Understanding Sound Environments: Common Soundscapes and Their Effect on Hearing Aid Users' Listening Abilities

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ii Abstract

The goal of this project is to understand the experiences of people who wear hearing aids in non-speech environments. This study has two distinct cohorts: people who wear hearing aids and people who do not. The primary method of this study is the soundwalk, which involves taking participants to different key areas around the Eriksholm Research Centre (ERC) to actively listen at pre-defined locations. After the soundwalk, the researcher conducts semi-structured interviews with the participants, allowing the pre-survey results and other thoughts to be further explored. These results were then coded and analyzed using grounded theory, and subsequently compared to identify key differences in cohort experiences.

The overall results indicate that specific interests in certain sounds and the ability to describe those sounds play a significant role in determining the differences in participant experience, in addition to a hearing aid's ability to mitigate wind and traffic noise and the wearer's ability to identify electric and hybrid cars.

Keywords

Hearing aids, soundscapes, accessibility, inclusive design, equity in healthcare

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iv Abreviations

A1-5 - Hearing aid cohort participants 1-5

ANSI - American National Standards Institute

AI - Artificial Intelligence

BTE - Behind-the-ear (hearing aid)

ERC - Eriksholm Research Centre

dB - Decibel (unit of measurement corresponding to volume)

DNN - Deep Neural Network

FDA - Food and Drug Administration

HA - Hearing aid

IEC - International Electrotechnical Commission

ISO - International Organization for Standardization

ITE - In-the-ear (hearing aid)

ITU - International Telecommunication Union

MoCA - Montreal Cognitive Assessment

OTC - Over-the-counter (hearing aid)

RIC - Receiver-in-the-canal (hearing aid)

SPL - Sound Pressure Level

TMA - Terminal Maneuvering Area

TP - Test Person (study participant)

U1-5 - Non-hearing aid cohort participants 1-5

WHS - Wind and Handling Stabilizer

v Definitions

Acoustic ecology: A field of study that explores the relationships between living beings (including humans) and their sound environment (Lorenzi et al., 2023).

Clipping: Occurs when a sound signal is cut off at a specific frequency due to the high volume being limited by the input system, resulting in distortion (Andersen et al., 2021).

Gain: The strength of the amplification measured in dB (Andersen et al., 2021). A gain above 0 dB indicates a volume increase, and below 0 dB indicates a decrease.

Masking: The covering of sound by another sound to drown out or make less noticeable the original signal (Andersen et al., 2021).

Occlusion: An effect caused by the complete blocking of the ear canal (Hengen et al., 2020).

Schema: A particular listening environment (Lorenzi et al., 2023). For example, a hearing aid wearer in a restaurant listening to a single speaker directly facing them with a variety of background noise would be one schema.

vi A Note on the Language in the Paper

Participants in this study are explicitly differentiated into two groups: those who wear hearing aids and those who do not. This is purposeful, as the research focuses on whether participants experience different sound distortions or other effects based on how their *devices* react, rather than on their hearing loss. As such, participants in the group of non-hearing aid wearers may have hearing loss or tinnitus. This does not invalidate the experience, as the comparison is directly between the use and non-use of the device. Usage is defined as daily wear, so participants who may use a hearing aid only in specific situations were not eligible to participate in the non-hearing aid wearing group; however, this would be an interesting area of future research.

Any use of the word “normal” will only be referenced in quotes from other papers or the participants themselves, as everyone’s experience is unique and “normal” as a descriptor for my study is meaningless. I also strive to follow the philosophy of inclusive design, which emphasizes “one size fits one,” and this perspective will be evident throughout the paper. This means that, despite data being aggregated where appropriate (for example, weather conditions), each participant is treated as an individual, and themes derived from their experiences will aim to highlight their similarities while noting each person's unique preferences.

The hearing loss scale commonly used in audiological practice in 2025 is provided below for reference (American Speech-Language-Hearing Association, n.d.). Note that it is common for people to have a “sloping hearing loss,” in which they have no or little hearing loss between specific frequencies, but then it becomes mild to profound at the higher frequencies:

- **Mild**: 25-40 dB
- **Moderate**: 40-55 dB
- **Moderately severe**: 55-70 dB
- **Severe**: 70-90 dB
- **Profound**: 90 + dB

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1.0 Introduction

There are an infinite number of sounds that people experience as they go about their lives: a car honking, a doorbell ringing, a pigeon cooing or water falling; sounds communicate meaningful information. Sounds let you know where you are in space relative to others, whether there are other things around, and communicate intention and emotion through words and other verbal indications. Hearing aid design is currently focused on improving speech intelligibility and comprehension, but this often leads to a limited understanding of how hearing aids handle the rest of the sounds in the world. There are many ways to move about the world, and not having access to sound does not mean there is no possibility for communication or experiencing music, for example, but living in a world catered for people able to hear sound means that hearing aids can provide access to a broader sensory experience that is commonly lost from noise exposure throughout one's lifetime.

Untreated hearing loss can lead to serious health consequences, including social isolation and loneliness, as well as an increased risk of dementia (Babajanian & Gurgel, 2022; Uchida et al., 2018; Castiglione et al., 2016). When it is difficult to hear, and the person with hearing loss relies on speech to communicate with those around them, the added cognitive effort required to follow a conversation can take a toll (Hussein et al., 2022; Hornsby, 2013). However, hearing technology is growing exponentially, with new devices being released annually that feature artificial intelligence (AI) integration, health monitoring, and noise reduction (*Oticon Intent™*, 2024; *Phonak Audéo Sphere™ Infinio*, 2024; *Genesis AI | Starkey*, 2023).

Hearing aids can improve oral communication in many scenarios, but work best in one-on-one, quiet environments (Stoop, 2022). The devices' ability to separate those signals becomes weaker as the sound scenes become more complex, whether there are more speakers or background noise (Andersen et al., 2021). Hearing aids amplify all noise around the wearer, which can result in over-amplified background noise, making it harder to follow conversations or focus on specific sound sources (Stoop, 2022; Jespersen et al., 2021). Several factors can contribute to dissatisfaction and challenges in understanding speech in different situations, as the environment can impact the hearing aid's ability to process the noise around. For example, wind may be over-amplified outside, making it difficult to converse while walking.

People without hearing loss do not often face the same challenges when conversing in noisier environments (Petersen et al., 2022). There are known disparities between individuals who use hearing aids and those who do not regarding their experience of aural environments (Wu et al., 2014). Hearing aids cannot completely eliminate the effects of hearing loss and have technological limitations that often result in these disparities in listening experience. As such, hearing aid users are frequently disadvantaged in particular listening environments (Jespersen et al., 2021; Lesica, 2018). With the aging boomer population increasingly using hearing devices (Ramkissoon & Buchanan, 2017), understanding the listening disparities between hearing aid wearers and their non-aided peers is crucial for the upcoming decade of hearing aid development.

Mitigating background noise is the primary focus of most hearing aid research, as researchers strive to enhance speech-based communication through noise reduction software and voice enhancement algorithms. But what about non-speech-related sounds? People encounter many other sounds daily that can contribute to their mental well-being, specifically sounds in nature. However, if hearing aid research only focuses on improving speech-based communication, what happens when people with hearing aids try to experience those natural environments?

1.1 The Problem

While understanding speech is crucial in oral communication, non-speech sounds can provide critical contextual cues that humans rely on to determine their location, identify those around them, and assess their safety (Lelic et al., 2024). Additionally, the world has many sounds to offer, providing a variety of feelings that people often overlook when they experience a significant loss, which prompts them to consider hearing aids (Apoux et al., 2025; McGeoch & Rouw, 2020). If hearing aids are known to provide a different listening experience, then it is essential to understand what that experience entails and how device makers can enhance future iterations of the hardware and software setup.

1.2 Current Solutions

The hearing aid industry is rapidly evolving, with major platform launches being released every 1-2 years and technology upgrades available even more frequently. Several processing steps and strategies have been employed by current and past devices to clean up the incoming signal, primarily to enhance speech-related frequencies and attenuate others (Le Goff et al., 2016). Hearing aids tend to rely on directionality to inform where to focus the signal, meaning the sounds directly in front of the wearer are prioritized (Yee et al., 2017). In older models, this front focus was less developed, resulting in background sounds being missed or limited (Green et al., 2022; Andersen et al., 2021). In the context of going for a walk in nature, as this project focuses on, this means that a significant portion of the natural environment would be altered.

The second solution involves using an external microphone that streams sound directly into the hearing aid, such as the ConnectClip by Oticon (*Oticon*, 2018). Direct streaming ensures that the most amplified signal sent to the hearing aid is the speaker's voice, maximizing the speech intelligibility of the conversation (Chen et al., 2021). However, this solution is optimized for speech, thereby specifically filtering out environmental sounds that can limit the listening experience. Meanwhile, wireless microphone solutions tend to be expensive and ineffective in encapsulating an entire soundscape (Scarinci et al., 2022). While solutions exist to address the challenges that listening situations pose for hearing aid wearers, there are still issues with these solutions, particularly in maintaining situational awareness without over-amplifying surrounding sounds. These solutions are again focused on improving speech communication, leaving out the other soundscapes hearing aid users might experience daily.

Some mechanical solutions exist, and hearing aid users creatively solve these issues themselves. For example, wearing a hood or bandana over the devices to block out the wind, or using specialized products like Ear Gear —a spandex sleeve that shields the devices from the wind — to protect them from sweat, a common issue for cyclists (Gear for Ears, n.d.). However, these aim to mitigate or make a listening environment bearable rather than improve the sound quality or focus of the hearing aids.

1.3 Inspiration

I was inspired to conduct this study out of a passion I have fostered for over a decade: working with individuals who have hearing loss and use hearing devices. This project initially aimed to investigate commonly overlooked soundscapes that young people experience but are not currently accounted for in mainstream hearing aid research, such as athletes in gym settings or culturally specific, non-speech-related sounds that youth with hearing aids may encounter. When partnering with a hearing aid company, it becomes challenging to find unique test subjects, as traditional hearing aid research often relies on homogeneous participant demographics. As such, I pivoted to using the test subjects in the participant pool made available to me. I decided to focus on nature, as it is essential for maintaining physical and mental well-being, especially among the older population that I would be working with (Cox et al., 2017b). I would also like to acknowledge the invaluable support of my colleagues at Eriksholm, who helped shape the course of this project and my perspective on the work. The book "The Last Wilderness: A Journey Into Silence" by Neil Ansell (2018), shared with me by Dr. Laurel Carney during a placement at the ERC, was instrumental in helping me understand the challenges of having a passion for nature while experiencing hearing loss. It also led me to the work of Dr. Christian Lorenzi, a prominent researcher in hearing science who leads the field of soundscapes, which greatly aided me in building a background in this area.

