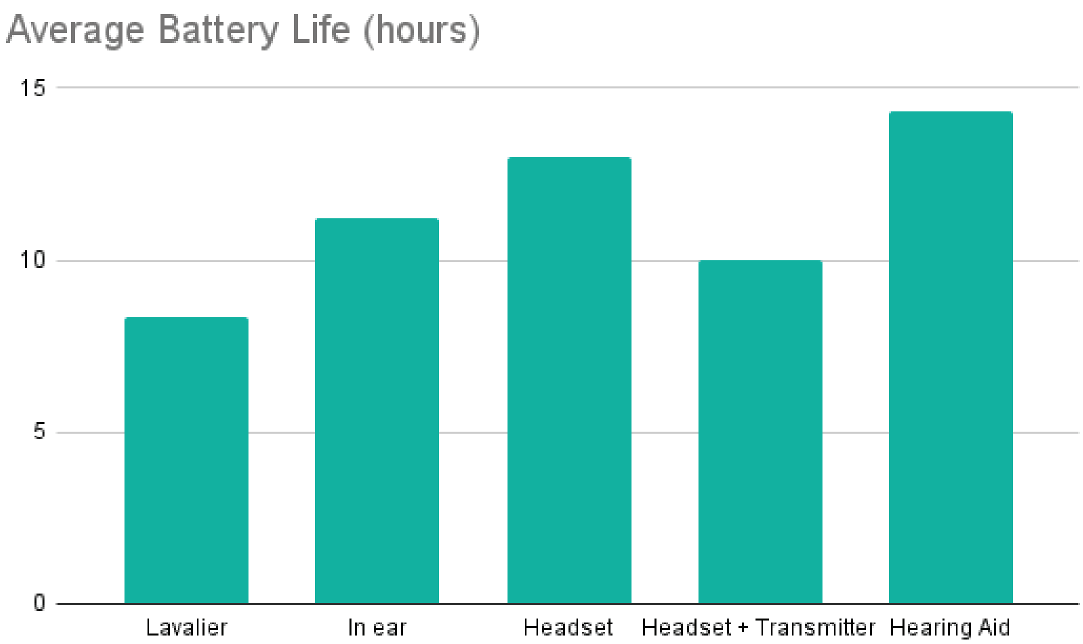


Figure 43: Average battery life (hours) of product groups presented in Figure 42

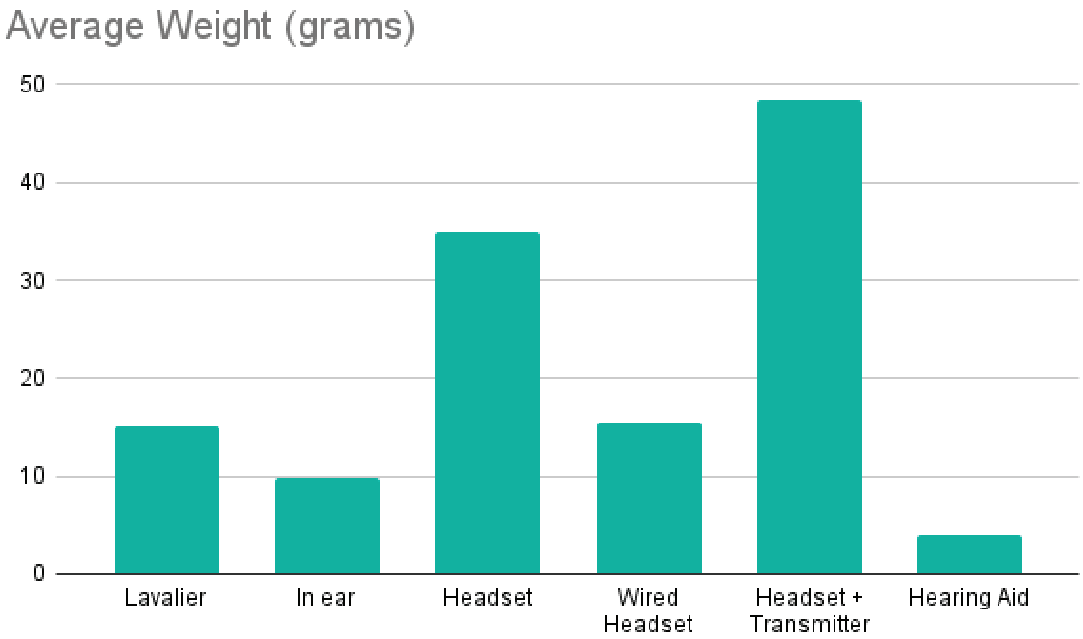


Figure 44: Average weight (grams) of product groups presented in Figure 42

At four hours, the battery duration is at the lower end of the scale. Many comparable products also feature portable charging cases to extend usage time. Hearing aids generally have the longest battery life since they require minimal power to function. According to Sarow (2024), the battery life of hearing aids varies depending on the listening environment, the type of device, and the settings.

In terms of weight, the current 23 g battery exceeds that of most comparable products. This highlights the need to reconsider the size and capacity of the battery to reduce the device's overall weight.

Based on all the insights and data from this chapter, the following improvement points were identified for the next design iteration:

- Adjust the PCB to better fit the product's shape.
- Optimise the external form for comfort and size.
- Reduce the total weight.

5.3 CONCEPT ITERATION

In order to gain a better understanding of PCB layouts, two wireless microphones were disassembled and analysed: the BOYA Mini and the HUACAM Lavalier. Both are clip-on lavalier microphones with a dongle for phone connection.

Figure 45: BOYA mini wireless microphone and connection dongle

The BOYA Mini (Figure 45) measures 31 × 15 × 16.4 mm, weighs 5 g and includes a 65 mAh battery offering approximately six hours of use. It operates on a 2.4 GHz digital frequency (BOYA Mini | MINI Size & AI Noise Cancelling, n.d.).

Figure 46: HUACAM wireless lavalier microphone and connection dongle

The HUACAM Lavalier microphone measures 57 x 15 x 10 mm, weighs 5.3 grams and offers a battery life of approximately 5–6 hours. Like the BOYA Mini, it uses a 2.4 GHz digital frequency.

Both microphones were disassembled to compare their internal PCB layouts (Figures 47 and 48).

Figure 47: Disassembled view of the BOYA mini showing key internal components, including the battery, printed circuit boards, microphone, electrical contacts, Lightning connector, and housing parts

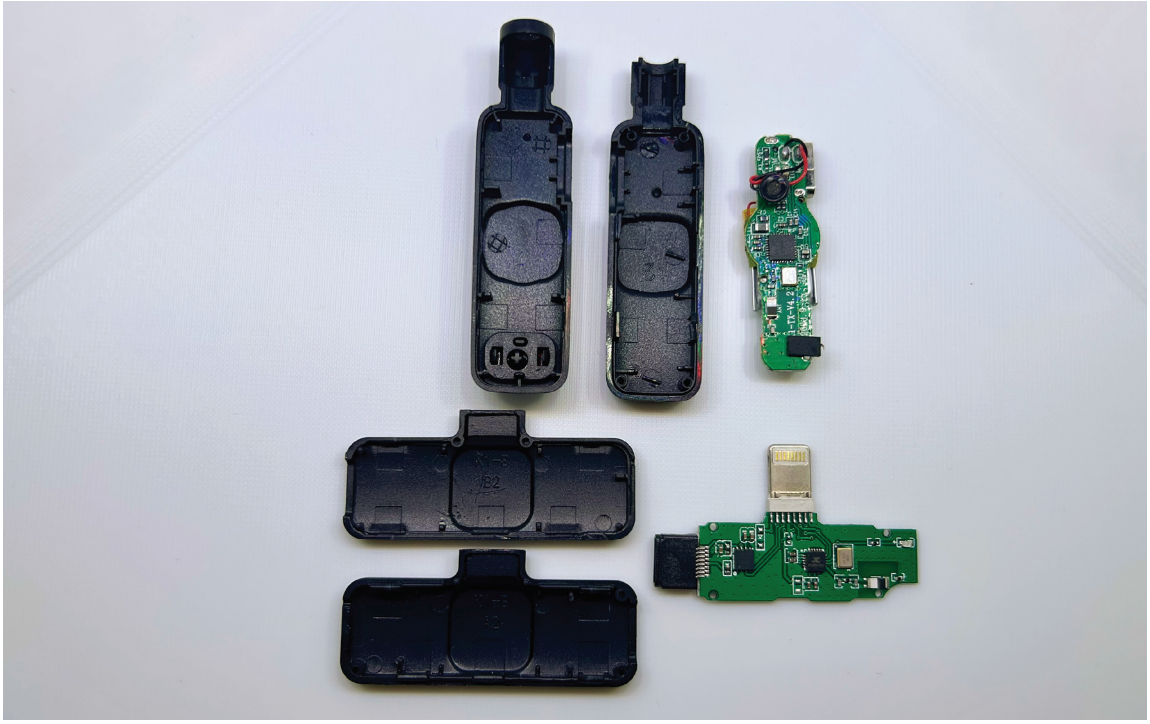


Figure 48: Disassembled view of the HUACAM Lavalier showing key internal components, including the battery, printed circuit boards, microphone, Lightning connector, and housing parts

Key findings from the disassemblies include:

- Casing: Disassembly of the BOYA Mini proved difficult as the case was glued shut, resulting in it having to be broken open to access internal components such as the battery. In contrast, the HUACAM casing used snap-fits, making it easier to open without adhesives. However, two out of four snap-fit hooks broke during disassembly, which made reassembly difficult.
- Internal layout: The BOYA Mini has a very compact design, tightly integrating all components into a small housing. The HUACAM layout appeared less dense, with more internal space.
- Component size: Some components, especially the batteries and chips, were notably smaller than those considered in Chapter 5.2.
- PCB dimensions:
  - BOYA Mini: 21 × 11 × 5 mm; PCB weighs 2.18 g; casing weighs 2.78 g.
  - HUACAM Lavalier: 38 x 12 x 6 mm; PCB weight 2.35 g; casing weight 2.95 g.

Based on these findings, the PCB design in Chapter 5.2 was revised. Notably, the battery occupied much of the earlier models' size and weight. However, the BOYA Mini's 65 mAh battery claims to deliver six hours of usage, suggesting that the earlier estimate of four hours for an 85.56 mAh battery was understated.

The HUACAM's battery appears slightly larger, but its capacity is not stated, though it is likely to be similar.
Figure 49 shows the updated PCB design's revised component list. Components highlighted in green have been replaced with smaller alternatives to make the device more compact and lightweight. See Appendix O for the updated list of components.

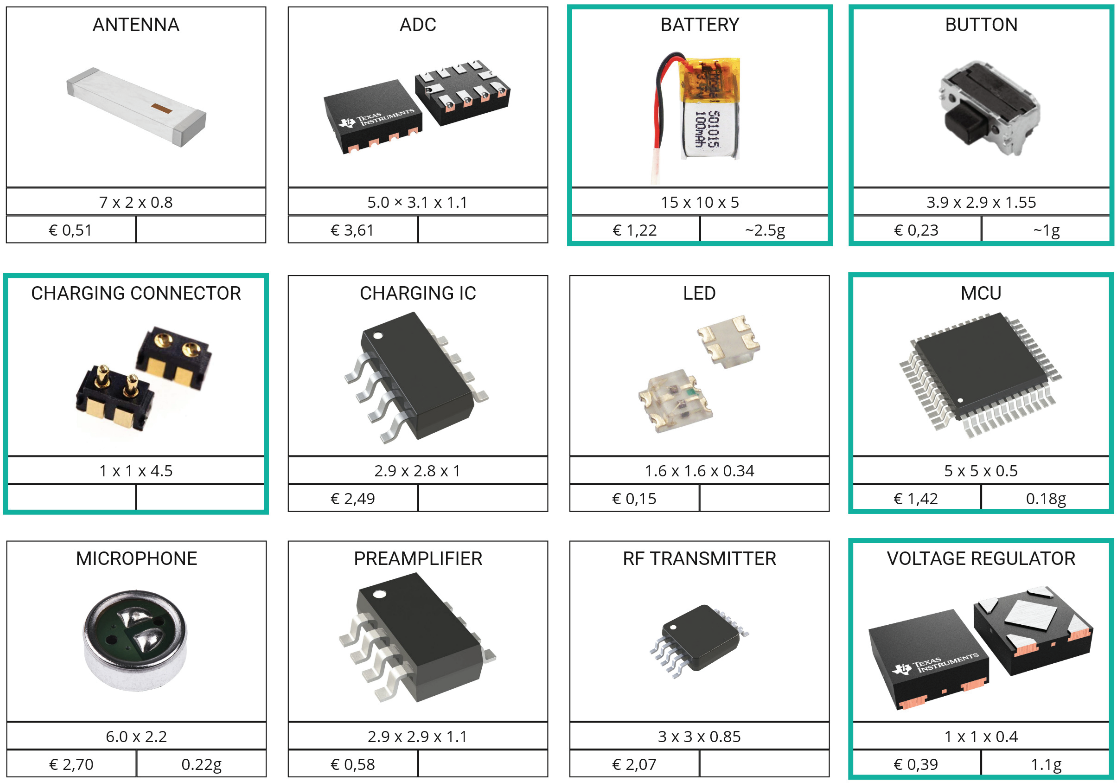


Figure 49: Updated PCB component list including a new battery, button, charging connector, MCU and voltage regulator

FORM ITERATION

In this design, weight and size are both critical considerations. While the battery has a significant impact on both, the placement of electronic components also influences the overall form factor. Placing components efficiently can help minimise the size and shape of the device. To explore this further, the form of the device was reconsidered. Figures 50 and 51 show the initial sketches and clay models that were used to investigate alternative shapes.

Figure 50: Figure: Exploratory sketches investigating alternative shapes to minimise product size

Figure 51: Clay models based on the sketches presented in Figure 50

In the earlier prototype, all the electronic components were concentrated in the lower part of the device. This layout limited how compact the overall design could be, particularly since the upper section was solely used for ear fitting adjustments. To address this issue, the possibility of splitting the PCB between the top and bottom sections was explored. This would not only reduce the size of each housing, but also potentially result in a lighter, better-balanced product.

Figure 52 shows two clay models based on this approach. In this design, both sections contain electronic components, and the circular mid-section acts as a hinge that allows for adjustable sizing.

Figure 52: Clay models with a hinged structure that can be adjusted to different sizes, featuring varied body shapes to accommodate different internal component layouts

Various hinge mechanisms were considered to accommodate different ear sizes while maintaining structural strength and comfort. By combining ideas from the earlier and newly developed models, a new hybrid form was created (Figure 53). Using the flexible materials from the earlier prototype as the basis for the hinge allowed for a more integrated and compact shape to be achieved.

Figure 53: Final combined design of the wearable microphone. It comprises two separate bodies that contain the internal components, as well as a hinge mechanism with an internal wire for size adjustment.

Figure 54 illustrates the size and length adjustments. The middle section of the ear hook can be bent to modify its size, and the microphone wire can be adjusted by rotating the hook either forward or backward.