1.4 Research Questions and Goal

1. Primary: How do the listening experiences of hearing aid users compare with people without hearing loss?
2. Secondary: How might any differences in listening experience between the two study groups be addressed?

The goal of this project is to understand the experiences of people who wear hearing aids in an uncommonly studied environment, i.e. in nature without speech sounds. The focus on hearing aids comes from the knowledge that these devices have several limitations, which means that natural hearing is not fully restored through their use. Therefore, to properly explore this topic, a comparison method was chosen, allowing hearing aid users to have a reference point with those who do not wear hearing aids. If the ideal standard for hearing aids is to restore an individual's hearing to "normal" levels (i.e. levels that would no longer require a hearing aid), then the listening experiences of people who do not need hearing aids are a good reference point.

The secondary question is intended to use the results garnered to answer the primary question. It is helpful to understand someone's experience, but what can be done to improve that experience is the true purpose of this kind of research. I do hypothesize that:

1. Hearing aid user satisfaction will be higher in soundscapes with minimal background noise.
2. Non-hearing aid participants will have generally higher satisfaction rates than hearing aid users.

1.5 Potential Applications of the Research

Knowing the desires of HA users now, we can use this to inform future HA developments. Importantly, understanding how experiences differ between HA and non-HA users can help fill the gaps in what is currently missing from HA programming. Additionally, hearing aids are undergoing rapid development, with the introduction of AI (Morgan et al., 2022). As this technology is introduced, it will be crucial to ensure that it is being trained on real-life scenarios that reflect a HA user's listening environment (Balling et al., 2021). This technology has the potential to mitigate traffic noise while still providing the user with awareness of their surroundings, can enhance natural soundscapes, and will likely soon be able to better respond to noisy conditions, such as windy days (Morgan et al., 2022). The data collected from this study could theoretically be fed into a model to teach it strategies such as reducing wind when a user is cycling or purposefully accentuating bird calls when a user is walking in the forest, for example.

The other potential benefit of this research is providing more customized remote-fitting experiences. A HA user who wants a better experience in natural soundscapes can enter their preferred environment while their audiologist makes those adjustments in real-time. The research can serve as a prompting tool for clinicians to better support patients who wish to experience these non-speech environments. Given the increase in remote fittings since the onset of the COVID-19 pandemic in 2020, this has the potential to spread widely, including applications in direct-to-consumer devices that provide remote support only (Van Eeckhoutte et al., 2024; Saunders & Roughley, 2020).

1.6 Eriksholm Partnership

This project was completed in collaboration with the Eriksholm Research Centre (ERC) under Oticon. This partnership began in September of 2023, at the beginning of my Inclusive Design degree at OCAD University. After multiple rounds of proposals, the research team at the ERC and I agreed to complete the data collection at the Eriksholm campus in Snekkersten, Denmark. As part of this collaboration, I worked as a student researcher for two and a half months, living in Nivå, a town near Eriksholm. During this time, I spent half the day in the office, either preparing the study's questions and recording devices or collecting data through the soundwalk and interviews afterward.

While in the office, I benefited from the fantastic minds around me, and a portable data collection tool was created in collaboration with coworkers external to the original project team. Not only did I have the recording equipment readily available, but I also had an audiologist capable of programming hearing aids to match my participant's hearing loss on the spot. Using the Eriksholm campus was invaluable to this project due to its perfect setting, which balances traffic noise in the front yard with a forest in the backyard, and its access to a great staff and the necessary physical tools to complete the research. As part of this relationship, I will return to Denmark in May 2025 to present my findings to the company, with the future goal of publishing them.

1.7 Project Scope

As with any research project, it is crucial to understand the limited context and capabilities within which this project operates. For example, this project is limited to one specific location, the Eriksholm campus, which has its own unique soundscape and does not represent all of the sounds a person might encounter daily. The participants are relatively homogenous, which provides a benefit in limiting external influences, but they also lack the diverse perspectives that can be gained from unique demographics. This project is also limited to ten participants due to the number of people available in the Eriksholm participant pool. Most importantly, this study is dedicated to the experience of non-speech sounds. As such, the study is centred on situations with no speech, and speech itself will not be deeply explored throughout this thesis. The implications of how the project is scoped are further explained in Section 5.5.

1.8 Researcher Positionality

The focus of my research pertains to a vast community of people united by the experience of hearing loss. As a researcher, I do not share this experience with my participants. As a result, I strive to incorporate the perspectives of those with lived experience into the types of questions I ask, the methods I employ, and the lens through which I view the results. While I do not have hearing loss, I have been a grandchild, close friend, employee, and student of people with varying degrees of hearing loss. The perspectives shared with me in all my interactions with the community are evident in my work, from inspiring my chosen topic to the methodology I implemented. My previous work in this field is referenced in Section 2.4, which outlines my research background.

2.0 Background

The following section details hearing aids, including a brief timeline of their technological advances, and features an analysis of similar studies that informed the development of my research. The background section explains how artificial intelligence relates to this project and why this research is important, while also highlighting my background as a researcher and discussing some potential future applications of this project.

2.1 What is a Hearing Aid?

A hearing aid (HA) is a device that can be worn in or on the ear, amplifying sound for people with hearing loss (Mills, 2011). The device uses a microphone to receive external sounds and processes those noises through the device into a flexible dome in the ear or through a custom ear mould (Ferguson et al., 2017). There are traditionally two types of hearing aids: one with the processing electronics housed in a casing that sits behind the ear (BTE) and one that has the electronics housed inside the ear (ITE). Hearing aid models are chosen to best suit the type of loss and the lifestyle of the person requiring them (El-Gohary et al., 2017). The most common type of hearing loss is sensorineural (Tanna et al., 2023), which is the type of hearing loss this study will focus on. Another type of hearing loss, conductive hearing loss, often utilizes different hearing technologies (Payne & Wong, 2022); therefore, the following information is related explicitly to sensorineural loss and its associated devices.

HAs have a long history, dating back to before World War I (Zdrodowska, 2023; Mills, 2011; Levitt, 2007a). The first solutions to improve hearing ability were ear trumpets and cone-shaped devices that individuals could hold up to their ears to funnel the sound directly into their ear canals (Mylonakis & Martini, 2017). These were especially popular during the Victorian era in the 1800s (Levitt, 2007a). Later evolutions include pocket talkers, conversation tubes, and ear drums (Zdrodowska, 2023). In the last twenty years, hearing aids have undergone a digital transformation with the invention of the Digital Signal Processing (DSP) chip (Levitt, 2007b). With the digitization of these devices comes enhanced signal processing, allowing for the ability to move beyond simply amplifying sound to start filtering and adjusting noise levels.

2.2 History of Hearing Aid Sound Processing

2.2.1 Analog Versus Digital Hearing Aids

Analog HAs were limited in their ability to process incoming sounds. They primarily focused on amplifying sounds, with some models capable of transposing frequencies or adjusting the balance across frequencies, thereby editing the original signal (Gengel & Foust, 1975). They may also feature multiple programs that can be set to amplify more or less as the user requires, but this still needs a manual change by pressing a physical button on the hearing device (Arlinger, 1997). Digital hearing aids, however, go beyond amplification, as the original signal is converted into a digital one, allowing it to be processed before being converted back into a physical signal again (Levitt, 2007a). Digital hearing aids are more customizable, as they can have specific and unique signal adjustments tailored to each user's hearing loss and lifestyle (Schweitzer, 1997). They are programmed with a prescription created by audiologists from a patient’s audiogram, custom-made to fit the hearing aid specifically to the patient’s unique hearing loss (Mondol & Lee, 2019). The DSP chip revolutionized hearing aid design, enabling the introduction of technologies like noise reduction. DSP chips were first developed in the 1980s but gained mainstream popularity around the early 2000s (Levitt, 2007b; Schweitzer, 1997; Widin, 1990). Nowadays, very few clinics sell analog hearing aids due to the numerous benefits that digital hearing aids offer (Center for Devices and Radiological Health, 2022).

2.2.2 Digital Signal Processing

Digital hearing aids can be programmed to manipulate a sound signal in various ways, aiming to address the issues associated with purely amplifying the signal. If a signal is amplified without filtering, as with an analog HA, the background noise is amplified as much as the sounds the user wants to hear (Government of Canada, Canadian Centre for Occupational Health and Safety, 2024). This makes the desired signal a lot harder to discern. The two primary approaches to mitigating noisy situations are directionality and digital noise reduction (Ahmadi et al., 2018). Directionality primarily refers to beamforming, which is covered in Section 1.2. Digital noise reduction is the process of separating sounds based on their frequency and adjusting the gain to reduce the noisy signals and increase the frequencies associated with human speech (Ahmadi et al., 2018; Wong et al., 2018). The Wiener filter is commonly used in digital noise reduction to restore an audio signal covered with background noise (Kumar & Chari, 2019; Serizel et al., 2009). These filters are implemented differently across hearing aid companies, with proprietary algorithms that add their signal focus and gain adjustments. For example, the Oticon Real has moreSound and SoundNavigator in both its Intent and Real models (Gade et al., 2023).

Digital hearing aids are typically offered at various technology levels and associated price points, each with distinct filtration features (Plyler et al., 2021). The more advanced models offer enhanced technology for noise reduction and improved capability to handle noisy situations (Glista et al., 2024). These higher technology levels typically benefit users with more severe hearing losses as they often provide a larger range of customization for noise suppression (Bannon et al., 2023). Further feature differences are highlighted in Section 3.4.2.1. The device brand, type, and technology level can all impact a hearing aid user’s listening experience (Bannon et al., 2023; Picou, 2022). This is especially true when a new hearing aid platform is released, such as the Oticon Intent, which processes auditory signals using a proprietary software platform, Sirius, and sensors to account for user head positioning (Sound Hearing, 2024b). The Oticon Real uses an older model called Polaris and has the previous generation of trained neural network (Sound Hearing, 2024a). The Oticon Intent is better equipped to handle body movement and adjust surrounding sounds, which would impact the user’s listening experience of a soundscape.

2.2.3 Fitting hearing aids

Prescription hearing aids are specifically programmed for an individual's hearing loss based on their audiogram (Mondol & Lee, 2019). An audiogram demonstrates the type of hearing loss and the frequencies an individual cannot hear (Dou et al., 2024). It is acquired from a hearing test done by an audiologist. A hearing aid is "fit" with particular settings that correspond to the amplification required to address the loss captured in the audiogram (Polonenko et al., 2010). Specific features can also be toggled on or off, and custom programs can be created to adjust the gain response in different listening environments. For example, if a user often bikes, they may have a program that has higher decibel suppression of wind noise than if they are at home, having a quiet conversation, and do not need that kind of noise reduction at all. As hearing aid technology advances, devices are becoming increasingly customizable, allowing for further unique adjustments to suit the individual wearer's specific needs. The HA wearer's listening experience can be significantly influenced by the successful fit of a HA to their particular hearing loss and lifestyle needs (Davidson et al., 2022; Bennett et al., 2021).

There are also physical aspects of the device that can be customized for each wearer, such as the type of ear moulds, size of receiver, and ventilation options. Individuals with more severe levels of hearing loss tend to benefit more from closed dome or custom ear moulds that mostly occlude the ear, preventing sound from leaking in and ensuring that the entire incoming signal is amplified (Hengen et al., 2020). For others with a milder loss, open dome or larger vented moulds are often used instead, as they can benefit from their residual hearing while still getting the amplification they need. This also makes their own voice sound more natural as no occlusion effect[1] distorts it. The receiver type for receiver-in-the-canal (RIC) hearing aids depends on the severity of hearing loss as well. Since receivers are where the incoming sound is amplified, higher receiver levels have a greater amplification capability (Bolandi et al., 2024). For the Oticon Real, there are four receiver types: 60, 85, 100, and 105 (Oticon Government Services, n.d.). The higher levels are used for more profound losses, but can also be a matter of preference in terms of feedback production and comfort.

2.2.4 The Introduction of Artificial Intelligence

In the early stages of digital hearing aids, determining which schema HA users were experiencing in order to implement the most effective filtering methods was based on a series of heuristics (Bentler & Chiou, 2006). This meant that HA companies were using the known properties of speech in comparison to common, mostly static background noises to apply gain reduction (lowering the volume) to specific frequencies. Oticon is known for being one of the first companies to implement a "comodulation" algorithm, applying gain reduction to non-harmonic sound signals (Bentler & Chiou, 2006). This algorithm ensured that sounds like music would be amplified according to the HA wearer's prescription rather than being reduced and considered as unwanted noise, as had been done traditionally.

[1] See Section v for definition

Current digital hearing aids still use heuristics, albeit more informed and complex, to infer the schema that the HA user is in. The benefit of machine learning in these devices is the improved ability to estimate those schemas more accurately. Then, more targeted filtering can be applied to improve the listening experience in that specific environment (Andersen et al., 2021). Oticon originally referred to this schema classification as "Artificial Intelligence" in 2006 (Bentler and Chiou). In the most recent releases of Oticon hearing aids, machine learning models are used that are trained on thousands of hours of speech and noise to differentiate between the two (*Oticon Intent™,* 2024). Knowing which sounds to focus training the model on is important because the number of parameters a model has, the bigger it will be, and the more memory it will require (Mondol & Lee, 2019). This is why the Phonak Sphere hearing aid, with its additional AI-dedicated DEEPSONIC chip, is larger than the more recent HA releases, due to the size of its model and the need for more battery to process these sounds (*AI Noise Cancelling Hearing Aid | Phonak Audéo Sphere™ Infinio*, 2024). The product page claims this model is trained on 22 million sound samples.

This project is particularly relevant in ensuring that AI models are also taught to recognize non-speech sounds, not just as noise to be reduced. AI models learn from the material they have been given, which is why they must be able to learn non-speech sounds to prioritize either boosting the gain or providing other filtering methods. AI has the potential to apply the inclusive design principle of "one size fits one" to hearing aids. However, it must be done with careful consideration in its training and filtering methods. Understanding the experiences of hearing aid users in various non-traditional testing environments, particularly in real-world scenarios, can provide more effective training for these models and enable better handling of such situations in the HA digital filtration program (Yellamsetty et al., 2021).

2.2.5 The Future of AI in Hearing Aids

The introduction of AI will lead to rapid increases in hearing aid development, but we will also see changes as Over-the-Counter (OTC) HAs become more mainstream and technology like Bluetooth Auracast is introduced. Bluetooth Auracast is an enhanced version of the current Bluetooth connection technology commonly found in most cell phones and wireless devices (Frazier, 2024). Auracast enables more devices to connect without requiring intermediary devices, such as the OticonConnect covered in Section 1.2. One of the most common complaints of HA users now is issues with Bluetooth connectivity, so improvements in this technology will both remove some of the financial barriers by not requiring multiple devices to add with streaming and make it easier to use hearing aids for everyday activities like watching TV or listening to music (Bennett et al., 2021). Because the United States Food and Drug Administration (FDA) regulates the dispensing of OTC hearing aids, there may be future regulatory changes regarding their use and sale. This may be seen globally as the devices become regulated or deregulated by each country's respective health legislators. In a Canadian context, OTCs are not currently approved for sale by Health Canada (Zhang, 2025). Still, the upcoming

Apple AirPods Pro 2's hearing aid features successfully passed as the first over-the-counter hearing support device in Canada (Zhang, 2024).

The goal of hearing aids is to replicate how the brain analyzes sounds and compensate for the loss of some of those neural pathways (Kestens et al., 2021). The introduction and further development of AI in HAs can lead to improved latency (sound processing time) and further customization of a user's sound preferences (Fabry & Bhowmik, 2021). Once a model understands an individual's preferences for noise reduction and gain adjustments within a particular schema, it can provide higher-quality predictions to better cater to each wearer's needs in that unique listening environment (Balling et al., 2021). It can also do some of the processing that the brain might no longer have the neural pathways to do, such as separating sound signals and highlighting unique qualities in a speaker's voice (Fabry & Bhowmik, 2021). Some of these features are already being introduced, along with health monitoring and, as with the Oticon Intent, movement sensors to better adjust to the spatial layout of a listening environment (*Oticon Intent^{TM}*, 2024). The future is bright in the world of hearing aids.

2.3 Literature Review

2.3.1 Soundscapes

Soundscapes have been defined differently over the years as research in the domain has evolved to become more specific than its origin, "sound landscape" (Grinfeder et al., 2022). Academic research in this field gained momentum in the 1970s, when Canadian musician R. Murray Schafer initiated the World Soundscape Project and coined the term "soundscape" in the field of academia (Adams et al., 2008; Truax, 1974). This project was led by researchers R. Murray Schafer, Hidegard Westerkamp, Barry Truax, Howard Broomfield, Peter Huse, and Bruce Davis (Toronto Biennial of Art, 2019). The World Soundscape Project research originated in Vancouver, Canada, and began with recordings of various sound environments across the city (Wyman, 1974; Schafer, 1968/1998). The database of recordings was developed as the team expanded their recordings to cities in other parts of Canada and Europe.

It is interesting to note that most of the original research team were music composers. This led to an interesting movement of using soundscape in composition, such as Westerkamp's project examining soundscapes and their relationship with auditory ecology and presenting it in a musical format (Westerkamp, 2002). The only member of the team who was not a composer by training was Howard Broomfield, who specialized in anthropological recordings and practiced soundwalks to gather recordings for use on a local radio show (Ridington, 1988).

The views on soundscapes and their development from the World Soundscape Project must be updated, as the views of R. Murray Schafer purposefully aimed to exclude certain types of sounds, often dismissing culturally-specific music as "uncivil" (Goh, 2021). More concerningly, Schafer frequently presented his project recordings as representative of Canada while actively excluding Indigenous and immigrant communities (Yoganathan, 2022). My project references Schafer's work due to its strong ties to academic discussion about soundscapes, but it does not follow the mindset that sounds are inherently good or bad in some objectifiable way, as Schafer believed (Adams et al., 2008).

While the World Soundscape Project defined a soundscape as the relationship between a person and the sonic environment around them (Schafer, 1973), I refer to a soundscape more broadly as an environment where individuals experience sounds. "Sonic environments" or soundscapes can be measured and evaluated using a variety of methods, such as recordings, sound mapping, and soundwalks. Soundscape research between 2005 and 2015 is often concentrated in the urban development domain, as it can have grave impacts on well-being in local areas (Liu et al., 2014). However, there are many other areas of applicability in specific environmental and cultural contexts which will be further explored throughout this paper.

2.3.2 The Benefit of Nature

Being in nature has many proven health benefits, as humans thrive in clean-air green spaces (Zhou et al., 2023; Bonnell & Littenberg, 2022; Egner et al., 2020; Cox et al., 2017a). Part of these benefits stems from experiencing the sounds that accompany natural environments (Kumpulainen et al., 2025). It is common for people to listen to natural sounds to relax when they cannot go outside, such as during massages or while falling asleep (Largo-Wight et al., 2016). However, for people with hearing loss, those sounds may be muffled or entirely removed from their perception (Apoux et al., 2025; Miller-Viacava et al., 2023). Birds with high-pitched tweets and subtle sounds like the wind can become distorted through the microphone on the hearing aid, turning those once serene locations into more stressful environments (*Problem & Solutions | Hear Birds Again*, 2022). Since hearing aid research is primarily focused on speech, the benefits of natural sounds are not currently accessible to many HA users, especially as their hearing loss becomes more profound and thus more complex to address with amplification alone (Lelic, 2024).

It is also well-documented that, in addition to nature soundscapes providing benefits to the listener, urban soundscapes, especially those heavily dominated by traffic sounds, can be detrimental to a person's well-being (Gilmour et al., 2024; Yun et al., 2024; McGeoch & Rouw, 2020). As a result, the listening stops during the soundwalk were specifically selected to achieve a balance between beneficial natural sounds and harmful traffic sounds. This helps evoke more feeling statements from the participants to describe their experience, as each soundscape has been shown to influence an individual's well-being (Alvarsson et al., 2010).