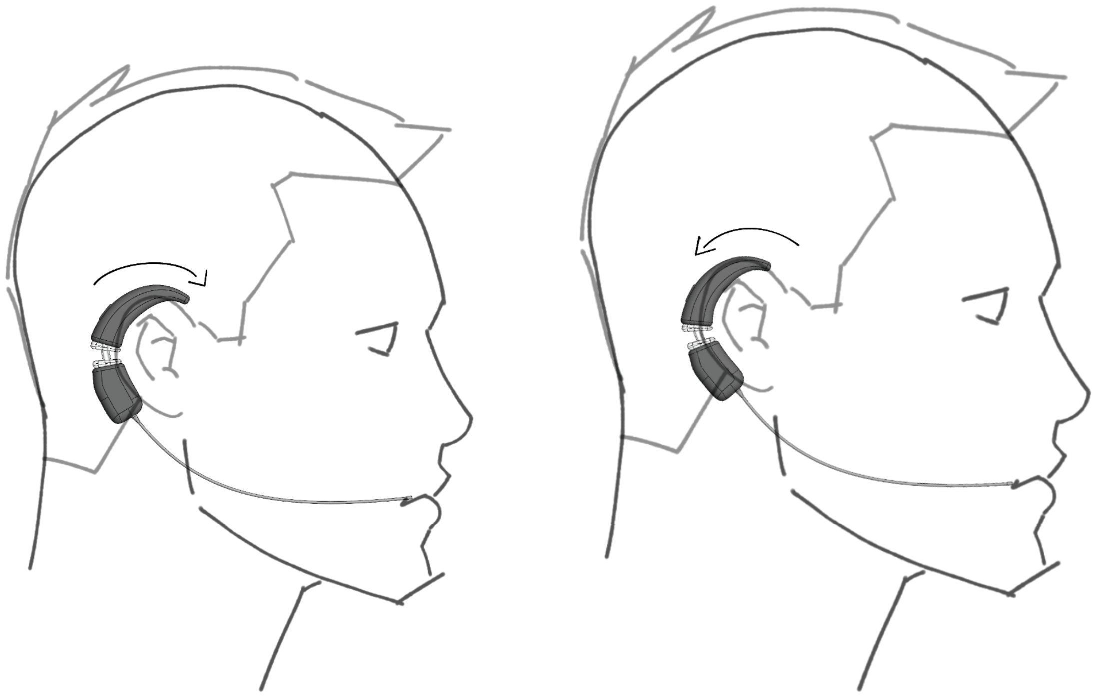


Figure 54: Adjusting the length of the microphone wire by rotating the hook behind the ear to fit smaller or bigger faces

CONCEPT MODEL

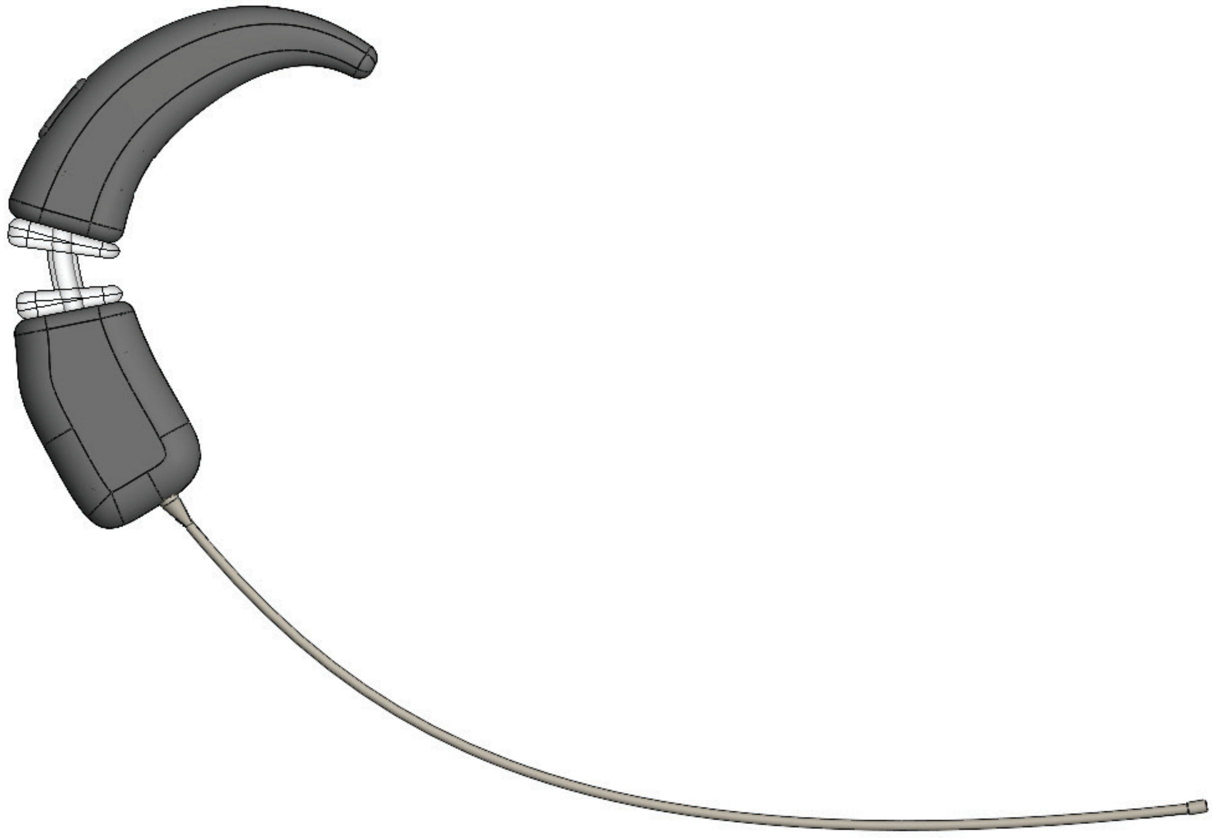


Figure 55: Final concept model with a black body and a beige microphone wire

Figure 55 illustrates the final design. The PCB is positioned in the top half of the microphone hook, with the bottom half containing the battery and microphone wire (Figure 56). Both sections are connected by a flexible joint that allows size adjustment. The hollow tube of the flexible joint provides space for the metal wire and cables that connect the components.

Taking the outer casing and internal components into account, the total weight is approximately 7 grams, which satisfies the requirement outlined in Chapter 2.5. This weight is also comparable to that of the wireless microphones analysed in Chapter 5.3. Figure 57 shows a detailed view of the PCB layout.

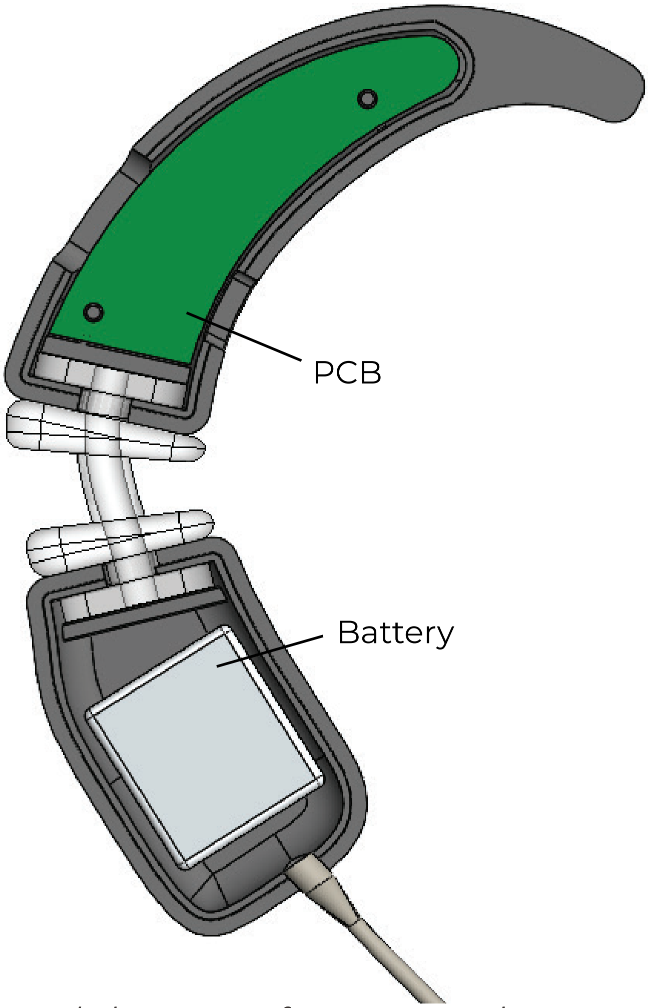


Figure 56: Internal placement of components: battery and PCB

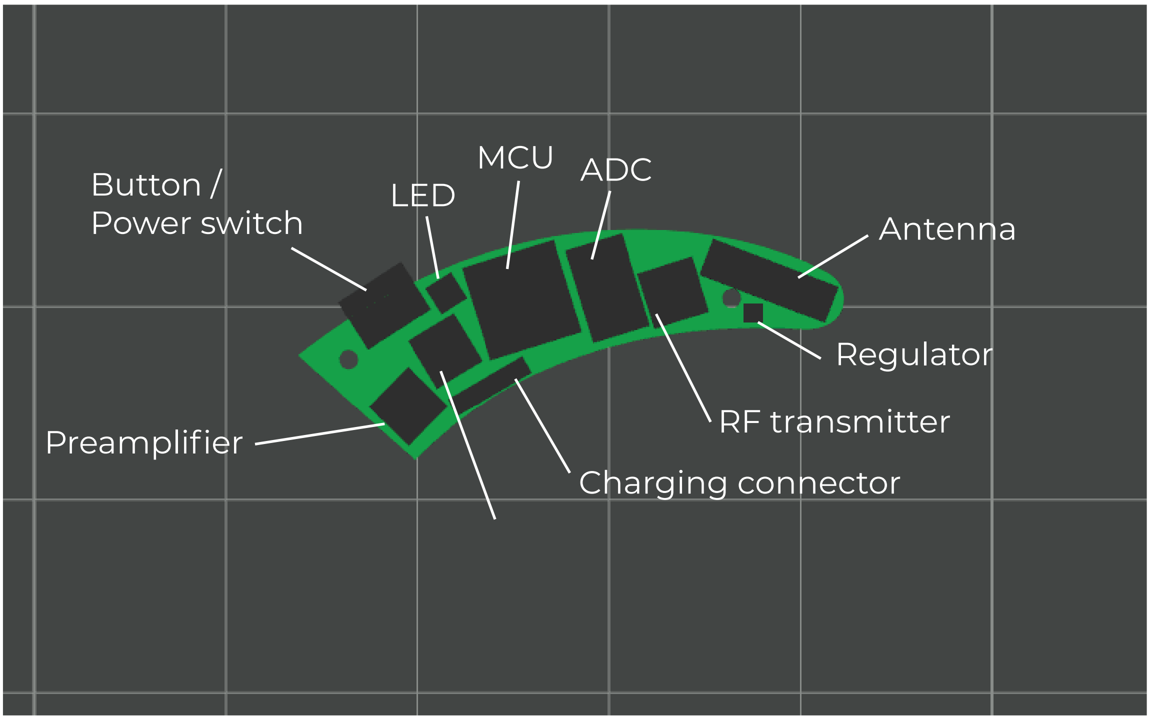


Figure 57: Components placed on the PCB of the microphone

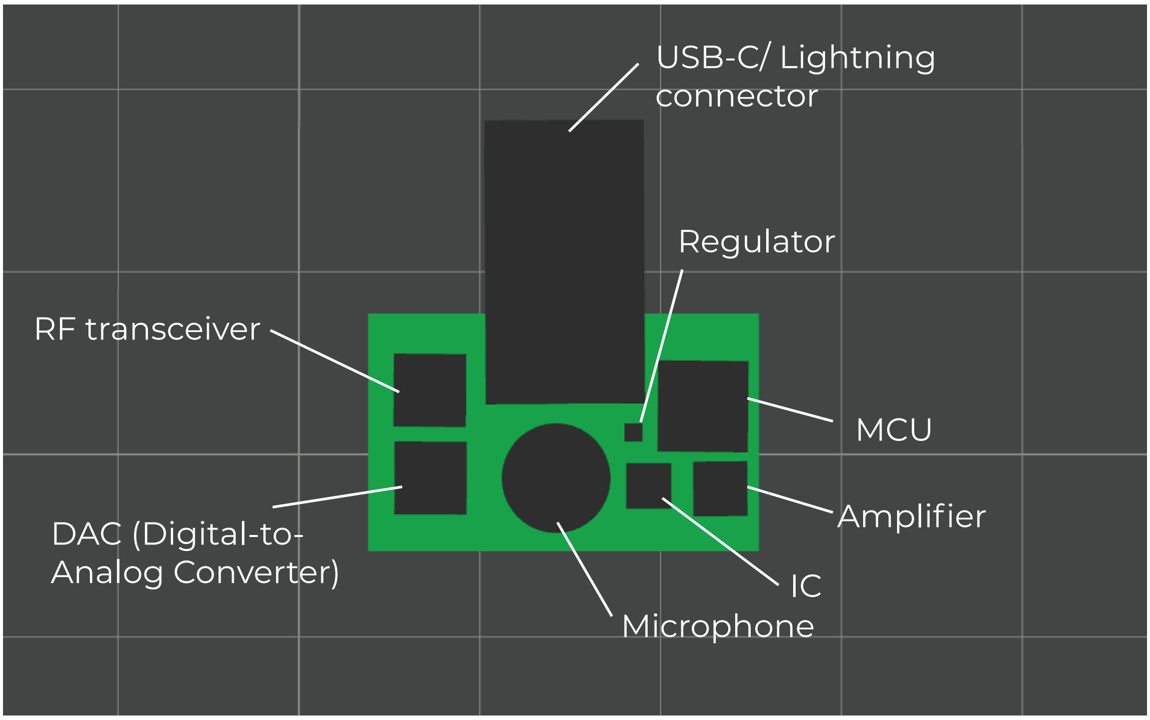


Figure 58: Components placed on the PCB of the connection dongle

In order to use the wearable microphone, it must first be connected to the dongle. The dongle receives the audio from the microphone and sends it to the Whispp app for conversion. The converted audio can then be sent to an external audio output source. The dongle also has a built-in microphone, enabling users to speak directly into it when the wearable microphone is not in use, which makes the system easy to use in a variety of settings. Figure 58 shows the PCB layout of the dongle.

5.4 AUDIO OUTPUT

As discussed earlier, the following devices can be used as audio output sources: hearing aids, phone speakers, wireless speakers, headphones and earphones. To enable audio output from the microphone system, two connection scenarios are considered:

1. Using the phone's built-in Bluetooth
   In this scenario, the phone establishes a wireless connection with external output devices. Any Bluetooth-enabled audio device, such as headphones, earbuds or speakers, can be connected. This offers flexibility, especially for users who already own compatible devices. However, the potential for latency introduced by Bluetooth transmission must be taken into account, particularly during real-time conversations.

2. An alternative is to use a wireless connection module in the dongle.
   This alternative involves embedding a wireless transmission system within the dongle itself. While this reduces reliance on the phone's Bluetooth, connectivity is limited to audio output devices that are compatible with the dongle's wireless protocol. Therefore, a matching set of output devices should be provided alongside the microphone and dongle to ensure compatibility.

In the second scenario, there are still a few options for the types of output sources to provide. Figure 59 shows the use setup and two options for carrying the microphone and audio output sets.