2.3.3 Previous Studies

Soundscapes research is abundant in the urban design domain; however, there is a limited understanding of the experiences of HA users in those environments. There are at least three studies that include HA wearers as participants: Lorenzi et al.'s study on the perceptual experiences of humans in natural soundscapes (2023); Davies et al.'s study also on the perception of soundscapes, however, with a focus on language used to describe them (2012); and Miller-Viacava et al.'s study on how hearing loss alters soundscapes (2023).

Lorenzi et al.'s study (2023) comprehensively examined natural soundscapes to understand the biological need for humans to perceive the soundscape around them. While the primary goal of the study is primarily tied to cognitive science, the secondary research question aims to investigate whether the perception of natural soundscapes is restored through the use of hearing aids. This study finds that the abilities of the cohort with hearing loss are "severely disrupted" when they attempt to discriminate natural sound scenes. While this can, in part, be attributed to the reduced audibility of the scene overall, there is evidence to suggest that a cognitive aspect also hinders the sound quality of the scene. This study provides further indication that more research is needed when examining soundscapes and hearing aid users, as this remains a largely unexplored domain.

Davies et al. (2012) used multiple cohorts of participants, with one group being participants who wore hearing aids. This research inspired the inclusion of a pre-survey in my study, as it offers the benefit of understanding a participant's expectations before the soundwalk begins. The primary goal of Davies et al.'s study was not to highlight the differences in experiences among participants, but to develop a method for evaluating soundscapes using different vocabulary. Therefore, participants were prompted to select their feelings from existing lists of sound descriptors. While this approach has the potential to reduce challenges arising from language differences between participants, it may still be limited by the words the participant is familiar with, rather than capturing their genuine emotions. It also does not leave space for elaborating on that experience, which is especially important in cases where a language barrier exists. This issue is further discussed in Section 3.4.4.

Some studies, including those involving participants with hearing loss and/or HA wearers, have been conducted in a laboratory setting, such as Miller-Viacava et al.'s pilot study in 2023. While the results of this study were interesting, as they indicated that participants with hearing loss did not perform as well as individuals without it, there were indications that reduced audibility was only one factor contributing to the different results. This potentially highlights further challenges that people with hearing loss experience, such as degraded neural connections between the ears and the brain, thereby affecting their ability to process sound. Since this study did not take place in situ, further studies would be needed to confirm these differences and their impact on real-world situations.

2.3.4 Knowledge Gap

There are two primary knowledge gaps that my study addresses. The first is that hearing aid companies typically focus only on device speech optimization in noisy environments, leaving out non-speech environments such as traffic or natural sounds. While newer models are starting to address the importance of spatial awareness, such as the Oticon Intent, there is still a lack of programmatic development tuned specifically for non-speech sounds. The second gap is that a plethora of soundwalk studies exist, but few involve participants wearing hearing aids, and even fewer compare participant experiences. As such, this field can be deeply expanded, as evidenced by the future research topics in Section 6.2.

2.4 Researcher Background

I entered this master's degree with a bachelor's degree in Knowledge Integration, a unique degree that specializes in user experience design. I focused my undergraduate degree on my interest in audiology and design by taking minors in philosophy and psychology. My bachelor's thesis was completed in collaboration with a Danish audio technology start-up, Augmented Hearing.io. I took a more psychological and linguistic approach by collaborating with the Lab for Infant Development and Language (LIDL) at the University of Waterloo to develop phrases that incorporate commonly confused English phonemes. These phrases were accompanied by various background noises that differed in terms of the balance between constant and dynamic sounds. These audio clips were then processed through the company's proprietary software to remove background noise and assess how well the key phonemes were preserved. This project inspired me to explore a master's degree, so I returned to Denmark to continue working in the Danish audio sector.

2.5 Significance

Globally, the aging population is reaching high levels as the "baby boom" generation enters their late 60s and 70s (LeRouge et al., 2014). Given that the majority of hearing aid users are over the age of 65 (Government of Canada, 2021a) and are at a greater risk of social isolation due to their advanced age (Chen & Schulz, 2016), the additional challenges associated with communicating with hearing aids may further exacerbate this vulnerability. It is also known that the preference for natural environments increases with age (Yu & Kang, 2010; Bjerke & Østdahl, 2005). Understanding how natural soundscapes are affected by hearing aid processing thus has the potential to enhance the listening experience of a population, both by increasing the likelihood of users wearing hearing aids and increasing their exposure to natural environments. This study can potentially be used to pinpoint the sound profiles that need to be better incorporated into future hearing aid fitting software and in newer Deep Neural Networks (DNNs).

Beyond the aging population, it is simply important for hearing aids to be optimized for all possible listening environments. There could be a child who goes to kindergarten in the forest, a teenager training to be a trail runner, or a mid-career ecologist studying bird habits who all use hearing aids to experience those environments. Hearing aids enable speech comprehension of unprecedented quality, with improvements made every year with each new device and platform release (Desai et al., 2024). However, it is time for hearing aids to catch up in non-speech environments so they capture and understand user experiences directly in the field, rather than in a controlled lab environment. While this project may contribute only a small drop in the ocean of understanding required to enhance hearing aid quality in natural sound environments, it has the potential to impact the listening experience of all hearing aid users, even those beyond the typical aging population.

3.0 Methodology

The following section will outline the development and conduct of the study. Topics include the ISO framework used, participant information and demographics, details on survey questions and data collection, the selection process for each location during the soundwalk, and other related content. The methodology is primarily based on the ISO/TS 12913-2:2019(E) standards, but it is also influenced by prior studies in the field, as detailed in Section 2.3.

3.1 Framework

The foundation of this project was inspired by studies that utilized the International Organization for Standardization (ISO) (Aletta & Torresin, 2023; Mancini et al., 2021; Aletta et al., 2019). The ISO has a comprehensive set of standards for different methods researchers can use to conduct soundwalks. The methodology for this study was developed through close consultation with these standards, given their replicability and established reliability in environmental sound analysis (Aletta et al., 2019). This ISO framework was combined with grounded theory to extract in-depth analyses from the qualitative interviews. This is one of the three methods presented in Annex C of document ISO/TS 12913-3:2019(E). It was deemed most appropriate for this project due to its reputation and benefit in design research (Khambete & Athavankar, 2010).

3.1.1 ISO Standards

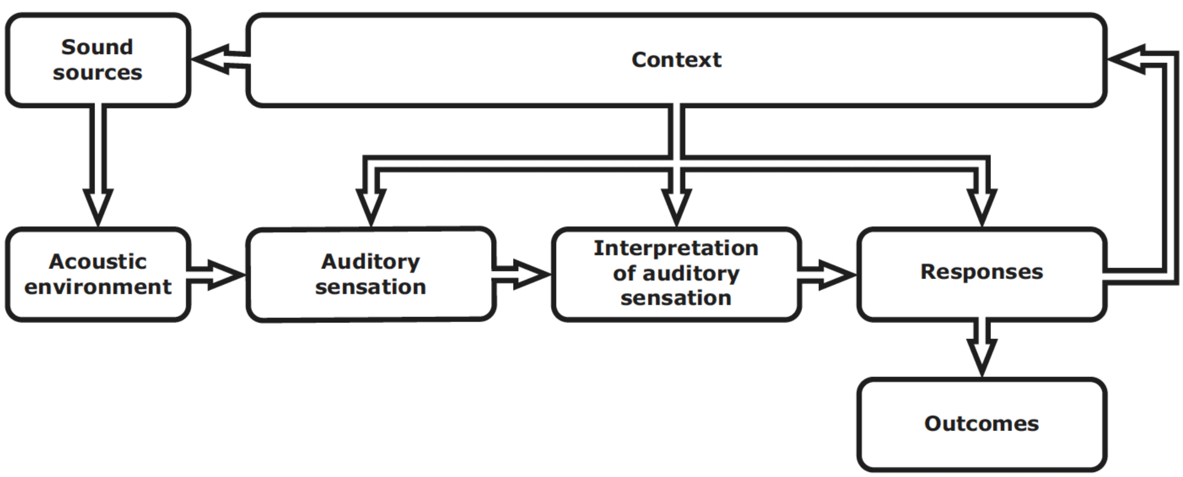
The ISO framework used in this study outlines methods for collecting data from participants, as well as from sound recordings, and suggests analysis methods based on the collected data. There are three documents dedicated to soundscapes and soundwalk procedures: ISO/TS 12913-1:2014 (E), ISO/TS 12913-2:2018 (E), and ISO/TS 12913-3:2019 (E). The first document is dedicated to defining terms related to soundscapes and the various factors that may influence an individual's experience of them. This is best summarized in the ISO Chart, Figure 1, from the 2014 document. The 2018 document serves as the primary reference for designing soundscape studies, as it details the three methods – A, B, and C – along with their respective data collection requirements. Finally, the 2019 document serves as a follow-up to the 2018 document, covering the analysis of data collected using each of the methods.

I chose a combination of all three ISO standard methods for my study. Methods A and B are quite similar, however, their question approach differs. My study uses both methods in tandem, in addition to method C, as A and B are the methods that detail the actual act of a soundwalk. In contrast, C focuses on gaining insights through conversation rather than in situ. The combination of methods is encouraged, based on previous research highlighting some of the benefits that can be achieved by using methods A and B in tandem (Aletta et al., 2019). Method A is a procedure for collecting data through in situ surveys that aim to capture affective responses using a five-step Likert scale. Questions focus on identifying the categories of sounds heard and how they fit into predefined soundscape descriptors (e.g., calm, chaotic, pleasant). Method B, however, asks participants to write down the eight most notable sounds they hear, which is a question I also chose to use in my study. As a researcher, I believe this prompt encourages participants to listen more thoughtfully, as they are asked to identify sounds rather than simply categorize them. Method A's focus on affect is prevalent throughout my study, as I examine the expectations and feelings associated with sounds. Considering ways participants describe sounds, including the emotional implications, will also be included in Section 4.0.

Method C has the benefit of collecting richer data from each participant. In this method, the focus for data collection and analysis is semi-structured oral interviews, rather than written questionnaires. This was most appropriate for my study, both because of the in-depth insights and unique questioning pathways I could explore as a researcher and because most of my participants only knew English as a second or third language. Methods A and B rely on written answers and reading questions from surveys in a way that increases the risk of misunderstanding between the researcher and the participant. This is mitigated through conversation, as my participants were comfortable speaking English and asking me questions, but some preferred writing their answers in Danish. Therefore, Method C was suitable for facilitating better communication and providing opportunities for clarification.