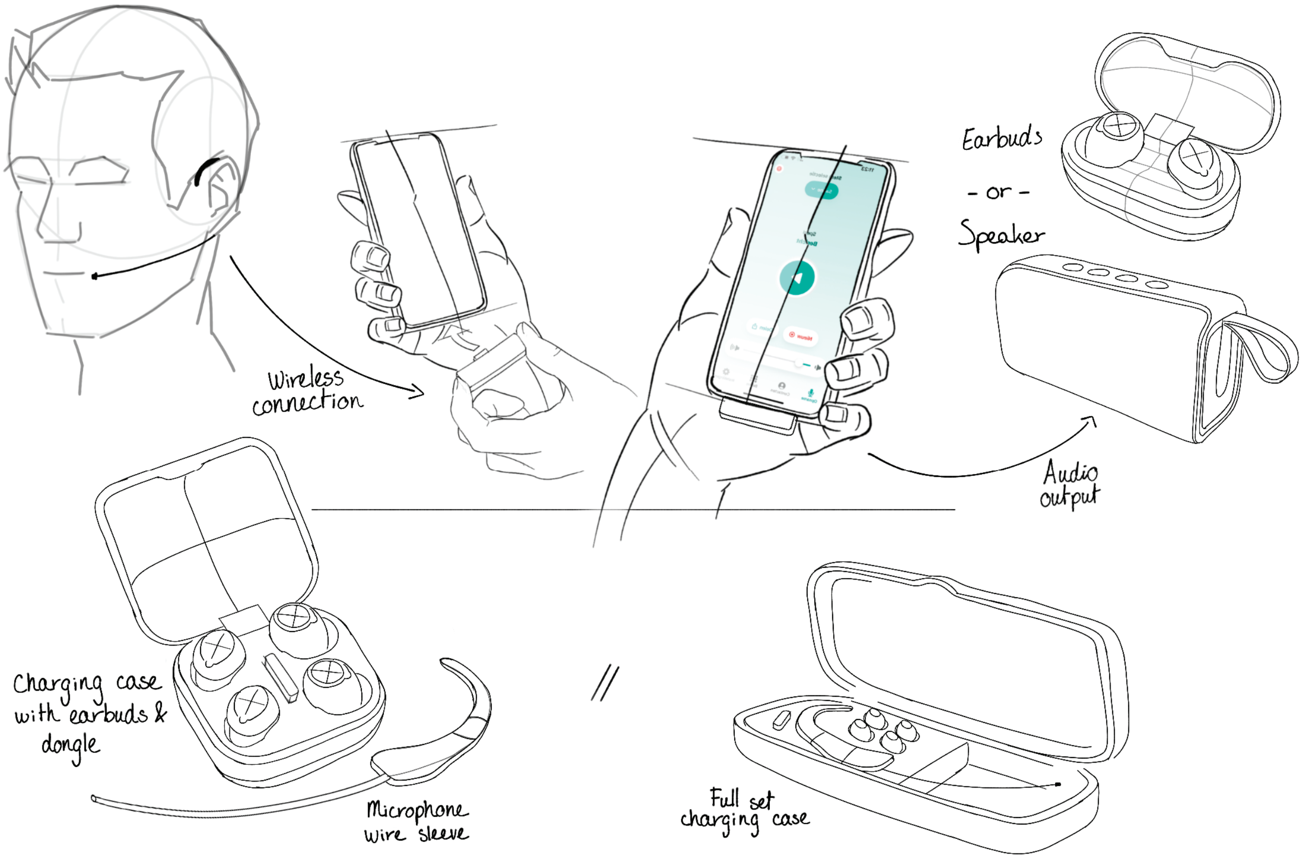


Figure 59: Setup of the wearable microphone, dongle and output options (earbuds or speaker), as well as two carrying options for the microphone and audio output sets

In this setup there is either an option for a wireless speaker, or a small carrying set including two pairs of earbuds for listeners to use.

In an earlier questionnaire in Chapter 4.1, participants were asked which audio output option they would prefer and whether they would prefer it as part of a set. Of those who were interested, half preferred a complete set to just a microphone and earbuds or a speaker. This was seen as the most convenient option, as they would always have everything with them.

5.5 USER TESTING

Further evaluation of the microphone requires feedback. User testing can be used to evaluate the microphone's physical design and usability. This leads to the following research aim:

The aim of the test is to observe how users interact with the product, identify potential usability issues and gather feedback on comfort and appearance. These insights will then be used to refine the design.

Ten participants were involved in the user testing. Unfortunately, none of these participants are from the intended target group. They have therefore been asked to simulate having a voice disorder. The participants are of mixed gender and range in age from 24 to 78. See Appendix P for full user test details.

This user test consists of five parts:

1. Project explanation
   Participants were introduced to Whispp, the product, its purpose, and the test context.
2. Inspect and wear the microphone
   Participants were asked to handle the device, figure out how it should be worn, and comment on its comfort and appearance.
3. Listener perspective
   Participants then switched roles to experience the system from the listener's side by wearing the provided earphones.
4. Simulate interaction setup
   In a roleplay scenario, participants imagined being in a café and were asked to take the device from its case, set it up, and hold a short conversation about their morning. This helped to assess the ease of use of the device in everyday contexts.
5. Post-test reflection
   Finally, participants reflected on their overall experience with the system by answering questions about its usability and comfort, and suggesting areas for improvement.

FINDINGS

Overall, participants reported a positive experience with the prototype. Most found it relatively easy to work out how to wear the device, often comparing its placement behind the ear to that of a hearing aid. While the microphone design was considered intuitive, the adjustable microphone wire caused some confusion, as several participants did not position it close enough to the mouth, which could affect performance.

Opinions on the device's appearance were mixed. Some appreciated its simplicity and subtle design, while others suggested matte finishes or skin-tone colour options to make it less noticeable. Hairstyles also influenced visibility: some participants covered the device with their hair, while others did not mind it being seen. Overall, participants agreed that functionality was more important than appearance; if the device helped them to communicate more clearly, its visibility was a minor concern.

In terms of the listener's experience, participants tested the provided earbuds. While they were suitable for short conversations, they were not considered comfortable for long-term use. Some found the single ear tip uncomfortable and were concerned about blocking out environmental sounds. Open-ear headphones were suggested as a better alternative, as they allow users to stay aware of the environment and avoid hygiene concerns related to shared devices. Participants appreciated the simplicity of the provided earbuds and their lower latency compared to personal devices, and most said they would choose them for reliable performance. However, the earbuds were viewed as more appropriate for private, one-to-one conversations than for group situations, where a speaker would be preferable. Participants also noted that not all earphones have built-in volume control, and felt that listeners should be able to adjust the volume independently.

When asked whether they would change their speaking behaviour while using the device, some participants said they might speak more slowly or clearly at first to ensure everything was captured. However, several noted that the device would actually encourage them to speak more, as it would reduce the need to repeat themselves. Comfort ratings were generally high, averaging around 4 out of 5. When worn correctly, participants often forgot they were wearing it. However, misplacement could cause the microphone wire to move around and become distracting. Most participants said they would feel comfortable using the device in public, with some suggesting that it could raise awareness of voice disorders and assistive technology.

SUGGESTIONS FOR IMPROVEMENT

Participants highlighted several areas for improvement, including:

- Waterproofing or sweatproofing for daily wear.
- Additional colour options.
- Better adjustability of the microphone wire
- Easier access to volume control for listeners.

A reasonable price range for the device was suggested to be between €100 and €200. Some participants also wondered whether it might eventually be covered by insurance if it were classified as a medical device.

CONCLUSION

Participants saw strong potential in the wearable microphone, appreciating its ability to support clear, real-time communication. While refinements in appearance, comfort, and output options were suggested, the core concept was considered highly valuable. As one participant noted, “This could be life-changing for some people.”

5.6 PRODUCTION

COLOUR SELECTION

Earlier in the design process, a collage was created to explore the visual appearance of the product (Van Boeijen et al., 2013). The collage featured sleek lines and neutral and transparent colours, and it served as a reference for the design of the wearable prototype (Figure 60).

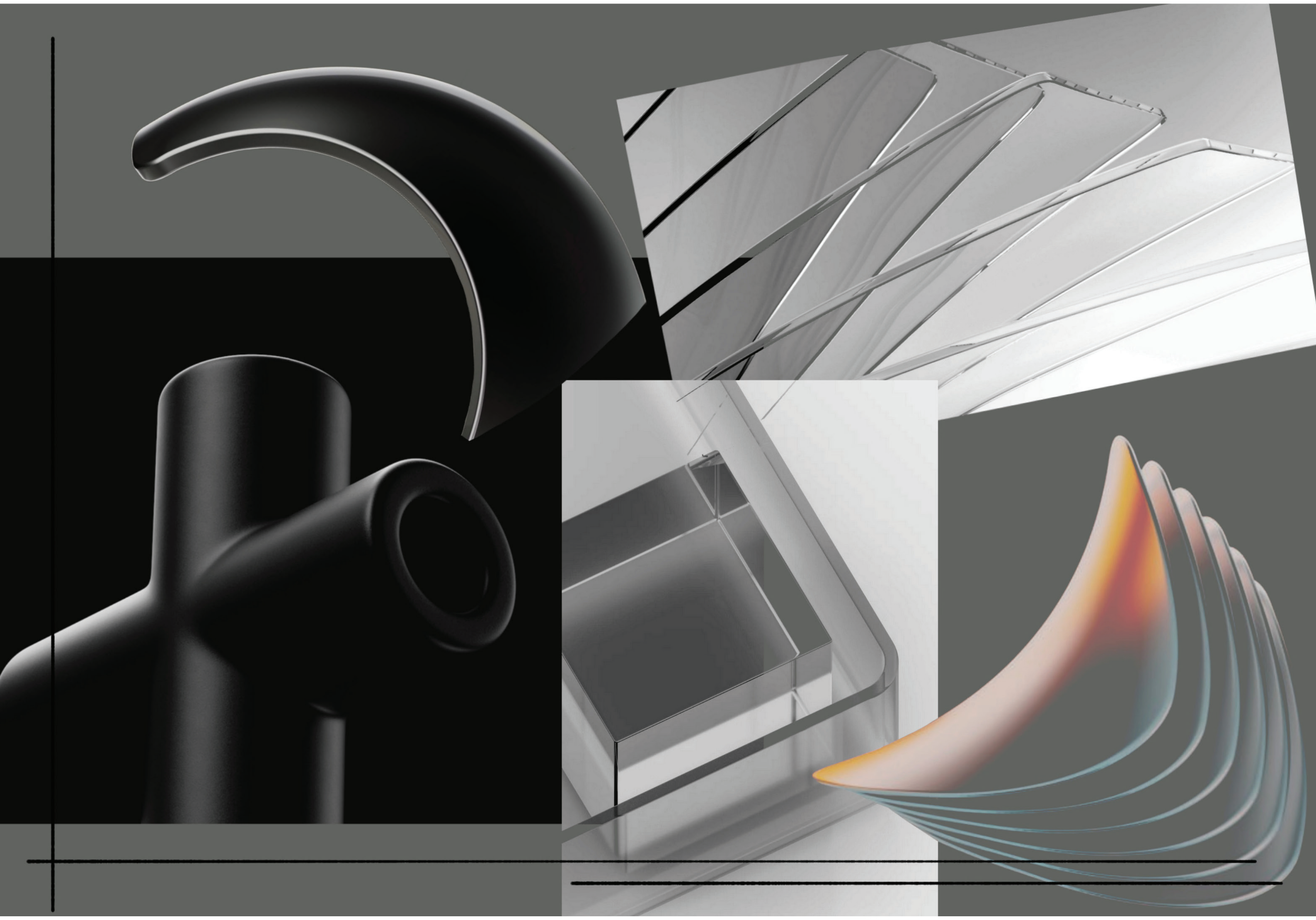


Figure 60: Collage used as a reference of the wearable microphone design

During user testing, participants provided feedback on the black colour of the prototype. While some users liked this colour, others suggested offering an alternative. As discussed in Chapter 5.1, most similar products are produced in neutral colours. Hearing aids, in particular, are typically made in neutral or earth tones to blend with the wearer's skin or hair colour (Figure 61).

Figure 61: Common hearing aid colours (Hearing Aid Styles Explained, 2025)

As the initial production run is expected to be small (approximately 100 units), offering numerous colour options would not be practical. Providing two colours would allow for personalisation while maintaining production efficiency. A light option, such as beige, and a dark option, such as black, would accommodate most preferences. Figure 62 shows two prototypes of the colour options.

Figure 62: Prototypes in beige and black with a transparent middle

MATERIAL SELECTION

Selecting the right material is key to ensuring the durability and comfort of the wearable microphone. Since hearing aids are worn in the same location, they were used as a frame of reference. Most hearing aids have outer casings made from lightweight yet durable plastics such as acrylic or polycarbonate (PC). These materials are both hypoallergenic, helping to prevent skin irritation from prolonged contact (Pittsburgh Ear LLC, 2025). A comparison between the two materials was performed using Ansys Granta EduPack. Since the wearable microphone will be frequently worn and removed, it may be dropped during use. As stated in the list of requirements (Chapter 2.5), the device should be drop-resistant from a height of two metres. Polycarbonate offers greater drop resistance than acrylic, making it the better choice for this device.

The middle section of the microphone requires a flexible material. The prototype used a translucent TPU for this purpose, but TPU has poor UV resistance and can turn yellow over time when exposed to sunlight (Ansys Granta EduPack, 2024). Silicone is a suitable alternative, offering excellent UV resistance and skin compatibility.

This flexible section contains a thin 1 mm metal wire that enables the device to be moulded to fit securely around the ear. During user testing, however, the wire sometimes bent sideways, causing the device to lose its shape. While it can be manually corrected, using Nitinol, a shape-memory alloy, would allow the microphone to naturally retain a clamped position, improving stability and preventing unwanted bending.

MANUFACTURING METHOD

Injection moulding is the ideal manufacturing method for wearable microphone, as it enables precise and consistent production of small shapes. This efficient process supports the production of multiple units of uniform quality and allows for different colours, while minimising material waste. This makes it well suited to the expected low-to-medium production volume of the device.

The housing of the wearable microphone requires a closure that is both secure and serviceable. Small snap-fits were considered, but they proved to be too fragile. Larger snap-fits could provide greater strength, but careful design is required to prevent breakage, as observed in other disassembled products. Snap-fits allow the device to be opened for maintenance or repair, whereas gluing the housing would make reopening extremely difficult.

The design of the housing also directly impacts the injection moulding process. Features such as snap-fits must be carefully considered to ensure that the mould can be produced and that the parts can be reliably ejected without defects. Complex or fragile features could complicate manufacturing, increase costs, or lead to higher rejection rates.

COST

The production cost of the microphone housing is €5.74 and that of the carry case is €5.46. The PCB and additional components, such as the speaker or earbuds, account for the largest portion of the cost at €63.43. This brings the total production cost to €75.61 for the complete set and €40.15 for the microphone alone.

When overheads, retail margins and taxes are included, the estimated retail price of the full set is around €200, with the microphone costing approximately €100 alone. Detailed cost calculations are provided in the Appendix.

Given the low production volume, it may also be feasible to use a 3D-printed mould with aluminium inserts. This approach could significantly reduce initial tooling costs.

CHAPTER 6 - CONCLUSIONS

This project set out to design a wearable microphone to support individuals with voice disorders in their everyday communication. Research confirmed that many existing assistive devices are bulky and visually obtrusive, and do not combine comfort, usability, and discretion. At the same time, the research highlighted how important it is that these devices not only function technically but also fit seamlessly into the user's daily life. The outcome is a concept with potential, which the client company regarded as a promising foundation for further development.

The project followed a user-centered design approach, beginning with in-depth research into the needs, challenges, and daily experiences of individuals with voice disorders. Insights were gathered through a combination of literature review, analysis of existing assistive devices, and direct engagement with members of the target group wherever possible. As the project progressed, it became clear that working with a small, specialised user group presents unique challenges. Recruiting participants and obtaining sufficient data proved difficult, emphasising the need for creative research methods. Despite these limitations, however, the research provided valuable guidance for defining design criteria, understanding real-world user needs and informing decisions throughout the concept development stages. It also became evident that even small amounts of information could offer significant insights and influence the design process meaningfully.