Figure 1

Elements in the Perceptual Construct of a Soundscape (ISO, 2014)



Note. A chart showing the relationships between related concepts that create a soundscape

3.1.2 Comparison Study Method

This study has two distinct cohorts, differentiated by their use of hearing aids or lack thereof and are otherwise intended to be as homogenous as possible. The two cohorts are designed to be compared to see how the listening experiences of individuals wearing hearing aids may be influenced by their devices. As stated in Section 2.3.3, Davies et al. included a group of participants with hearing loss in their study and provided some general insights comparing the experiences of this cohort with those of the cohort without hearing aids (2012). However, this study was not designed to understand the overall impact of how the use of a hearing aid influences soundscape experiences. My study values the experiences of the hearing aid wearing cohort most, as it is their experiences that I ultimately wish to improve and will thus influence my final recommendations.

Having non-hearing aid users to compare with HA wearers helps provide some context to their experience, highlighting any similarities or differences that might be due to a hearing aid's ability to process non-speech sound environments. Without comparing the two cohorts, there would be uncertainty stemming from the unknown nature of the soundscape itself. For example, it could be particularly overwhelming, uncomfortable, or very satisfying and comforting, which may have nothing to do with the hearing devices the cohort is wearing. Studies in the hearing science domain typically include a control group of listeners with "normal hearing" (Stone et al., 2022), but my study intentionally does not. I cover this difference in terminology in more detail in Section vi.

3.2.3 Expectations

Beyond the hypothesis, I expected the method of individual instead of group soundwalks would yield differences in study experience, as it is impossible to control the weather and other external variables covered in Section 3.6. This is especially true due to the small cohort size and the unique experiences each participant brought to the study. I expected participants to have a higher preference for the forest corner location and the lowest preference for either the bus stop or the tower, given the differences in traffic presence and its impact on well-being documented in Section 2.3.2. The courtyard and forest path locations are between the big road and the forest corner, so I expected higher levels of variability in preference for this location. Based on the sound dampening that the building provides for the courtyard area, which the forest path area lacks, it would follow that the courtyard would rank slightly higher.

3.2 Methods

This study uses three primary methods to gather insights and collect qualitative and quantitative data. The primary method of this study is the soundwalk, which, as previously defined, involves taking participants to different key areas around the ERC to actively listen at pre-defined locations. The second part of the study takes place immediately after the soundwalk, during which the researcher conducts semi-structured interviews with the participants. This is also where pre-survey results and other thoughts from participants throughout the soundwalk can be further explored. Finally, all the data points collected from the interviews and written questionnaires are coded; the interview transcripts are annotated, and key quotes are extracted to highlight the experiences of each participant. This information is then used to inform the final results.

3.2.1 Soundwalks

A soundwalk, as defined by the World Soundscape Project, is a process in which researchers guide participants on a purposeful walk, either encouraging active listening throughout the entire walk or stopping at key locations to listen for a set time (Westerkamp, 2002; Schafer, 1993/1977). In the paper "Soundwalk Approach to Identify Urban Soundscapes Individually," the authors explain that this methodology was originally created to have participants purposefully focus on listening to their surroundings in order to appreciate them (Jeon et al., 2013). From there, soundwalks began being applied in urban design and architecture, where studies focused on the sonic experience of urban areas like residential neighbourhoods, university campuses, and parks (Sun et al., 2023; Mancini et al., 2021; Liu et al., 2014; Yu & Kang, 2010). The benefit of soundwalks in this field is that they are accessible to everyday users of the space, allowing for future design to be influenced by the people living and working in the area. It is important to note that soundwalks only achieve their purpose when the people with lived experience of the topic being studied are consulted.

This methodology is most suitable for addressing the research question about how HA users experience natural environments, as it captures a real-life snapshot of how they perceive sound in those natural spaces. Hearing aid research is often conducted in a lab to control the numerous variables that can accompany sound, including interference, unexpected noises, and visual stimuli, which can significantly influence a person’s listening experience (Lelic et al., 2024). In some testing scenarios, an in-lab setup with an ear canal simulator, an anechoic chamber, and a speaker array is beneficial. However, given that this project wants to 1) test non-speech-related sounds and 2) test real-world scenarios to examine how a hearing aid responds to different soundscapes in the field, a soundwalk is an effective methodology. It is standardized through ISO procedures (International Organization for Standardization, 2014). Still, it leaves flexibility in terms of options for conducting the soundwalk in a way that best suits the study topic, location, and participant needs.

In following the ISO standards, participants did not evaluate their listening environment while travelling between locations (International Organization for Standardization, 2018). This means that factors like speech, as I guide them to the following location, or footsteps from the participant or myself are mitigated for each soundscape evaluation. The evaluation positions were designed to expose participants to purposefully selected combinations of traffic and natural environments. While this may create a researcher bias in how participants are directed to listen, it does not negatively impact the individual listening experience (Jeon et al., 2013). In a soundwalk in an urban planning context, where a participant chooses to face may matter more because they are evaluating the environment, not the participant’s listening ability, as I am in the study.

This study was conducted as ten individual soundwalks, rather than one with both cohorts or two with each cohort attending one walk, due to the logistics of the personal interviews and the flexibility of participant schedules. There were many benefits to running these walks individually, primarily the ability to conduct in-depth one-on-one interviews with each participant, as the soundwalk experience was still fresh in their minds. The issue with performing a group walk is that participants would either need to participate in a focus group afterward, which presents communication challenges, especially for individuals with hearing loss who are more likely to experience listening difficulties in group settings (Verge et al., 2023), or they would need to wait while I interviewed each person. This would result in an unequal amount of time between walk experiences, leading to potential memory loss and an excessively long wait for the last participant, with interviews taking approximately thirty minutes each. Since the ISO recommendations were not developed to account for hearing aid users and people with hearing loss, it was necessary to adjust the settings to ensure a quiet and easy conversation setting for the interviews to be conducted within a reasonable amount of time after the soundwalk.

3.2.2 Individual Interviews

Individual interviews were conducted after the soundwalks in accordance with ISO Method C for soundwalk research (2018). One-on-one interviews were chosen for the depth that can be gained from guided conversations. It was also especially important to have an oral aspect of data collection, as the majority of my study participants knew English as a second language and typically used it only for communicating verbally at work, not for writing. Having this time with each participant garnered greater insights into their thought process in a more accessible setting. Interviews were semi-structured to guide the conversation while allowing participants to explore more thoughts from their pre-survey written answers and the location questions from the soundwalk itself. ISO encourages this semi-structured approach, stating researchers should be open to spontaneous questions (ISO-C3.3, 2018).

3.2.3 Coding

Grounded theory was the primary method, in accordance with ISO/TS 12913-3:2019(E) and common qualitative data analysis practices (International Organization for Standardization, 2019; Acun & Yilmazer, 2017). Grounded theory is a research approach that ensures all insights are “grounded” in what the participants have shared (Turner & Astin, 2021). As a result, it involves reviewing the interview transcripts multiple times, so that by the time of analysis, the researcher is intimately familiar with the participants’ statements. Then, the participants’ words are used to contextualize every insight, making it a more robust practice as each insight can be directly tied to a sentiment expressed in the interview. Coding can also be applied to field notes, survey questions, and any other related research material. For this study, only the interview transcripts are being coded; however, they are then cross-referenced with other participant data, including their pre-survey and questionnaire results, as well as their profile in the ERC participant database.

3.2.4 Procedure

Participants were first presented with a consent form in both English and Danish in a quiet room, and I ensured that they understood everything before we began our walk. Then, I set up the recording equipment and guided the participants to five locations across Eriksholm's campus. Participants were given a pen and a clipboard with five sheets and one questionnaire for each stop on the walk. The questions were the same for each location and identical for both cohorts (see Appendix A). The participant would be directed to stand for three minutes, facing a pre-determined direction. During this time, they were invited to take notes on what they were hearing and to answer some of the questions on the questionnaire. I would record those three minutes on my computer after directing the Klangfinder ear canal simulator next to the participant, facing in the same direction. I would also take notes on the environment and specific variables such as temperature, humidity, and wind level. Afterward, participants were given a few more minutes to complete the questions for that location before we moved on. Once we had visited all five locations, we returned to the interview room, where participants were asked to reflect on what they had just experienced and their overall impressions of their daily sound environments (see Appendices B and C for interview questions). This interview was recorded and transcribed for future reference and analysis. This process was repeated a total of ten times.

3.3 Location Considerations

3.3.1 Location Choice

There were a variety of options available for recording locations, but due to the ease of access and the starkly contrasting soundscapes within a small footprint, the Eriksholm campus was ultimately chosen. In deciding on an area, the two main priorities were to reach a variety of soundscapes within a thirty-minute walk that was comfortable for older participants and to maintain as much consistency in the soundscape as possible. As covered in Section 3.1.1, the ISO standard recommends conducting a group walk so that all participants experience the same soundscape simultaneously. However, this study employed individual walks, which means factors such as weather, traffic levels, and employee activity on campus could vary for each participant.

The locations on campus were chosen after careful consideration and consultation with employees at Eriksholm. The specific variables considered, as well as their potential impact on the soundscapes, are covered in Section 3.6, but there are a few additional factors that were reviewed before the start of the study. Claus Nielsen, the primary consultant for location selection, has been working with Oticon and later Eriksholm for almost forty years. He was an excellent resource for my project, as he had practiced as an audiologist and had many years of experience working with HA users and adjusting their devices based on specific complaints about their sound environments. The goal was to select as diverse locations as possible, so that each stop provided a unique listening experience. A diversity of soundscapes will lead to richer results, as participants are exposed to different sounds that can evoke a range of emotions and reactions to their environment.