A number of recommendations have been outlined for the project. On the technical side, the device requires further detailing before it can be considered production-ready. Comfort and durability should be tested in long-term use, and additional trials with individuals from the target group are essential to validate the design. Beyond technical refinement, future development should include testing in real-world environments, such as workplaces and social gatherings, to evaluate its usability in everyday situations. Considering developments in related fields, such as hearing aids integrated into smart glasses, it is also advisable to monitor technological trends and explore how the concept might adapt or integrate with these.

Reflecting on the process, I found that carrying out all steps of the design process independently was both challenging and insightful. This involved project management in a way that I had not experienced before. Although there were setbacks, I learnt how to structure a design project from start to finish, prioritise tasks and adapt when things did not go according to plan. One thing I noticed during this project is that the more you delve into the material, the more difficult it becomes to decide what is most important. Since it is impossible to do everything, you have to make decisions about where to focus. Learning to zoom out and refocus on the bigger picture was one of the most valuable lessons I learned from this experience.

One of the main objectives of this project was to expand my technical expertise and deepen my understanding of electronics by designing a product around them. As the device had to be developed from scratch, I gained a significant amount of knowledge through research. This improved my understanding of hardware and showed me how closely tied its development is to the design process as one cannot be completed without understanding the other. Collaborating with the client was another valuable aspect of the project. It taught me how to communicate design decisions more effectively, incorporate feedback, and appreciate the importance of clear and consistent communication throughout the process.

Although the process presented challenges, it provided valuable experience in the management of independent projects and technology-driven, user-centred design. The project demonstrated how AI technologies can be applied to assistive products and that design considerations such as comfort and discretion are just as important as technical performance. Overall, the project produced a promising concept for future development and allowed me to strengthen my skills in project management, design methodology, and technical problem-solving.

REFERENCE LIST

Ad Hoc Committee on Service Delivery in the Schools. (1993). Definitions of communication Disorders and Variations. *In American Speech-Language-Hearing Association.* https://doi.org/10.1044/policy.rp1993-00208

An artist's guide to microphone polar patterns. (2023, October 17). *Ditto Music.* https://dittomusic.com/en/blog/an-artists-guide-to-microphone-polar-patterns

Andersen, M. (2024, July 23). *This app uses AI to turn your whisper into speech.* Fast Company. https://www.fastcompany.com/91125955/whisp-app-innovation-by-design-2024

Ansys Granta EduPack (24.2.1.) [Computer software]. (2024). https://www.ansys.com/

Barche, P., Gurugubelli, K., & Vuppala, A. K. (2020). Towards Automatic Assessment of Voice Disorders: A Clinical Approach. *Interspeech 2020,* 2537–2541. https://doi.org/10.21437/interspeech.2020-2160

BOYA mini | MINI Size & AI Noise Cancelling. (n.d.). BOYA. https://store.boyamic.com/products/boya-mini

Bradshaw, K. (2025, February 6). *Open Fit Hearing Aids - What are open fit hearing aids and what are the benefits?* Hearing Aid UK. https://www.hearingaid.org.uk/hearing-aid-advice/what-are-open-fit-hearing-aids

Ceva. (2023, May 28). *Gaming is Next Driver for Bluetooth Low Energy and LE Audio.* https://www.ceva-ip.com/blog/gaming-is-next-driver-for-bluetooth-low-energy-and-le-audio/

Çiyiltepe, M., & Şenkal, Ö. A. (2017). The ageing voice and voice therapy in geriatrics. *Aging Clinical and Experimental Research*, *29*(3), 403–410. https://doi.org/10.1007/s40520-016-0597-3

Design Council. (n.d.). *The Double Diamond - Design Council*. https://www.designcouncil.org.uk/our-resources/the-double-diamond/

Ear Solutions. (2023, September 27). *How to seamlessly wear BTE hearing aids and glasses?* https://earsolutions.in/how-to-seamlessly-wear-bte-hearing-aids-and-glasses/

Echovoice ® EV7 TM Voice Amplifier NEW MODEL. (n.d.). Hearing Products International. https://www.hear4you.com/product/echovoice-ev7-voice-amplifier-model-2021/

How it works. (n.d.). [Video]. Whispp.com. https://whispp.com/

Idris, M. R., Irdayanti, M. N., & Ramlee, M. (2023). A review of microcontroller design in future industrial revolution. *AIP Conference Proceedings.* https://doi.org/10.1063/5.0149680

Ingham, R. J., Bothe, A. K., Jang, E., Yates, L., Cotton, J., & Seybold, I. (2009). Measurement of speech effort during Fluency-Inducing conditions in adults who do and do not stutter. *Journal of Speech, Language, and Hearing Research, 52*(5), 1286–1301. https://doi.org/10.1044/1092-4388(2009/08-0181)

Krischke, S., Weigelt, S., Hoppe, U., Köllner, V., Klotz, M., Eysholdt, U., & Rosanowski, F. (2005). Quality of life in dysphonic patients. *Journal of Voice, 19*(1), 132–137. https://doi.org/10.1016/j.jvoice.2004.01.007

Malini, K., & Rajkumar, R. (2020). SPEECH AND LANGUAGE IMPAIRMENT: SYMPTOMS, TYPES, CAUSES, TREATMENT AND ASSISTIVE TECHNOLOGY. In K. Saileela, (Ed.), Inclusive Education (pp. 159-178). DK International Research Foundation. https://d1wqtxts1xzle7 cloudfront.net/67231573/Inclusive_Education-libre.pdf?1620313585=&response-content-disposition=inline%3B+filename%3DRole_of_Community_Colleges_in_Inclusive.pdf&Expires=1748874110&Signature=Kf2scOjfdAST8KXp5oJ3Z0av57E0XlKSnxGkfN2FeDON0gaoRwGxzotXNR3ShRK11GcnDoJ59PicSD5pH7cFrnJ1io359ufSu1Zkg-sJMUwIO8zK8DLS9V1usS9PGEL1w3yuO6aOXpCfZzDtHs9TDVSivDgLfuDGpUz0yQdsRPoi-lt5XTeqX~JbP2-EmIyg8q5Mhr-yaKqu-9s04AF~4dqn0t5djwomXw0aBOJhhrumYu9jcpCkbI8zqoWb2wkxLtwT6Ss0yoeuBn4JM8F~ZukJ6skW--5EqpVc0W0mTGoBvgpbIGNtz9eI4wYqOhB5giMHyW3gfqeLewPg6yI7wQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA#page=165

Mangar, D., Sprenker, C. J., Karlnoski, R. A., McDonough, J. P., Dodson, R. K., Brashears, B. H., Downes, K. L., & Camporesi, E. M. (2013). Are anatomical landmark measurements accurate for predicting endotracheal tube depth? *International Journal of Advanced Nursing Studies, 2*(2), 66–73. https://doi.org/10.14419/ijans.v2i2.820

Martins, R. H. G., Amaral, H. a. D., Tavares, E. L. M., Martins, M. G., Gonçalves, T. M., & Dias, N. H. (2016). Voice Disorders: Etiology and Diagnosis. *Journal of Voice, 30*(6), 761.e1-761.e9. https://doi.org/10.1016/j.jvoice.2015.09.017

Martins, R. H. G., Pereira, E. R. B. N., Hidalgo, C. B., & Tavares, E. L. M. (2014). Voice Disorders in Teachers. A review. *Journal of Voice, 28*(6), 716–724. https://doi.org/10.1016/j.jvoice.2014.02.008

Merrill, R. M., Anderson, A. E., & Sloan, A. (2011). Quality of life indicators according to voice disorders and voice-related conditions. *The Laryngoscope, 121*(9), 2004–2010. https://doi.org/10.1002/lary.21895

Naqvi, Y., & Gupta, V. (2020). Functional Voice Disorders. *StatPearls Publishing*.

Oliveira, P., Ribeiro, V. V., Constantini, A. C., De Oliveira Barbosa Cavalcante, M. E., Sousa, M. D. S., & Da Silva, K. (2022). Prevalence of Work-Related Voice Disorders in Voice Professionals: Systematic Review and Meta-Analysis. *Journal of Voice*. https://doi.org/10.1016/j.jvoice.2022.07.030

Paolini, M. & Senza Fili. (2018). *Latency matters.* https://www.exfo.com/contentassets/49201c4a29d44694a3a89e402f854f8e/exfo_flyer_latency-matters_senzafili_exfo_v1_en.pdf

Prasetyo, A. T., & Putri, I. L. (2021). Anthropometric Study of Human Ear: A baseline data for ear reconstruction. *Journal of Craniofacial Surgery, 33*(4), 1245–1249. https://doi.org/10.1097/scs.0000000000008199

Roy, N., Merrill, R. M., Gray, S. D., & Smith, E. M. (2005). Voice Disorders in the general Population: Prevalence, risk factors, and occupational impact. *The Laryngoscope, 115*(11), 1988–1995. https://doi.org/10.1097/01.mlg.0000179174.32345.41

Sahoo, R. K. (2022). Interview as a Tool for Data Collection in Educational Research. In *Tools of Data Collection in Educational Research*. Lucky International. https://www.researchgate.net/publication/360313105_Interview_as_a_Tool_for_Data_Collection_in_Educational_Research

Sand, B., Shapiro, L., & Neff, W. (2024, June 2). Why restaurants are so loud, and what science says we can do about it. *The Washington Post*. https://www.washingtonpost.com/science/interactive/2024/loud-restaurant-noise-health-effects/

Sarow, A. (2024, June 5). *Hearing Aid Batteries: How long does each size last? Best Hacks.* https://www.soundly.com/blog/hearing-aid-batteries#:~:text=Orange%2Dtab%20batteries%20ready%20to,needed%20and%20features%20in%20use.

Sharma, R., & Shrivastava, M. (2024). Aura cast: A new milestone over the existing versions of bluetooth. *AIP Conference Proceedings, 3111*(1). https://doi.org/10.1063/5.0221465

Stachler, R. J., Francis, D. O., Schwartz, S. R., Damask, C. C., Digoy, G. P., Krouse, H. J., McCoy, S. J., Ouellette, D. R., Patel, R. R., Reavis, C. W., Smith, L. J., Smith, M., Strode, S. W., Woo, P., & Nnacheta, L. C. (2018). Clinical Practice Guideline: Hoarseness (Dysphonia) (Update). *Otolaryngology and Head and Neck Surgery/Otolaryngology--head and Neck Surgery, 158*(S1). https://doi.org/10.1177/0194599817751030

Suppa, A., Costantini, G., Asci, F., Di Leo, P., Al-Wardat, M. S., Di Lazzaro, G., Scalise, S., Pisani, A., & Saggio, G. (2022). Voice in Parkinson's Disease: A Machine learning study. *Frontiers in Neurology, 13*. https://doi.org/10.3389/fneur.2022.831428

University of Minnesota. (n.d.). *Categories of voice disorders.* https://med.umn.edu/ent/patient-care/lions-voice-clinic/treatments/voice-disorder-categories

Van Boeijen, A. G. C., Daalhuizen, J. J., Zijlstra, J. J. M., & Van Der Schoor, R. S. A. (2013). *Delft Design Guide* (4th ed.). BIS Publishers.

Van De Vorst, R., & Van Vugt, F. T. (2023). Exploring Feasibility and Effectiveness of Occasional Whispering in Adults who Stutter: Subjective and Objective Evaluations. *Advances in Cognitive Psychology, 19*(1), 92–103. https://doi.org/10.5709/acp-0381-x

Whispp.com. (2023). P*ositioning paper "Whispp and stuttering."* https://whispp.com/wp-content/uploads/2023/10/Positioning-paper-Whispp-and-stuttering-20231008.pdf

Whispp. (n.d.). https://whispp.com/

Whispp. (n.d.). *Company - Whispp*. https://whispp.com/company/

APPENDIX A
Project brief

Name student Naomi Lolling **Student number** 4,857,941

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Enhancing communication for people with voice disabilities

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This project is aimed at addressing the needs of individuals dealing with voice disabilities, which can become an obstacle in people's social life and work as it can impact communication and social integration.

Whispp, the client, has developed Assistive Voice Technology to mitigate these challenges. This technology can render their whispered or rough esophageal speech voices clear and comprehensible. The objective of this technology is to enhance the quality of life of users, enabling effective and confident communication.

The project's main stakeholders are:
1. Whispp: The company is focused on customer acquisition and retention, with the goal of delivering impactful solutions and fostering long-term engagement.
2. Whispp users: Individuals with speech impairments that are in need of access to high-quality, user-friendly products and services.
3. Financial stakeholders: Investors and shareholders are primarily interested in tangible returns on investment.

The opportunities in this area lie mainly in the relative newness of the market. As it has not yet been fully explored, there is potential for growth. However, as there is much more to explore, there is also a lot that could be improved upon.

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introduction (continued): space for images

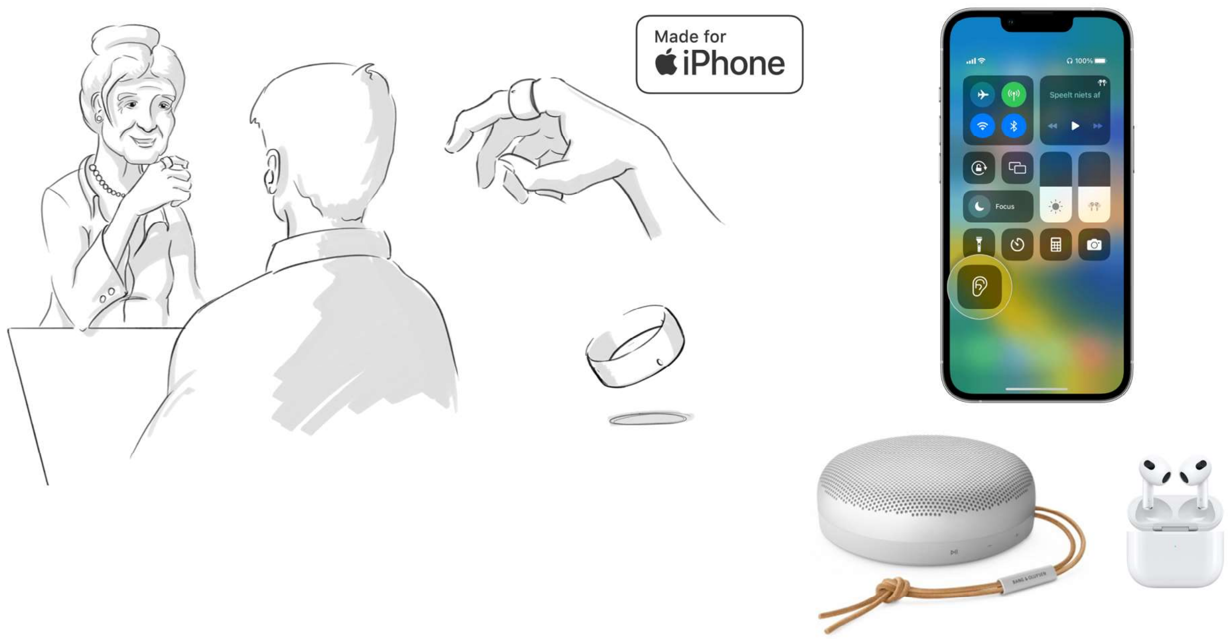


image / figure 1 Whispp's initial concept idea

image / figure 2

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

At the moment, Whispp offers its services through its app, which is mainly used during phone calls. This improves the user's voice for the listener at the other end of the call. However, their voice disabilities cause problems not only during phone calls, but also in everyday situations. To address this, Whispp's usage would need to be adapted to suit these other situations.

For this, Whispp wants to develop a small microphone that users can speak into. By using existing components, this microphone can be introduced into the market quickly. The microphone will be used by connecting to the Whispp app, which will process and enhance their voices. The processed audio will then be transmitted to another device, such as a speaker or earphones, so others can hear the transformed voices in near real-time.

By extending the use case of the technology, users can benefit even more from its use. Creating more value for all stakeholders.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design of a speech enhancement device that utilises existing components to improve communication for individuals with voice disabilities.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

As the user is central to this design, the first step is to define the context. Through interviews, questionnaires and online research, the scope can be narrowed down, leading to relevant background information and a desired use case.

From there, various design methods will be used to generate ideas. For example, sketching and prototyping will be used to develop ideas into concepts. The client has relevant connections with technology companies that may have valuable insight into the topic. Brainstorming sessions with these companies could be very fruitful for the design phases as well as for validating ideas and concepts. Focus groups with the target group will also be used to further test/validate ideas and prototypes.

Together with manufacturing/cost research, this can provide a clear and complete concept for the client.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	1 Jul 2024
Mid-term evaluation	28 Jan 2025
Green light meeting	21 Feb 2025
Graduation ceremony	28 Mar 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✓
For how many project weeks	25
Number of project days per week	4,0

Comments:
The full project is done part-time, as I am co-running a startup on the side.
Project planning includes in total 6 weeks of vacation.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I want to start this project because I think the product can have a big impact on people's lives. And with AI getting bigger, the human-AI interaction is a relevant topic to tackle.

During the Master's programme, I learned more about user-centred design and found a deeper interest in it. With this project, I hope to prove my skills in designing a product for users and also develop it further with a more specific and vulnerable target group.

In terms of personal learning ambitions, I want to delve deeper into technology during this project. While it has been touched upon in several courses, this project takes it a step further with its application and limitations in product size. Another learning ambition is to work more closely with the client. During most projects so far, the client is only involved during presentations and evaluation moments. So, it would be beneficial to learn to plan and have discussions and meetings with the client more often.

APPENDIX B
Interview

1. **Introduction & Background**
- Could you tell me a little more about your voice disorder?
- How long have you been experiencing it?
- Is your voice always the same, or are there days when it's better or worse?

2. **Impact on daily life**
- In which situations does your voice bother you the most? (e.g. with certain people or in particular settings).
- What kinds of problems do you encounter because of it?
- How do you usually handle situations like this?
- What challenges or obstacles do you face in everyday situations because of your voice?

3. **Experience with Whispp**
- Do you currently use Whispp to make calls?
- How long have you been using it?
- What has your experience been like so far?
- Are there any features you particularly like or dislike?
- What would you like to see improved?

4. **Other assistive products**
- Have you used any other assistive products before?
  - If so, in what situations did you use them?
  - If not, do you think you would need one? In what situations might you use it?

5. **Future features & needs**
- Whispp is currently working on a live feature that will enable face-to-face conversations with real-time voice translation without any noticeable delay.
  - Do you think this feature could improve your daily life?
  - Can you think of any situations where it would be useful?
- If you could design the ideal product to support you in face-to-face conversations, what would it look like?
  - What would the interaction be like?
  - What features would it have?
  - Would it be small or large, portable or wearable?
  - How would you like your conversation partner to hear you? Through earphones, a Bluetooth speaker or another method?

6. **Closing**
- Is there anything else you'd like to share, or any questions you'd like to ask me?

APPENDIX C
Survey

General questions about your disability/disorder and Whispp

- How long have you been affected by your voice disability/speech disorder?
  - <1 year
  - 1-5 years
  - 6-10 years
  - >10 years

- How much do you think your voice disability/speech disorder affects your ability to speak?
  [1 - Not at all] ~ [7 - Very much]

- How long have you been using Whispp?
  - <6 months
  - 6 months - 1 year
  - >1 year

- How often do you use Whispp?
  - <1 time(s) a week
  - 1-5 time(s) a week
  - 6-10 times a week
  - >10 times a week

Questions about in person conversations

Whispp's Live Conversations feature:
This innovative technology enhances real-time interactions, allowing for effortless spoken communication in the same room. Whispp's advanced AI technology instantly converts whispered and vocal cord-impaired speech into clear, natural speech, enabling live, face-to-face conversations without noticeable delay.

- How important is it for you to have clear and relaxed face-to-face conversations again?
  [1 - Not important] ~ [7 - Very important]

- What kind of conversations are affected by your voice disability/speech disorder?
  - One-on-one conversations

    - Conversations in small groups (3-6 people)
    - Conversations in larger groups (>6 people)
    - Conversations with strangers/unacquainted people
    - Conversations in loud environments
    - Presentations
    - None

- What tasks/activities in particular are difficult for you? Why?

- Would being able to use Whispp's Live Conversations feature with these difficult tasks/activities help alleviate the difficulties?
  [1 - Not at all] ~ [7 - Very much]

- In what social situations could you see yourself using Whispp's Live Conversations feature to have clear and relaxed conversations?
    - Friendship circles
    - Home and family gatherings
    - Workplace and professional settings
    - Educational institutions
    - Community and Community and public spaces

- Do you have any comments or thoughts you want to share?

Questions about product preferences

- If you could create the perfect product to assist you with your voice disability/speech disorder in face-to-face conversations, what would it be and what features would it have?

- How would this product improve your life or help you achieve your goals?

- What do you think of this idea?
  "A device for face-to-face conversations: You hold or wear a small device with a microphone inside. You speak into the device as you would into the Whispp app. The device is connected to the Whispp app and makes your voice clear and understandable. Your conversation partner has a Bluetooth device, such as earphones or a speaker, and can hear your clear voice. "
  [1 - Not useful] ~ [7 - Very useful]

- Why or why not?

- What is the maximum you would be willing to spend on a device like this for face-to-face conversations?

- 0 EUR/USD
- 10 EUR/USD
- 20 EUR/USD
- 30 EUR/USD
- 40 EUR/USD
- 50 EUR/USD
- 60 EUR/USD
- 70 EUR/USD
- 80 EUR/USD
- 90 EUR/USD
- 100 EUR/USD
- >100 EUR/USD
- I wouldn’t want to buy it

- Do you have any comments or thoughts you want to share?

Personal details

- What is your gender?
    - Male
    - Female
    - Prefer not to say

- What is your age?
    - <25 years
    - 25-35 years
    - 36-45 years
    - 46-55 years
    - 56-65 years
    - 66-75 years
    - 76-85 years
    - >85 years

- What type of voice disorder/speech disorder do you have?
    - Amyotrophic Lateral Sclerosis (ALS)
    - Complete or partial laryngectomy (TLE)
    - Multiple Sclerosis (MS)
    - Muscle tension dysphonia (MTD)
    - Presbyphonia - vocal cord complaints due to old age
    - Radiotherapy of the throat only
    - Parkinson’s disease
    - Recurrent Respiratory Papillomatosis (RRP)
    - Spasmodic Dysphonia (SD)

- Stutter
- Traumatic brain injury
- Vocal cord nodule/polyp/cyst
- Vocal cord paralysis
- Voice tremor
- I don’t know

APPENDIX D
Informed consent form

25/07/2024

Je wordt uitgenodigd om deel te nemen aan een onderzoek genaamd “Communicatie verbetering voor mensen met stemproblemen”. Dit onderzoek wordt uitgevoerd door Naomi Lolling van de TU Delft en Whispp.

Het doel van dit onderzoek is om probleemgebieden te achterhalen op sociaal vlak voor mensen met stemaandoeningen en inzicht te krijgen m.b.t. voorkeuren voor mogelijke productvorming. Het onderzoek zal ongeveer 10 minuten in beslag nemen. De data zal gebruikt worden voor een masterscriptie van industrieel ontwerp, TU Delft. Je wordt gevraagd om jouw ervaringen rondom stemaandoeningen en ideeën over gebruikssituaties voor Whispp.

Zoals bij elke online activiteit is het risico van een data breuk aanwezig. Wij doen ons best om jouw antwoorden vertrouwelijk te houden. We minimaliseren de risico’s door persoonlijke data lokaal te bewaren, bij benoeming van de data voor de scriptie wordt deze geanonimiseerd.

Jouw deelname aan dit onderzoek is volledig vrijwillig, en je kunt je elk moment terugtrekken zonder reden op te geven. Je bent vrij om vragen niet te beantwoorden. De verzamelde data wordt na de afronding van de scriptie verwijderd.

GELIEVE DE JUISTE VAKJES AAN TE KRUISEN	Ja	Nee
A: ALGEMENE OVEREENSTEMMING - ONDERZOEKSDOELEN, DEELNEMERS TAKEN EN VRIJWILLIGE DEELNAME		
1. Ik heb de informatie over het onderzoek gedateerd *25/07/2024* gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent: ● Een audio-opgenomen interview waar aantekeningen worden gemaakt ● De audio opnames zullen getranscribeerd worden ● De audio opnames zullen na de duur van de scriptie verwijderd worden	☐	☐
4. Ik begrijp dat de studie 01/02/2025 eindigt.		
B: MOGELIJKE RISICO'S VAN DEELNAME (INCLUSIEF GEGEVENSBESCHERMING)		
5. Ik begrijp dat mijn deelname het volgende risico met zich meebrengt: mentaal ongemak. Ik begrijp dat dit risico wordt geminimaliseerd door het interview op elk moment stop te kunnen zetten.	☐	☐
6. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden in publieke reputatie.	☐	☐
7. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een data breuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een data breuk: anonimisering, beperkte toegang tot gegevensopslag, transcriptie.	☐	☐
8. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam en leeftijd, niet gedeeld worden buiten het studieteam.	☐	☐
9. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt op 01/02/2025	☐	☐
C: PUBLICATIE, VERSPREIDING EN TOEPASSING VAN ONDERZOEK		
10. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor de masterscriptie en toepassing voor productontwikkeling.	☐	☐
11. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdragen anoniem te quoten in resulterende producten.	☐	☐

GELIEVE DE JUISTE VAKJES AAN TE KRUISEN	Ja	Nee
D: (LANGDURIGE) OPSLAG, TOEGANG EN HERGEBRUIK VAN GEGEVENS		
12. Ik geef toestemming om de geanonimiseerde data van probleemgebieden en voorkeuren die over mij verzameld worden gearchiveerd worden in TU Delft repository opdat deze gebruikt kunnen worden voor toekomstig onderzoek en onderwijs.	☐	☐
13. Ik begrijp dat de toegang tot deze repository open is.	☐	☐

APPENDIX E
Connection methods

Wired connection	
Advantages	• Stable connection • No battery
Disadvantages	• Wire tangling • Limits movement • Longer setup time
Latency	x
Module size	x
Price (EUR)	1 - 5
Use case	Any

Bluetooth	
Advantages	• Freedom of movement • Automatic reconnection • BLE is designed for devices that need to conserve battery life, such as wearables • Compatible with most on the market speakers • Its limited range minimizes interference from other devices • No need for additional receivers as it directly connects to smartphones
Disadvantages	• Battery dependent • Lower data transfer rates • Latency
Latency	100 ms - 200ms
Module size	5 x 5mm
Price (EUR)	1 - 10
Use case	Consumer electronics

DECT	
Advantages	• Freedom of movement • Stable frequency, good sound quality • No interference with Bluetooth devices and Wi-Fi • Large range of 30–50 meters indoors and up to 300 meters outdoors • Low power consumption
Disadvantages	• Battery dependent • Limited data transfer capabilities • Interference in crowded areas
Latency	30ms - 100 ms
Module size	10 x 20mm
Price (EUR)	10 - 50
Use case	• Wireless phones • Business communication

FM	
Advantages	• Freedom of movement • High audio quality • Stable signal transmission
Disadvantages	• Battery dependent • Potential for frequency interference
Latency	10ms - 30ms
Module size	10 x 10mm
Price (EUR)	1 - 20
Use case	• Live audio transmission • Professional audio • Wireless microphones

RF	
Advantages	• Freedom of movement • High audio quality • Suitable for crowded environments • Stable and consistent audio transmission
Disadvantages	• Battery dependent • RF signals are prone to interference from other devices operating in the same or overlapping frequency bands
Latency	10ms - 50ms
Module size	10 x 10mm
Price (EUR)	5 - 50
Use case	• Wireless microphones • Medical devices • Remote controls

APPENDIX F
Audio test 1

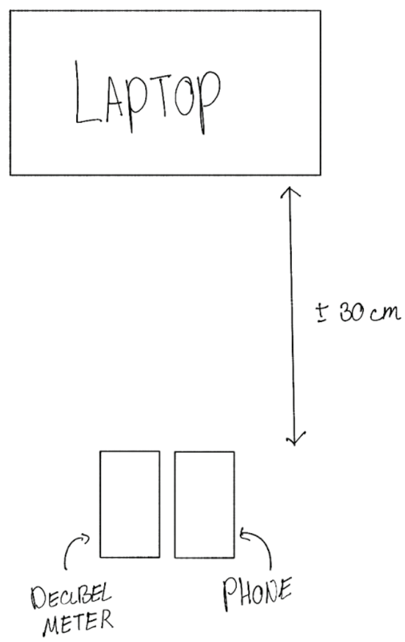
Volume requirements

1. Background & Research aim
As the target group has a relatively low voice volume, the aim of the research is to establish the volume levels required for the Whispp app to recognise and convert voices effectively.

- How much volume is required for Whispp to successfully convert a voice?
- Are there different volume requirements for different voice types?

2. Method
Equipment
Laptop with voice recordings, phone with the Whispp app, decibel meter.

Procedure
1. Create voice recordings featuring the following four voice types: total laryngectomy, spasmodic dysphonia, vocal cord paralysis and a healthy voice. Ensure that each recording contains 50 spoken words.
2. Arrange the laptop, phone and decibel meter as shown below.



3. Play the first audio recording at 20-30 dB (measured with the decibel meter) and use the Whispp app to record it.
4. Listen to the transformed audio in the Whispp app and note how many words are intelligible.
5. Repeat steps 3-4 with the other three audio recordings.
6. Repeat steps 3-5 with measured decibel levels at 40-50 dB, 50-60 dB, and 60-70 dB.

Data collection & analysis
Data is collected by listening to the output of the Whispp app and counting the number of intelligible words.

---

3. Results

Sound level	Measured decibel	Voice	Whispp output
Louder speech	60-70	Total Laryngectomy "rough/raspy voice"	49/50 words intelligible
		Spasmodic Dysphonia	50/50 words intelligible
		Vocal Cord Paralysis "whispered voice"	50/50 words intelligible
		Healthy voice	49/50 words intelligible
Regular speech	50-60	Total Laryngectomy "rough/raspy voice"	47/50 words intelligible
		Spasmodic Dysphonia	49/50 words intelligible
		Vocal Cord Paralysis "whispered voice"	50/50 words intelligible
		Healthy voice	49/50 words intelligible
Softer speech	40-50	Total Laryngectomy "rough/raspy voice"	45/50 words intelligible
		Spasmodic Dysphonia	46/50 words intelligible
		Vocal Cord Paralysis "whispered voice"	47/50 words intelligible
		Healthy voice	48/50 words intelligible
Whisper	20-30	Total Laryngectomy "rough/raspy voice"	3/50 words intelligible
		Spasmodic Dysphonia	0/50 words intelligible
		Vocal Cord Paralysis "whispered voice"	5/50 words intelligible
		Healthy voice	1/50 words intelligible

4. Discussion

The data is collected based on the listener's judgement. However, this judgement may be inaccurate, as being aware of what has been said may influence the outcome.