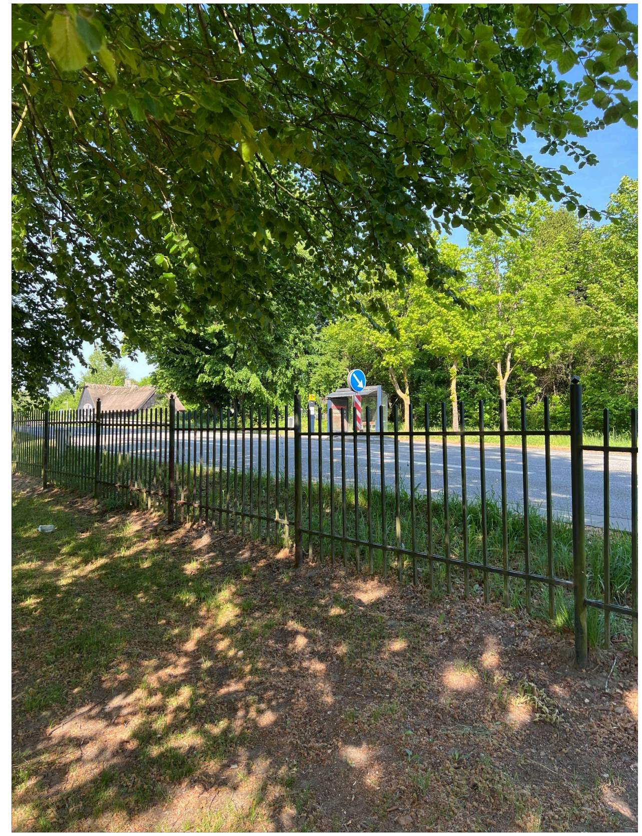
These stops were made distinct due to their proximity to a busy motorway, a forest and green space, and their placement between prominent structural and topographical features. Having a variety of physical layouts also provides participants with different masking levels, as the elevation varies across campus and buildings can block sound from the main road. It is known that vegetation and the placement of trees and bushes can impact the soundscape (Gaudon et al., 2022). While participants are not necessarily on Eriksholm's campus every day, the locations chosen reflect different real-life scenarios they may encounter.

Based on these considerations, the following five locations were chosen: the forest path, the bus stop, the courtyard, the forest corner, and the tower. Figure 7 shows a map of the Eriksholm campus, with each stop labelled.

Table 1

Location, Description, and Image of Soundwalk Stops

Location	**Description**	**Image**
1. The Forest Path	The stop is situated in a service corridor adjacent to the main office building and the parking lot. There is a gap in the trees where one can walk into the forest, but participants stood on a grassy section just over the curb, about 2-3 metres away from the entrance. This location, marked #1 in Figure 7, provides a split soundscape. One ear is exposed to man-made traffic, and the other to a natural forest scene, with only the participant's body between. Participants were asked to face the entrance of the path, with their left ear facing the main road across from campus and their right ear facing the forested green space, as seen in Figure 2.	**Figure 2** *The Forest Path*  *Note*. Photo indicates the view participants had, with no traffic visible

2. The Bus Stop	This soundwalk stop is located at the edge of Eriksholm's campus, marked #2 in Figure 7. The bus runs infrequently, only stopping at that particular stop in the mornings. No buses stopped during the soundwalk. This is both a real-life scenario that HA and non-HA users find themselves in, sometimes daily and the place on Eriksholm's campus that is most exposed to traffic noise. Participants were asked to face directly ahead, looking straight at the road. This perspective is illustrated in Figure 3.	**Figure 3** *The Bus Stop*[2]  *Note*. Participants were aligned perpendicular to the road, not along the angle of the camera

[2] Participants were standing at the bus stop on the other side of the road (not seen in photo) that did not have a shelter and thus did not affect the sound transmission of the traffic.

3. The Courtyard	This location was directly behind one of the campus buildings and surrounded by two others, making a "U" shape. As it was behind the building, it was shielded from wind and traffic noise from the main road. This location is most likely to experience "echo" or sound reflections due to its proximity to building walls. It is marked #3 in Figure 7. This may impact how participants experience auditory-spatial cues. Participants were asked to face the rear of the campus with their backs to the building. This exposed their hearing aids to the shielded traffic noise but provided more natural visual cues. This is shown in Figure 4.	**Figure 4** *The Courtyard*[3]  *Note*. This photo accurately indicates the perspective participants had at this stop

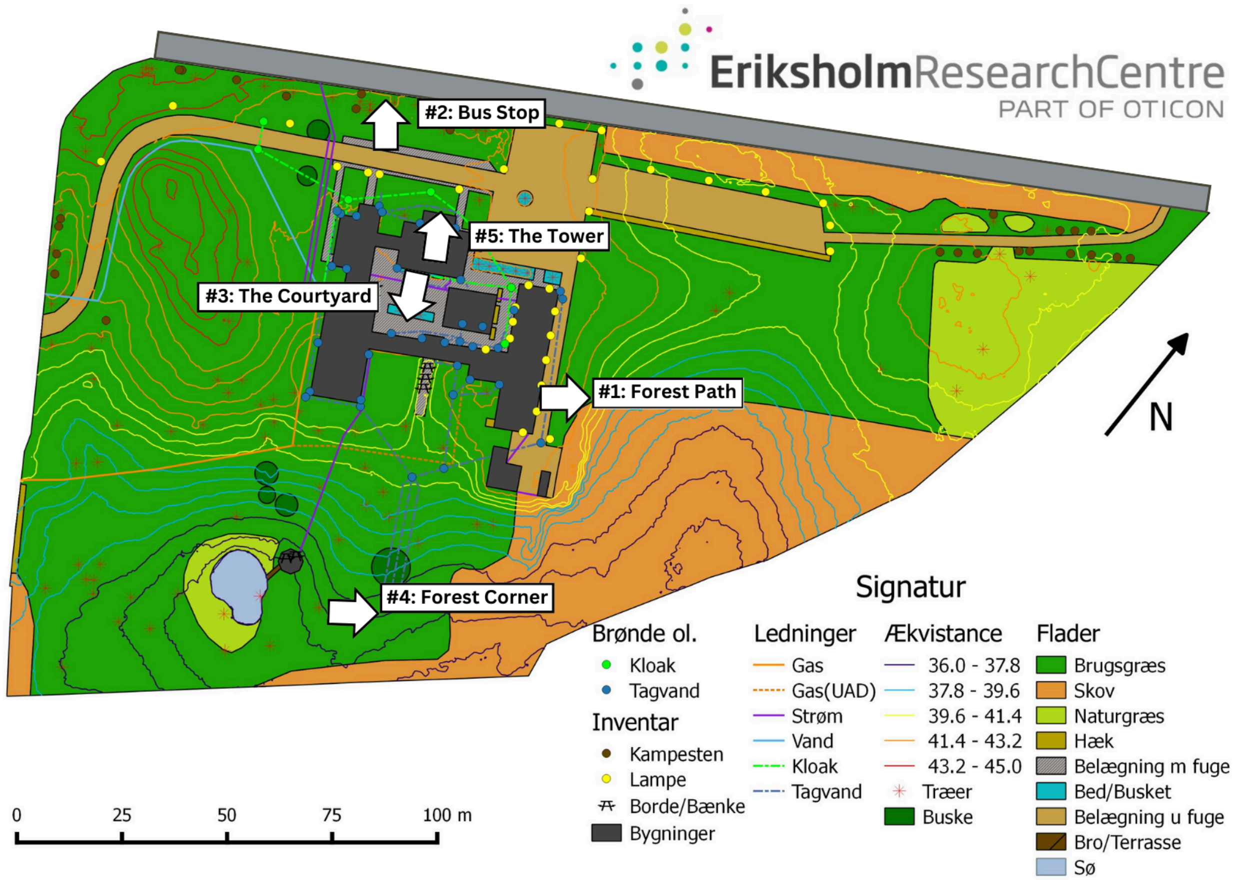
[3] This photo was taken in April of 2025 as it was missing from the original collection.

4. The Forest Corner	This location was at the farthest back corner of the Eriksholm campus, marked #4 in Figure 7. Due to the physical layout of the forest and the presence of brush and a stream close to the campus, I was unable to fully immerse participants in the forest scene. The area is situated in a depression, with the main buildings located on a small hill. The topological positioning and presence of the buildings heavily dampen the traffic sounds. Participants faced the forest, with the buildings on their left and an open field on their right. They were positioned to see only the greenery of the forest, lest a visual cue of the traffic make the sounds more prominent. This is illustrated in Figure 5.	**Figure 5** *The Forest Corner*  *Note*. Participants always stood to the right of Klangfinder

5. The Tower	The tower, marked #5 in Figure 7, is located in the centre of campus on the roof of a turret or "tower" structure. It was a special opportunity, as the tower is typically closed to visitors. This location was chosen for the angle and height. Being that high means being closer to leaves in the trees in the summer (when this study took place). It also allows participants to have a different experience trying to localize sound, as it is a similar soundscape to the bus stop, but from a significantly different height. Participants were asked to face directly ahead, looking straight at the road. The view, partially obstructed by trees, is shown in Figure 6.	**Figure 6** *The Tower*  *Note*. View from the tower facing the road

Figure 7

ERC Campus Map With Soundwalk Stops



Note. The campus map includes each soundwalk stop, labelled from 1 to 5 based on the order visited, and the arrows indicate the direction participants were facing. Image from Nielsen, R. (2017). *Eriksholm Research Centre Campus*.

3.3.2 Location Order

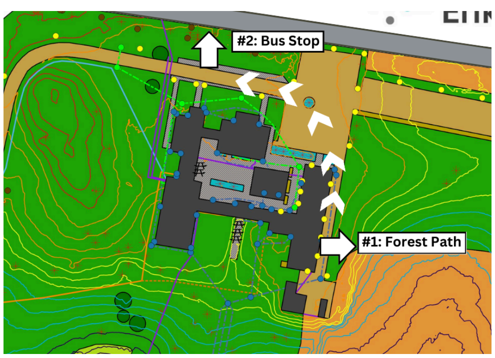
The initial location order was selected based on the path participants would take through the campus. I had initially devised it to be a spiral, starting with the bus stop near the interview room, then proceeding to the forest corner, the forest path, the courtyard, and finally, the tower. This resulted in a long walk between the bus stop and the forest corner, but it ended in the courtyard, which was next to the entrance to the building with the tower. This location order changed later in the study for two reasons: The first participant in the study noted that the bus stop location made their tinnitus much more noticeable and disruptive, which then impacted their listening experience at the rest of the locations; and the second issue was navigating the heavy recording equipment through the campus. The specifics of the setup will be covered in Section

3.7, but I had to carry a weighted-down wheelbarrow with a large post holding a heavy ear canal simulator. As a result, navigating from the forest corner to the forest path became a challenge, as it involved climbing a steep embankment.