---

5. Conclusions

The results show that the Whispp app can convert the user's voice more accurately the louder the speech volume. There does not appear to be an upper limit. However, the target group often cannot reach these high volumes, so this does not seem to be a problem. There is no significant difference between different voice types. The app could not pick up some words regardless of the volume, which could be due to the pronunciation of the words.

APPENDIX G
Audio test 2

Effect of background noise

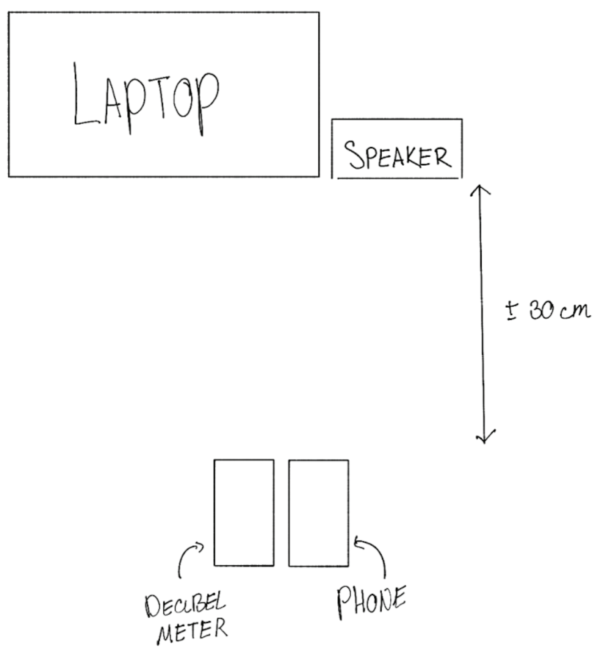
1. Background & Research aim
Loud environments are one of the biggest problems the target group encounters. This research aims to investigate the impact of background noise on the effectiveness of the Whispp app.

- How loud can the background noise be and still allow the Whispp app to perform effectively?
- Does the type of background noise make a difference?

---

2. Method
Equipment
Laptop with voice recordings, phone with the Whispp app, decibel meter, speaker.

Procedure
1. Place the laptop, speaker, phone and the decibel meter as shown below.

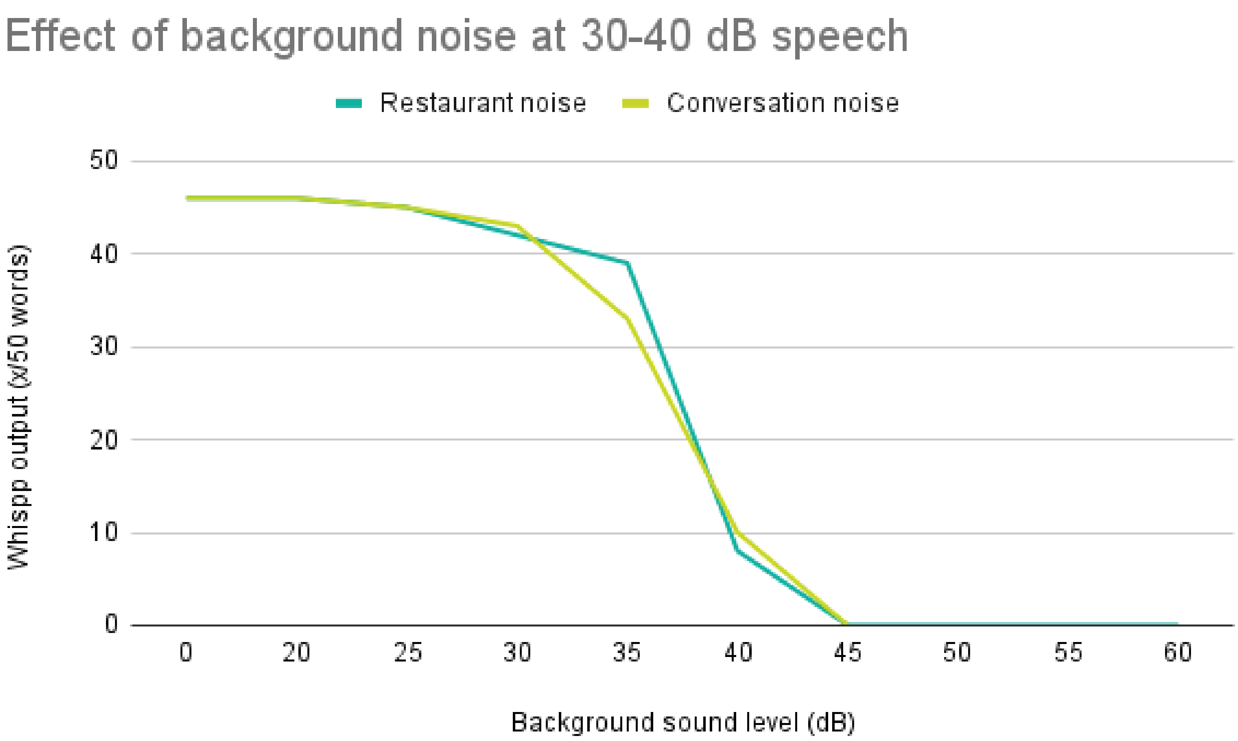


2. Play the first audio recording at 30-40 dB (measured with the decibel meter) and use the Whispp app to record it.
3. Listen to the transformed audio in the Whispp app and note how many words are intelligible.
4. Play the ‘restaurant’ background noise at 20 dB.
5. Repeat steps 2-3.
6. Repeat steps 4-5 with background noise at 25, 30, 35, 40, 45, 50, 55 and 60 dB.
7. Repeat steps 2-6 with conversation background noise.
8. Repeat steps 2-7 with audio recordings at 40-50 dB and 50-60 dB.

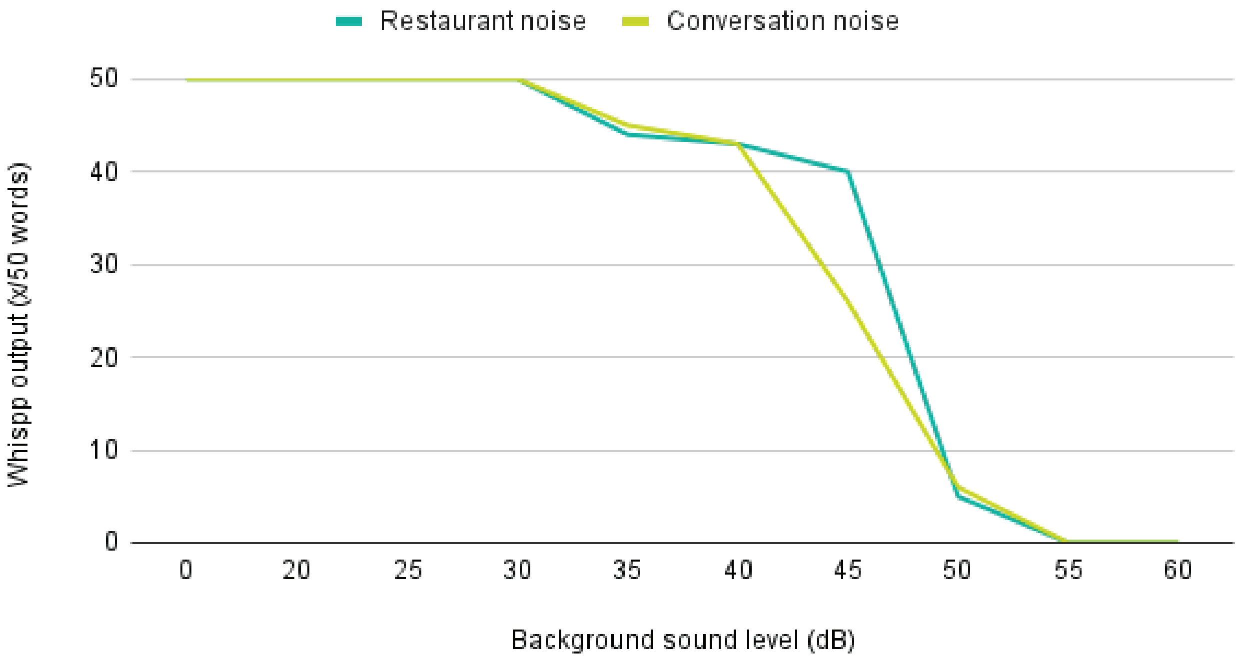
Data collection & analysis
Data is collected by listening to the output of the Whispp app and counting the number of intelligible words.

---

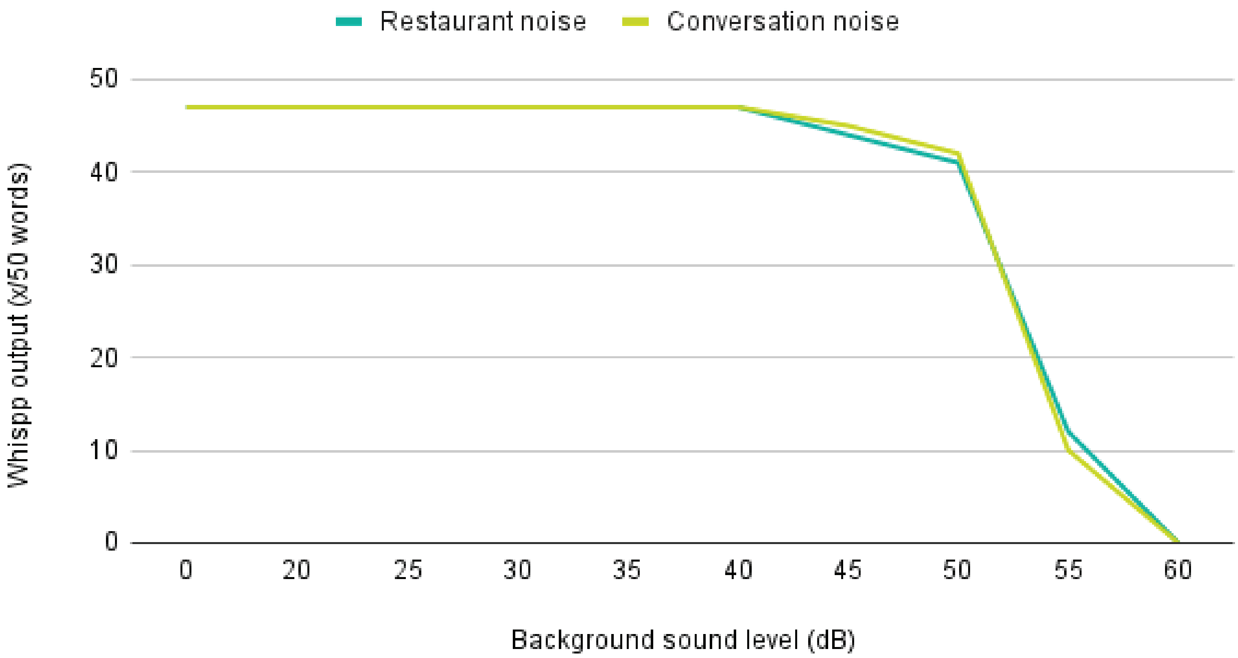
3. Results



Effect of background noise at 40-50 dB speech



Effect of background noise at 50-60 dB speech



4. Discussion

Background noise is often inconsistent in volume. Therefore, the outcome can vary in real-life situations. Data collection is based on the listener's judgement. However, this judgement may be inaccurate, as awareness of what is being said can influence the outcome.

---

5. Conclusions

In all three situations, the app's effectiveness drops just below the levels at which background noise and speech overlap. Provided the background noise level remains 10 dB below the speech level, the Whispp app can effectively convert voices.

There is no significant difference between background noise in restaurants and noise from conversations.

APPENDIX H
Audio test 3

Sound levels at wearable locations

1. Background & Research aim
As demonstrated in Audio Test 1, higher volume improves conversion effectiveness. As the target group prefers discretion, the aim of this research is to identify a discreet placement for the wearable that can still capture sufficient speech volume.

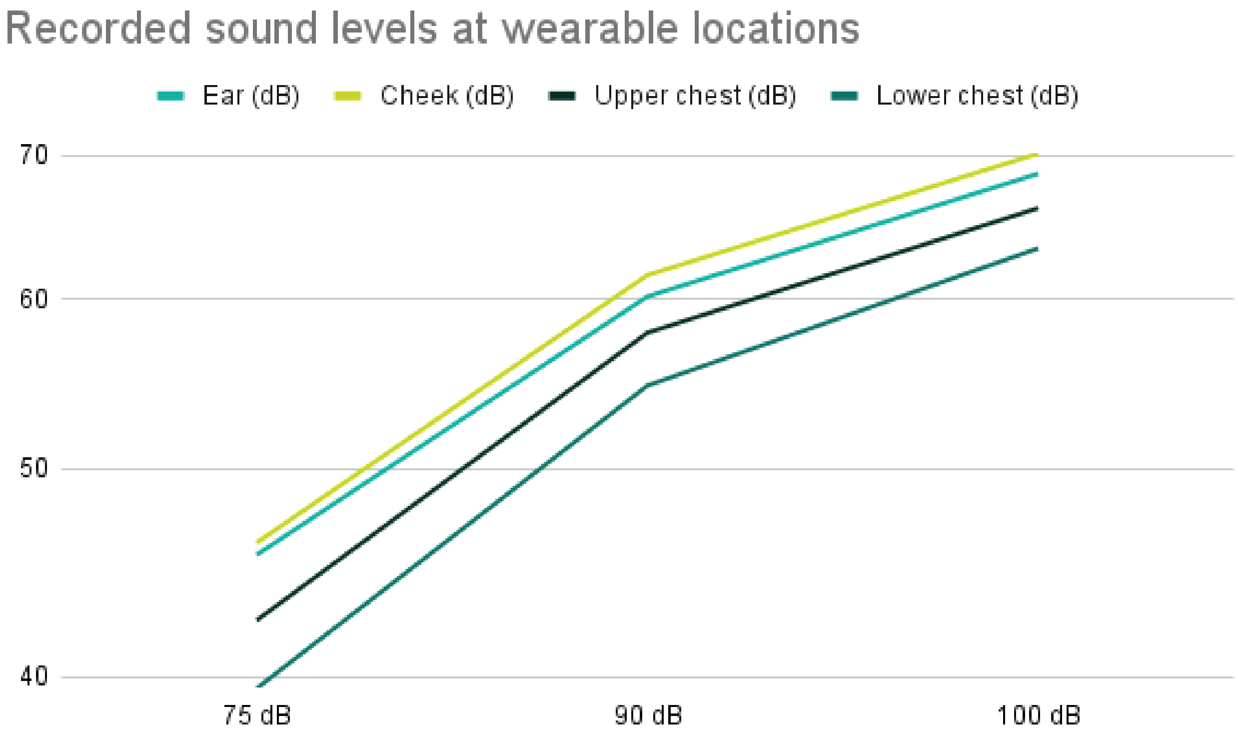
- Which regions of the upper body are most suitable for the placement of the wearable device?

2. Method
Equipment
Two phones (one and audio player, one with a decibel meter), earphones.

Procedure
1. Plug the earphones into the phone, then place one earbud in the mouth with the sound output facing outwards.
2. Play a static sound from the earbuds.
3. Using a decibel meter on a second phone, measure the decibel level at the mouth.
4. Set the volume of the static sound to 75 dB.
5. Use the decibel meter to measure the sound at the following points: the ear, the cheek, the upper chest and the lower chest.
6. Repeat steps 4-5 with 90 dB and 100 dB.