The location order was changed to address these issues: forest path, bus stop, courtyard, forest corner, and tower. This meant that participants started with a mixed soundscape closest to the interview room, before proceeding to the bus stop, and then had another mixed location (the courtyard) before arriving at the quietest spot, the forest corner. As I could not bring the recording setup on the wheelbarrow up to the tower, I could leave the equipment there and not worry about carrying it up the hill until after the interview, when I often had support from the groundskeeper. This final soundwalk pathway is reflected in Figures 8-11.

Figure 8

Path Between Forest Path and Bus Stop



Note. Arrows indicate the direction walked between stops on the soundwalk

Figure 9

Path Between Bus Stop and Courtyard

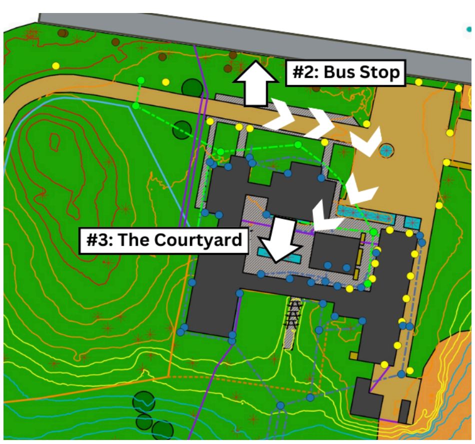


Figure 10

Path Between Courtyard and Forest Corner

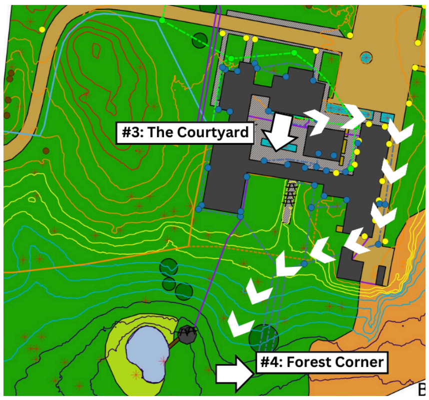
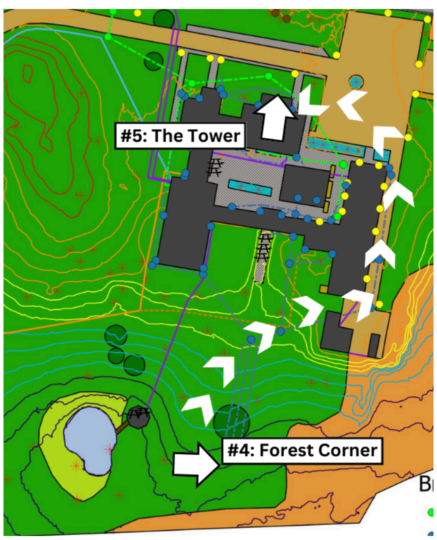


Figure 11

Path Between Forest Corner and Tower



3.3.3 Interview Timing

Two time slots were offered to participants to complete the walk: 9 am - 11 am or 11:30 am - 1:30 pm. To maintain consistency in the soundscape, the times were chosen to accommodate traffic, weather, and work patterns. This timing also ensured that regular habits, such as planes flying overhead or horses visiting the field on the property adjacent to campus, were consistently represented. The work schedules of Eriksholm employees combine on-site activities with remote work days, meaning the campus is busiest Mondays and Thursdays; two soundwalks took place on a Monday and two on a Thursday, but the entire staff was warned of my study times in advance and were very respectful to avoid interrupting the listening portions of the walk. The afternoon slot also occurred during employee lunchtime from 12:00 to 12:30 pm, when everyone eats communally in the lunchroom. This was mostly mitigated as participants often stopped by the courtyard, which is adjacent to the lunchroom, before lunchtime. However, TP A4's courtyard stop on a Monday afternoon did occur during lunch, and this is evident in their answers. Due to the time available to complete the study, it was not possible to conduct all interviews on the same day of the week. This would have further ensured habit maintenance and mitigated issues like the number of staff on campus, but it was not feasible for this project.

3.4 The Participants

This study has two cohorts of participants: hearing aid users (A1-5) and non-hearing aid users (U1-5). This meant a total of ten individuals, with five participants per cohort. As Section vi mentions, the distinction between the cohorts is based on hearing aid usage, *not* hearing loss. ISO standard C.2.3 in document ISO/TS 12913-2:2018 (E) states that the best practice is to have 20 participants per condition; however, given my limited time in Denmark and the size of the Eriksholm participant pool, this number had to be smaller. The ISO guidelines recommend collecting participants' professions, but due to the non-HA cohort being employees of Eriksholm, the concern of participants having background knowledge in the topic was already planned to be mitigated by finding active participants in the research pool. This is addressed in detail in Section 3.4.4.

3.4.1 Cohort 1: Hearing Aid Users

The first cohort was selected from the Eriksholm research pool and comprised existing members with HAs programmed by the Eriksholm audiologists, who have participated in studies before. The hearing aids worn by participants in this cohort were the Oticon Real, released in February of 2023 (*Oticon Real*, 2023). All HA users wore their devices regularly and depended on them to communicate in their day-to-day interactions. More details on each person's experience with hearing aids and device details can be found in Table 2. Participants in this cohort were compensated through the Eriksholm research pool, having been provided with free hearing aids (a $6,000 CAD value, Merit Hearing, 2024) and regular programming check-ins. The average age of this cohort was 70.4, with the youngest participant aged 64 and the oldest aged 77. The primary selection criteria for this cohort were that they wore the Oticon Real hearing aid for over one year to ensure they were comfortable with its usage; they spoke English, as I was conducting the interviews solo and did not understand enough Danish to conduct it effectively otherwise; and that they were all within a relatively close age range (i.e. within the same generation) to account for the tendency for older people to appreciate more natural sounds (Yu & Kang, 2010).

3.4.2 HA Cohort Device Specifics

Participants in the HA cohort all wore the same brand and generation of hearing aid. The Oticon Real was released in 2023 and was only recently replaced by the more recent generation Oticon Intent (*Oticon Intent*^{TM}, 2024; *Oticon Real*, 2023). Each participant had the same technology level, the highest option offered: Real 1 (Sound Hearing, 2024a). The features associated with this technology level include three environmental configurations, 10dB of difficult neural noise suppression, and six SuddenSound stabilizer configurations (Sound Hearing, 2024a). Oticon HAs were used because of the project's partnership with ERC, a part of Oticon. The ERC research pool participants were all fitted with the Oticon Real or the Oticon Intent. Only Real users were selected because the latter device was released mere months before the study began. It was important that only one type of hearing aid be used across the participants, due to the technological differences between hearing aid generations.

All HA cohort users were fitted bilaterally with two hearing aids, consistent with existing best practices in aural rehabilitation for individuals with mostly symmetrical hearing loss (Picou et al., 2022). This dual device use and symmetrical loss ensured consistency when participants faced a particular direction, since one ear would be exposed to a different sound scene. This is especially relevant for the forest path location, as one ear faces traffic and the other faces the forest.

3.4.2.1 Digital features of the Oticon Real hearing aid

The Oticon Real HA is built on a platform called Polaris and hosts MoreSound Intelligence 2.0 (Oticon, 2023). This particular program features several enhancements to improve the listening experience of HA users, particularly as it focuses on expanding the device's ability to distinguish between soundscapes and adjust the gain and signal filtration accordingly (Brændgaarde & Loong, 2020). One of the primary features relevant to this study is the Wind and Handling Stabilizer (WHS), which is designed to suppress incoming wind noise by digitally removing it from the incoming signal (Gade et al., 2023). Another feature is the OpenSound Optimizer, a program specifically designed to handle excess feedback by digitally suppressing the signal, in a manner similar to how WHS suppresses wind noise. Several of these features can be turned on or off based on the preference and benefit of the specific HA user. In this study, all features were enabled, but some had a greater influence on processing in specific programs (for example, the WHS does not need to be as high in quiet environments, so it may not be featured in the quiet program).

Table 2

Participant Profile of HA Users

Participant	A1	A2	A3	A4	A5
Age	71	69	64	77	71
Type of hearing loss	Mild-profound	Mild-severe	Mild-profound	Mild-moderate	Mild-severe
Years of HA use	10+	25+	25+	4	15+
Dome type	Bastip double vent / power dome[a]	Custom moulds	Custom moulds	Open dome - both ears	Custom moulds
Ventilation	N/A	0.8 mm / 0.8 mm	1.0 mm / 1.0 mm	N/A	1.0 mm / 1.4 mm
Receiver type	100	100	105	85	105
Tinnitus status	Quite bothersome and triggered by loud noise exposure	Present but described as not overwhelming	Present within the last year, clicking sound (not ringing)	No tinnitus	Mostly in left ear, but most present when not wearing HAs
Notes	-	Least comfortable with English	-	Most comfortable with English	-

[a] The first value listed is for the right ear, and the second is for the left ear for both the domes and the ventilation cells

3.4.3 Cohort 2: Non-Hearing Aid Users

The second cohort was comprised of Eriksholm staff. Participants in this cohort were recruited through the company's internal email system. According to the cohort's requirements, no participants wore hearing aids; however, one participant had unilateral hearing loss. The participants were from various departments across the facility, ensuring that the cohort did not consist solely of audiological experts. The average age of this cohort was 61.8, with the youngest being 58 and the oldest being 67. This cohort was recruited after the first cohort to match the ages and make the groups as homogeneous as possible. As the participants in the research pool were primarily retired, finding active staff older than 65 was a challenge, resulting in a lower average age for this cohort.

Table 3

Participant Profile of Non-HA Users

Participant	**U1**	**U2**	**U3**	**U4**	**U5**
Age	62	62	58	60	67
Tinnitus Status	Not currently experiencing tinnitus	In left ear	Both ears	In right ear	Both ears
Notes	Native English speaker	Participant has hearing loss in left ear (does not wear hearing aid)	-	-	-

3.4.4 Reconciling the Differences Between Cohorts

The participants in cohort two were more familiar with Eriksholm's campus and were experts in hearing science. While this might provide a slight advantage in terms of describing soundscapes, the participants in the HA cohort had participated in several studies at Eriksholm's campus, ensuring that the space was still familiar to them. They were all interested in their listening ability due to their decision to join the participant pool in the first place, with one participant having worked with Eriksholm since its founding in 1976 (Eriksholm, 2024).