Data collection & analysis
Data is collected by measuring the decibels at various locations on the upper body.

3. Results



4. Discussion

The volume of the earbud was higher than the typical speech level of most individuals in the target group. At a whisper level (20–30 dB), the recorded volumes may be insufficient for the Whispp app to recognize speech, as a significant portion of the signal would be lost.

5. Conclusions

All four locations lost around a third of their sound level. The cheek recorded the highest decibels, followed by the ear and the upper and lower chest.

APPENDIX I
Audio test 4

Sound levels on face positions

1. Background & Research aim
Audio test 4 showed that the audio levels were better at the recording points on the face. Since Audio test 1 showed that higher audio levels were preferred, the aim of this research is to narrow down the preferred microphone location on the face.

- Which areas on the face pick up enough volume for effective conversion in the Whispp app?

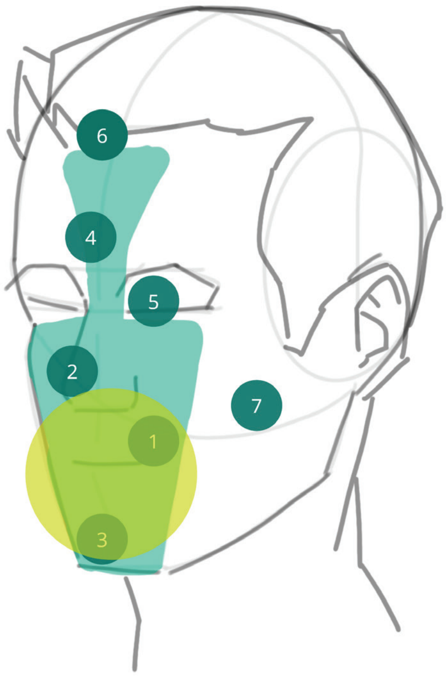
2. Method
Equipment
Two phones (one and audio player, one with a decibel meter), earphones.

Procedure
1. Connect/plug the earphones into the phone and place one earbud in the mouth (the sound output facing out of the mouth).
2. Play a static sound from the earbuds.
3. With the second phone, measure the decibel of the earbud at the mouth.
4. Maximise the earbud volume.
5. Use the decibel meter to measure the sound at the following points: side of the mouth, tip of the nose, chin, between eyebrows, underside glasses, forehead, and the middle of the cheek.

Data collection & analysis
Data is collected by measuring the decibel at various locations on the face.

3. Results

	1	2	3	4	5	6	7
Source (mouth)	Side mouth	Tip of nose	Chin	Between eyebrows	Underside glasses	Forehead	Middle cheek
66.1 dB	61.1 dB	60.4 dB	60.3 dB	59.6 dB	59.1 dB	58.2 dB	54.7 dB



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4. Discussion

The test used higher audio levels than normal speech to make the measurements easier to take, so the decibel levels in real life will be lower. The test was also conducted in a noise-free environment, meaning the effective area would probably be smaller in everyday scenarios.

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5. Conclusions

The closer the measurement is to the source, the higher the recorded volume. The green area shows the audio levels that can be effectively converted. The yellow area will most likely perform best in noisy environments.

APPENDIX J
Audio test 5

In mouth audio recording

1. Background & Research aim

The recorded volume increases as the microphone is positioned closer to the sound source. This test investigates whether the Whispp app can effectively convert speech captured by a microphone placed inside the mouth.

- Can the Whispp app recognise speech recorded from any position inside the mouth?

2. Method

Equipment

A phone with the Whispp app, wired microphone.

Procedure

1. Connect the microphone to the phone and open the Whispp app.
2. Place the microphone in the mouth (between the front teeth and the lips).
3. Start a recording in the Whispp app and whisper a few sentences totalling 50 words.
4. Listen to the recording in the Whispp app and note the number of clear words.
5. Repeat steps 3-4 with the microphone placed in different positions (between the teeth and cheek, between the teeth and tongue, behind the front teeth).

Data collection & analysis

Data will be collected by listening to the Whispp output of the recordings and counting the number of intelligible words.

3. Results

Location	Speech recognition		Notes
Front	9/50	10/50	Uncomfortable
Side	3/50	0/50	Not comfortable, but better then the front
Inner	1/50	0/50	Does not stay put
Front, back of teeth	0/50	0/50	Difficult to speak

4. Discussion

This test uses a relatively large microphone encased in a hard shell. This can generate unwanted noise when the mouth moves during speech. Using a different type of microphone may produce different results.

5. Conclusions

Currently, this result is not usable in practice. However, it could become a viable option in the future with improvements to the Whispp app or microphone noise filtering.

APPENDIX K
Audio test 6

Phone speaker output volume

1. Background & Research aim

One option for outputting the converted voice is through a phone speaker. A potential limitation of this method is that the maximum volume may be insufficient in noisy environments. This test aims to evaluate whether a phone speaker can produce sufficient sound to be clearly heard under loud background noise.

- Can the phone speaker generate enough volume to be intelligible in loud environments?

2. Method

Equipment

Two phones (one with the Whispp app, one with a decibel meter app), speaker.

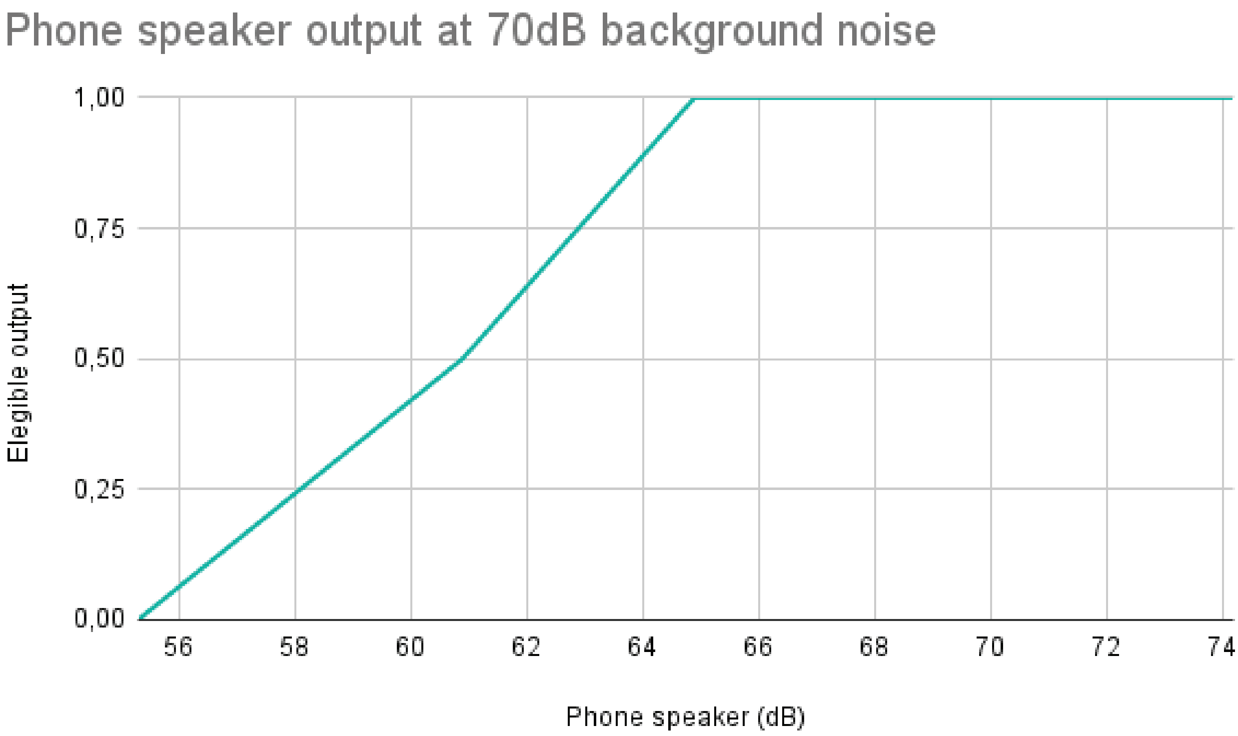
Procedure

1. Use the Whispp app to record a few sentences spoken in a soft whisper. Set the phone's speaker to maximum volume.
2. Place the speaker next to the phone.
3. Sit 20 cm in front of the phone and speaker, placing the second phone with the decibel meter next to you.
4. Play a recording of restaurant noise through the speaker. Use the decibel meter to measure and set the sound output to 70 dB.
5. Play the Whispp recording and measure the sound output again.
6. Play the background noise and the Whispp recording simultaneously and determine whether the voice is audible.
7. Reduce the volume of the phone speaker by one and repeat steps 5-6 until the recorded voice is no longer audible.

Data collection & analysis

Data will be collected using the decibel meter, as well as by listening to the output and determining whether the speech is audible.

3. Results



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4. Discussion

The type of background noise can affect how audible the recorded voice is. Since results are subjective, prior knowledge of the speech content may influence judgements as to whether it is audible. Additionally, since the phone speaker is directional, listening from different angles or from the opposite side can affect how well you can hear it. In this study, the listening distance was set at 20 cm, but in actual settings it could be greater.

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5. Conclusions

In an environment with 70 dB of background noise, a phone speaker can deliver an audible voice through Whispp when listened to from a distance of 20 cm.

APPENDIX L
Survey 2

Whispp's Live Conversations feature

- Would you be interested in using this feature?
  - [1 - Not at all] ~ [7 - Very much]

- If so, in what scenarios/situations do you see yourself using the feature?

- Have you ever used other assistive devices to help you in face-to-face conversations? If so, what kind?

Questions about product use

Whispp's Live Conversations feature allows you to talk face-to-face with Whispp. Four product concepts have been designed to make it even easier to use. These wearable products contain a microphone inside to replace the need to talk into the phone.

The concepts all work with the following steps:
1. Connect a pairing dongle to the phone to link the microphone to the Whispp app.
2. Wear the product and speak into it.
3. If desired, connect an output device (such as a Bluetooth speaker or wireless headphones). The converted voice can then be played through an external speaker device.

- What do you think of the general setup of the product?

- Concept 1: Around the ear boom
  This product features a discreet hook that wraps around the ear, with a small, skin-coloured microphone attached for minimal visibility. The design ensures a secure, comfortable fit and clear sound capture, providing a hands-free solution.
  How likely are you to use this product?
  - [1 - Not very likely] ~ [7 - Very likely]

- What are your honest thoughts on this product? What do you like, and what would you change?

- Concept 2: Extendable necklace
  The necklace has a built-in microphone that can be easily extended to be closer to your mouth for better sound pickup. Simply pull the microphone along the cord or hook it around your ear to optimise audio pickup. When not in use, it doubles as a sleek, stylish necklace, providing a hands-free solution for clear communication.
  How likely are you to use this product?
  - [1 - Not very likely] ~ [7 - Very likely]

- What are your honest thoughts on this product? What do you like, and what would you change?

- Concept 3: Ring
  This ring has a built-in microphone that clearly picks up your voice when you put your hand near your mouth. In quiet environments where your voice can be heard from a further distance, the ring can also be worn as a necklace, eliminating the need to hold your hand near your mouth.
  How likely are you to use this product?
  - [1 - Not very likely] ~ [7 - Very likely]

- What are your honest thoughts on this product? What do you like, and what would you change?

- Concept 4: Voice nosepiece
  This is a compact, comfortable device with a built-in microphone that fits discreetly inside the nose. Its soft outer shell and breathable design ensure comfort for extended wear, while the small breathing hole allows natural airflow.
  How likely are you to use this product?
  - [1 - Not very likely] ~ [7 - Very likely]

- What are your honest thoughts on this product? What do you like, and what would you change?

- Do you have any comments or other ideas you want to share?

Questions about listening options
Using the Live feature your speech is picked up by the microphone. For others to hear your speech, you need some kind of loudspeaker. This can come in many forms such as a phone speaker, a wireless speaker, wireless earbuds, wireless headphones or connecting them to hearing aids.

- Which of the speaker outputs are you likely to use? (tick all that apply)
    - Phone speaker
    - Wireless speaker
    - Wireless earbuds
    - Wireless headphones
    - Hearing aids

- In which scenario/situation would you use these options? And while talking to whom?

- If you are using the wearable microphone, would you be interested in having a complete set to use, which includes the wearable microphone and a wireless speaker/earbuds?
    - I would prefer just the wearable microphone
    - I would prefer the wearable microphone and the earbuds
    - I would prefer the wearable microphone and the speaker
    - I would prefer a complete set
    - I wouldn't want any of the options

- Please explain why

Personal details

- What is your gender?
    - Male
    - Female
    - Prefer not to say

- What is your age?
    - <25 years
    - 25-35 years
    - 36-45 years
    - 46-55 years
    - 56-65 years
    - 66-75 years
    - 76-85 years
    - >85 years

- What type of voice disorder/speech disorder do you have?
    - Amyotrophic Lateral Sclerosis (ALS)
    - Complete or partial laryngectomy (TLE)
    - Multiple Sclerosis (MS)

- Muscle tension dysphonia (MTD)
- Presbyphonia - vocal cord complaints due to old age
- Radiotherapy of the throat only]
- Parkinson’s disease
- Recurrent Respiratory Papillomatosis (RRP)
- Spasmodic Dysphonia (SD)
- Stutter
- Traumatic brain injury
- Vocal cord nodule/polyp/cyst
- Vocal cord paralysis
- Voice tremor
- I don’t know

APPENDIX M
PCB components

Microphone components	Part	Size (mm)	Weight (g)	Price (/100)
Microphone	RS Pro Uni-Directional	6.0 x 2.2	0.22	€ 2,70
Preamplifier	TLV9152	2.9 x 2.9 x 1.1		€ 0,579
ADC	ADS1115	5.0 × 3.1 x 1.1		€ 3,61
MCU	STM32L0	7.0 x 7.0 x 1.4		€ 1,47
RF module	Si4012	3 x 3 x 0.85		€ 2,07
Antenna	0868AT43A0020001E	7 x 2 x 0.8		€ 0,5159
Battery	ICP501421PS	22.5 x 14.1 x 5.2	23.02	€ 8,96
Charging circuit	TP4056	2.9 x 2.8 x 1		€ 2,49
Voltage regulator	AMS1117	6.7 x 3.7 x 1.7		€ 0,23
Decoupling capacitors	GCM188R71 C104KA37J	1.6 x 0.8 x 0.8	0.006	€ 0,064
Power switch	EL2 52 35J LFS	6.2 x 6.2 x 3.5		€ 0,23
Connector	685A02222001A1E	8–10 x 4 x 3		€ 4,16
LED	LTST-C19HE1WT	1.6 x 1.6 x 0.34	0.032	€ 0,147

Dongle components	Part	Size (mm)	Weight (g)	Price (/100)
Microphone	RS Pro Uni-Directional	6.0 x 2.2	0.22	€ 2,70
Amplifier	MAX98357A	3 x 3 x 0.75	0.15	€ 1,95
USB connector	USB4155-03-C	15.5 x 8.8 x 2.4		€ 1,075
USB-interface IC	FUSB302	2.5 x 2.5 x 0.5		€ 0,765
MCU	STM32F4	10 x 10 x 1.6	0.35	€ 3,10
DAC	TAD5242	4 x 4 x 0.5		€ 2,60
Voltage regulator	AMS1117	6.7 x 3.7 x 1.7		€ 0,23
RF Transceiver	Si4460	4 x 4 x 0.8	1.47	€ 3,13

APPENDIX N
Average battery life and weight

LAVALIER

Product	Battery life (h)	Weight (g)
RØDE Wireless Micro	7	18
RØDE Wireless GO (Gen 3)	7	35
PULUZ Wireless Lavalier Microphone	12	
BOYA mini	6	5
BOYA BY-V3	9	10.5
Hollyland LARK M2S	9	7
Average	8.3	15.1

IN EAR

Product	Battery life (h)	Weight (g)
Jabra Talk 5	11	9.7
EMEET AirFlow	8	8.5
New Bee M53	18	13.6
New Bee M52	8	7.2
Average	11.25	9.75

HEADSET

Product	Battery life (h)	Weight (g)
Arikasen Wireless Bluetooth Headset	10	
SHOKZ OpenComm2	16	35
2.4 GHZ wireless headset microphone set	6	
Average	13	35

WIRED HEADSET

Product	Battery life (h)	Weight (g)
Voice Technologies VT800	x	18
DPA 4266	x	10
DPA 4088	x	14
Point Source Audio GO-9WD	x	17
Point Source Audio EO-8WLh	x	17
Average	x	15.2

HEADSET + TRANSMITTER

Product	Battery life (h)	Weight (g)
SubZero Mini	6	45
Shure BLX14/P31-K3E with PGA31	14	60
EVO-E Water & Sweat Resistant Wireless Headset		40
Average	10	48.3

HEARING AID

Product	Battery life (h)	Weight (g)
Miracle-Ear ENERGY BTE R S	19	3.2
Miracle-Ear EASY BTE S 312		2.5
Miracle-Ear EASY BTE SP 13 EV	9	
HearingAs Bluetooth Rechargeable BTE	15	6.2
Average	14	2.85

APPENDIX O
PCB component iteration

Microphone components	Part	Size (mm)	Weight (g)	Price (/100)
Microphone	RS Pro Uni-Directional	6.0 x 2.2	0.22	€ 2,70
Preamplifier	TLV9152	2.9 x 2.9 x 1.1		€ 0,579
ADC	ADS1115	5.0 × 3.1 x 1.1		€ 3,61
MCU	STM32L031K6T6	5 x 5 x 0.5	0.18	€ 1,42
RF module	Si4012	3 x 3 x 0.85		€ 2,07
Antenna	0868AT43A0020001E	7 x 2 x 0.8		€ 0,5159
Battery	501015 3.7 v 100 mAh	15 x 10 x 5	2.5	€ 1,22
Charging circuit	TP4056	2.9 x 2.8 x 1		€ 2,49
Voltage regulator	TPS7A0233PDQNR	1 x 1 x 0.4	1.1	€ 0,39
Decoupling capacitors	GCM188R71 C104KA37J	1.6 x 0.8 x 0.8	0.006	€ 0,064
Power switch	SKTDLDE010	3.9 x 2.9 x 1.55	1	€ 0,23
Connector	2 pin Pogo pin SMD	1 x 1 x 4.5		€ 1,11
LED	LTST-C19HE1WT	1.6 x 1.6 x 0.34	0.032	€ 0,147

Dongle components	Part	Size (mm)	Weight (g)	Price (/100)
Microphone	RS Pro Uni-Directional	6.0 x 2.2	0.22	€ 2,70
Amplifier	MAX98357A	3 x 3 x 0.75	0.15	€ 1,95
USB connector	USB4155-03-C	15.5 x 8.8 x 2.4		€ 1,075
USB-interface IC	FUSB302	2.5 x 2.5 x 0.5		€ 0,765
MCU	STM32L031K6T6	5 x 5 x 0.5	0.18	€ 1,42
DAC	TAD5242	4 x 4 x 0.5		€ 2,60
Voltage regulator	TPS7A0233PDQNR	1 x 1 x 0.4	1.1	€ 0,39
RF Transceiver	Si4460	4 x 4 x 0.8	1.47	€ 3,13

APPENDIX P
User test

Materials:

- Mock up of the microphone and dongle
- Carry case with audio output devices (open ear earphones)
- Phone with Whispp app
- Video of Whispp use
- Mirror

Setup and questions:

1. Project explanation

This project is being carried out in collaboration with Whispp, a client company that has developed language-independent AI technology and a voice app designed to support individuals with voice impairments. Its Assistive Voice Technology enables users to express themselves clearly by converting whispered or rough esophageal speech into natural-sounding speech.

The Whispp app is primarily intended for individuals with voice disorders, which are more prevalent among older adults. The majority of Whispp users are over 50 years old. Voice disorders can affect the quality, pitch and volume of speech, making it difficult for others to hear and understand individuals.

Common challenges faced by users include:

- Delayed responses in conversations, often missing the moment to speak
- Frequently being asked to repeat themselves.

These issues are especially apparent in:

- Noisy environments (e.g. bars and public places).
- Large group settings (e.g. meetings).
- Spontaneous or informal conversations (e.g. chats with friends or strangers).

[Show a video from Whispp of an impaired voice and Whispp's conversion. (*How It Works*, n.d.)]

This project focuses on a new feature currently under development within the Whispp app: Live Conversation. Designed to enhance real-time, in-person communication, this feature instantly converts whispered or impaired speech into clear, intelligible voice using Whispp's AI.

The product is a wearable microphone. It is worn discreetly behind the ear, the microphone connects to a smartphone via a dongle. When the user speaks, the microphone picks up their voice and transmits it through the dongle to the phone, where it is processed by the Whispp app. The converted speech can be played back in real time through a variety of outputs, such as: a phone speaker, wireless speaker or earphones.

The purpose of this user test is to gather feedback on the product and its interaction design. I will guide you through a few steps in which you will interact with the system. This will be followed by some tasks and questions designed to understand your experience and gather your insights.

2. Inspect and wear the microphone

"Pretend you are a person with a voice disorder. This is your assistive microphone. Please wear it the way you think it should be worn."

Observations:
- Where they place it
- Comfort and fit
- Questions or hesitation

Questions:
- Was it obvious how to wear it?
- How do you feel about the way it looks in terms of shape, color, and visibility?

3. Listener perspective

"Now imagine you're the person on the other end, listening to someone speak using the microphone, and please wear the earphones."

Questions:
- Are the earphones comfortable and appropriate for this context?
- Would this method of communication feel personal or distant?
- This case comes with a pair of earphones and a microphone. You can also pair your own devices, but there will be higher latency. Would you prefer to connect your own devices to hear the person speaking, or would you prefer to use the provided earphones?

4. Simulate interaction setup

"Now, imagine that we're sitting at a café and you have the microphone case in your bag. Can you set up all the components of the device, and tell me how your morning went?"

Observations:

- Time it takes to set up

Questions:

- What do you think of the length of time it takes to set up?
- Would you speak differently, or more or less, because of the device?
- In what environments would using the device feel natural or awkward?

5. Post-test reflection questions

Questions about the device:

- On a scale from 1–5, how comfortable was the device to wear?
- Do you think people around you would notice or comment on the device?

Questions about the earphones:

- Do the earphones feel like the right solution for receiving the voice?
- Are there any concerns regarding the use of these earphones, such as comfort, hygiene or clarity?

Questions about the system as a whole:

- How natural did the interaction feel?
- If you could improve one thing about this system, what would it be?
- How much would you be willing to pay for this system if it made daily communication significantly easier?

- Do you have any final comments?

APPENDIX Q
Cost calculations

Name	**Housing**		**Production series**	**100**	**pieces**	**per component**
Material costs		**gross quantity/product**	**unit**	**price/unit**	**amount**	
semi-finished product	Polycarbonate	5.46336	g	€ 0.00	€ 0.02	
semi-finished product	Silicone	0.466872	g	€ 0.00	€ 0.00	
				total material costs	**€ 0.02**	**€ 0.02**
Processing costs	**capacity [pieces/hour]**	**machine hours**	**machine hourly rate**	**machine costs**		
machine 1	150	0.67	€ 15.00	€ 10.00		
machine 2	80	1.25	€ 15.00	€ 18.75		
etc.	1000	0.10	€ 0.00	€ 0.00		
finishing	1000	0.10	€ 0.00	€ 0.00		
				total machine costs	**€ 28.75**	
machines as above	**man/machine occupancy**	**working hours**	**man-hour rate**	**labour costs**		
machine 1	1	0.67	€ 18.00	€ 12.00		
machine 2	1	1.25	€ 18.00	€ 22.50		
etc.	1	0.10	€ 0.00	€ 0.00		
finishing	1	0.10	€ 0.00	€ 0.00		
				total labour costs	**€ 34.50**	
				total processing costs	**€ 63.25**	**€ 0.63**
Set-up costs series	**set-up time [h]**	**hourly rate setter**	**machine hourly rate**	**costs**	**per product**	
machine 1	10	€ 24.00	€ 15.00	€ 390.00	**€ 3.90**	**€ 3.90**
Tool costs	**purchase price**	**service life [units]**	**residual value**	**price/unit**		
mould A	€ 10,000	50,000	€ 0.00	€ 0.20		
mould B	€ 10,000	50,000	€ 0.00	€ 0.20		
subtotals	€ 20,000		€ 0.00			
average value	€ 10,000					
capital interest	0.0%	rentekosten	€ 0.00	€ 0.00		
				total tooling costs	**€ 0.40**	**€ 0.40**
General surcharges						
Failure factor*	1.0%	*Rejected products, see Kals for percentages			**subtotaal**	**€ 4.95**
Overhead factor**	15.0%	** General surcharge for production facilities				
total	**16.0%**					**€ 0.79**
		K_{Fi} for internal calculation:		**Production cost price Housing**		**€ 5.74**

Name	**Carry case**		**Production series**	**100**	**pieces**	**per component**
Material costs		**gross quantity/product**	**unit**	**price/unit**	**amount**	
semi-finished product	Polycarbonate	92	g	€ 0.00	€ 0.28	
			g	€ 0.00	€ 0.00	
				total material costs	**€ 0.28**	**€ 0.28**
Processing costs	**capacity [pieces/hour]**	**machine hours**	**machine hourly rate**	**machine costs**		
machine 1	100	1.00	€ 15.00	€ 15.00		
machine 2	1000	0.10	€ 0.00	€ 0.00		
etc.	1000	0.10	€ 0.00	€ 0.00		
finishing	1000	0.10	€ 0.00	€ 0.00		
				total machine costs	**€ 15.00**	
machines as above	**man/machine occupancy**	**working hours**	**man-hour rate**	**labour costs**		
machine 1	1	1.00	€ 18.00	€ 18.00		
machine 2	1	0.10	€ 0.00	€ 0.00		
etc.	1	0.10	€ 0.00	€ 0.00		
finishing	1	0.10	€ 0.00	€ 0.00		
				total labour costs	**€ 18.00**	
				total processing costs	**€ 33.00**	**€ 0.33**
Set-up costs series	**set-up time [h]**	**hourly rate setter**	**machine hourly rate**	**costs**	**per product**	
machine 1	10	€ 24.00	€ 15.00	€ 390.00	**€ 3.90**	**€ 3.90**
Tool costs	**purchase price**	**service life [units]**	**residual value**	**price/unit**		
mould A	€ 10,000	50,000	€ 0.00	€ 0.20		
mould B	€ -	50,000	€ 0.00	€ 0.00		
subtotals	€ 10,000		€ 0.00			
average value	€ 5,000					
capital interest	0.0%	rentekosten	€ 0.00	€ 0.00		
				total tooling costs	**€ 0.20**	**€ 0.20**
General surcharges						
Failure factor*	1.0%	*Rejected products, see Kals for percentages			**subtotaal**	**€ 4.71**
Overhead factor**	15.0%	** General surcharge for production facilities				
total	**16.0%**					**€ 0.75**
		K_{Fi} for internal calculation:		**Production cost price Carry case**		**€ 5.46**

Product	Wearable microphone

In-house manufacturing	price/unit	pieces/product	price per product		price per product
Housing	€ 5.74	1	€ 5.74		
Carry case	€ 5.46	1	€ 5.46		
		1	€ 0.00		
		1	€ 0.00		
			€ 11.20	**total production**	**€ 11.20**

Purchasing		price/unit	unit	unit/product	price per product		
PCB	€	22.430	set	1	€ 22.43		
Microphone wire	€	1.000	st	1	€ 1.00		
Speaker/earphones	€	30.000	set	1	€ 30.00		
Carry case parts	€	10.000	st	1	€ 10.00		
	€	0.050	st	0	€ 0.00		
					€ 63.43	**total purchases**	**€ 63.43**

Assembly costs		**assembly series**	100			
	capacity	**machine hours**	**hourly rate**			
assembly station	100	1.00	€ 30.00	€ 30.00		
set up assembly station	nvt	0.50	€ 30.00	€ 15.00		
manual assembly station	200	0.50	€ 2.50	€ 1.25		
packaging	200	0.11	€ 2.00	€ 0.22		
				total machine costs	**€ 46.47**	
	human/machine					
machines as above	**occupancy**	**working hours**	**hourly rate**	**labour costs**		
assembly station	1	1.00	€ 25.00	€ 25.00		
set up assembly station	1	0.50	€ 30.00	€ 15.00		
manual assembly station	1	0.50	€ 18.00	€ 9.00		
packaging	1	0.11	€ 18.00	€ 2.02		
				total labour costs	**€ 51.02**	
				total assembly costs	**€ 97.49**	**€ 0.97**

K_{ft} Production cost price of assembled product for internal calculation:	**Production cost price Wearable microphone**	**€ 75.61**

		Wearable microphone	
K_{Ft}	Production cost price of assembled product for internal calculation:		**€ 75.61**
F_{OB}	Overhead factor for general operating costs*	15%	
F_{OV}	Overhead factor for sales costs	5%	
F_{W}	Profit factor (unforeseen costs are paid out of profits, as it were)	20%	
	Total factor = product of (each of these factors + 1) minus 1	44.9%	**€ 33.95**
K_{V}	Ex-works sales price (you have to pay this if you collect your product from the factory yourself)		**€ 109.55**
	Intermediary margin (e.g. importer, wholesaler, supplier, distributor)	20.0%	**€ 21.91**
	Wholesale price		**€ 131.46**
	Retail margins (shops) are highly dependent on the sector and the product range, ranging from 25% for a webs	25.0%	**€ 32.87**
	Net sales price (excluding VAT)		**€ 164.33**
	VAT (= Value Added Tax, = sales tax)**	21.0%	**€ 34.51**
	Recommended retail price, normal shop price		**€ 198.84**

*) Before something is produced, a lot of work usually has to be done: not only the design process, but also, for example, prototyping in several stages, user research, market development, certification, patent applications and the like. If all this has to be factored into the product price, it can add up to quite a lot.

**) High rate = 21%, low rate = 6% (food, books), sometimes also levies such as the statutory disposal contribution.

NB These investments are already included in the price of the product, but must still be mentioned separately.

Developing design / packaging / ...	**Hours**	**rate euro/hour**		**amount**
	80	50.00	€	4,000
Developing tools	**uren**	**rate euro/hour**		**amount**
	16	40.00	€	640
Purchase of tools (per item, from sheets)	**Component**	**tools**	**Price**	
	Housing	matrijs A	€	10,000
	Housing	montagemal B	€	10,000
Possibly: purchase of special machine			€	0
only if it is depreciated over the production series!			€	0
Changes in production equipment / assembly	set up assembly station	labour	€	15
	set up assembly station	machine	€	15
Purchasing work inventory			€	-
			€	-
	Total investments	Wearable microphone	€	24,670

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