The other primary difference between the two cohorts is the language background of the participants. While everyone was able to converse in English, the non-HA cohort had better language skills on average, as they spoke English daily as part of their work. Some HA participants did have exceptional English, given their own work backgrounds, and the potential impacts of the differences in language ability will be further explored in Section 5.3.

3.4.5 Ethics Approval

I successfully received approval from the Research Ethics Board (REB) of OCAD University to use Eriksholm's participants from their research pool (approval #6370). Eriksholm also had ethics approval to do this research through its oversight committee. Participants in each cohort signed an English and a Danish consent form to ensure a complete understanding of their involvement in the study.

3.5 Developing Data Gathering Tools

Three data-gathering tools were pre-developed to garner the desired insights from participants: the pre-survey, the questionnaire for each soundwalk location, and the final interview questions. Previous soundwalk studies and the ISO guidelines informed the selection of all the questions. Before explaining how each was developed, it is worth discussing the language being presented to participants that may evoke specific responses. To ensure vigorous research standards are being upheld, questions should not lead participants into a specific answer that is not representative of their true experience. One of the primary biases that can result from soundscape research is the connotations associated with specific sounds. For example, "traffic" can be seen as a negative word simply because it is associated with frustration from sitting in traffic. To mitigate some of this bias, the ISO standards recommend using more neutral descriptions such as "road noise" instead of "traffic." For this study, I chose to retain the word 'traffic' as it was familiar to participants whose first language was not English. Additionally, 'noise' is a contentious term that may also carry a similar bias, thus not being addressed by the ISO's suggestion (Thompson, 2012). This bias is also irrelevant to the pre-survey sound ranking questions, as each sound was meant to be specific (for example, water falling), so each participant was referencing the same or similar sounds.

3.5.1 The Pre-Survey

All participants began by completing a short pre-survey, which is located in Appendices D and E. This was inspired by a previous soundwalk study that asked participants about their expectations prior to the soundwalk (Davies et al., 2012). There were two versions of the survey, one for each cohort. Due to some participants being less comfortable in English, especially writing, I sometimes wrote their answers as they dictated them to me. Most participants quietly filled in the survey, and I reviewed their answers during the interview portion of the study. This style was selected to gather data for comparison with their initial thoughts about their experiences in natural environments and their experiences in the moment from the soundwalk.

The HA participant survey was primarily focused on their typical HA use to give context to their relationship with their device and the settings they typically benefit from. Their survey consisted of nine questions and took participants approximately ten minutes to complete. The non-HA cohort took approximately five minutes to complete their version, which consisted of six questions. Their questions were similar to the other cohort, but were worded more generally to focus on the listening experience rather than the hearing device experience. I also included a preference scale for all participants to rate a series of sounds on a scale of 1 to 11. The sounds listed were chosen to fit within different classifications recommended in the ISO standards (Nature, Human, Machine) and to encompass some of the sounds participants might encounter during the soundwalk. This prompted a lot of great discussion, and the answers will be further discussed in Section 4.0.

The pre-survey aimed to understand more about the participants' expectations of the study, as well as provide a baseline of what sounds they are comfortable with or not. Asking these questions first also allowed me to address any misconceptions about the study itself before going on the soundwalk, as some participants expected it to be a speech-related study due to the other studies that Eriksholm had run in the past.

3.5.2 The Questionnaire

The questionnaire was used to collect participants' thoughts during the soundwalk. The questions were the same for each location and across the two cohorts. They can be viewed in Appendix A. Participants were given a clipboard with these questionnaires attached to carry throughout the soundwalk and answer during and immediately after each listening stop. Each questionnaire consisted of eight questions that focused on identifying sounds in the area, noting any conflicts with expectations, and expressing personal feelings about their listening experience.

These questions were developed from ISO-recommended Method C data points and prior soundwalk studies (Aletta et al., 2019; ISO, 2018; Jeon et al, 2013; Davies et al., 2012). There is also some overlap with the pre-survey, as this served as a comparison point for the expectation versus reality. For example, both asked participants about expectations, just in different contexts. The goal of the questionnaire was to allow participants to document any immediate thoughts and feelings as well as prompt specific behaviours. For example, asking participants to identify eight sounds gets them to listen more intently, which is the purpose of the soundwalk, but may be an unfamiliar activity in everyday situations.

The questionnaire responses are the primary data points for comparing the location experiences between participants. This is why each question was identical for both cohorts and all locations, ensuring the wording remained consistent and did not influence individual participants' thoughts. Participants also wrote their answers during and just after the specific soundwalk location to allow for their in-the-moment thoughts to be recorded. Both ISO methods A and B encourage this to occur in situ.

3.5.3 The Interview Questions

There are two versions of the interview questions, one for the HA cohort (located in Appendix B) and the other for the non-HA cohort (located in Appendix C). Both cohorts had similar questions; the only one that varied was whether HA users had unique sounds available to them due to their hearing devices. This meant the HA cohort had ten questions, and the non-HA cohort had nine. The questions were printed and given to participants from both cohorts to ensure they understood them, rather than relying solely on my verbal cues. This is an essential consideration for the HA cohort, but also applies to the non-HA cohort, as one participant still had a hearing loss but did not use amplification. It is also simply helpful to have as a reference sheet.

These questions began with a disclaimer stating that participants were not expected to disclose health information. While no questions specifically targeted that, the ethics committee at OCAD University recommended it, and I also verbally explained it to each participant. The interview questions aimed to address the participant's overall experience from the soundwalk and capture the specific feelings associated with specific sound descriptors. For example, if a participant wrote in their questionnaire that a fire truck passing by caused discomfort, I would prompt them to describe the feeling of discomfort as well as any associated behaviours to address it. The goal was to gain a deeper understanding of their ability to distinguish certain sounds, in order to later compare whether these sounds were masking others and thereby blocking sounds that the participants wanted to hear.

The interview questions were not asked in sequence but served as a framework to reference when necessary. This semi-structured interview format is commonly used in design research because it allows for more flexibility in following up on particular stories and leads to a more natural conversation style (McIntosh & Morse, 2015). As discussed in Section 3.1.1, it is also recommended by ISO C3.3. This approach worked well for the study, as the pre-survey questions and questionnaires could be discussed interchangeably as needed, resulting in fewer repetitions and more interesting connections between expectations and experiences.

3.6 Variables

A participant might encounter nearly infinite variables regarding possible sounds (Grinfeder et al., 2022). This section covers some of the most common influences on a participant’s experience and outlines the measures taken to mitigate them.

3.6.1 Weather

The weather posed a challenge throughout this study, as Denmark experiences a significant amount of rain, and multiple studies had to be cancelled or postponed due to this issue. One participant was unable to complete location five due to the rain (TP U4), and another participant had a pre-interview as we waited for the rain to stop, resulting in an extended conversation (TP U3). Another issue that arose with the rain is that the sound of tires contacting the pavement changes when the road is wet (Karpenko & Masliaiev, 2017). As a result, participants may be more likely to note discomfort from the traffic or identify traffic sounds farther away from their source.

The wind was also a challenge, as it is an important feature in a natural landscape, but it was impossible to replicate the same wind conditions during each soundwalk. Therefore, two participants experienced quite heavy wind (over 9 mph), while the others experienced wind speeds of less than 5 mph. This will factor into their responses and needs to be appropriately considered within the context of the wind that day. Finally, temperature and humidity can also affect sound transmission and the overall soundwalk experience. Higher humidity can lead to less sound absorption and, thus, an increase in volume (Bohn, 1988). Most participants had similar humidity levels, but the two impacted by the rain, TP U4 and TP U3, understandably also had more humidity that day. The specific details of each participant's weather conditions are presented in Tables 4 and 5.

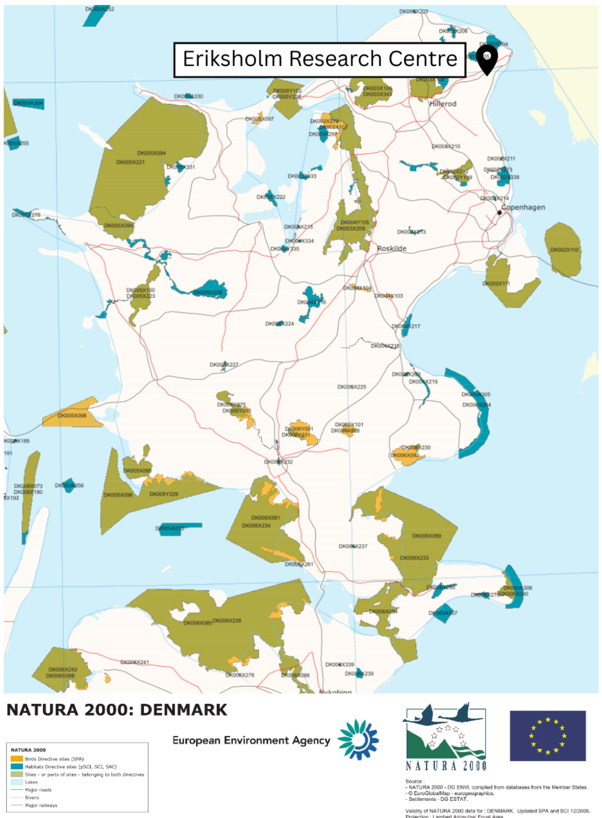
3.6.2 Animals

In a natural environment such as a forest, a variety of animals will make noise. These sounds occur randomly, so one participant will likely be exposed to more or less of these animal sounds than another. For example, if one participant does not mention hearing birds, it could indicate that their hearing aids are not picking up the high-frequency sound, but it could also mean that there were few birds present at that very moment. This is why recordings were taken, so the scenario can be listened to again to confirm what participants heard. For the scope of this thesis, the recordings are not being analyzed due to the limited time frame of this project, but their existence is referenced in the methods and results sections of this paper.

The three main animal sounds participants would be exposed to are birds, insects, and deer. The deer only appeared during one stop of one soundwalk, so it did not have a significant impact on the participant experience. The birds and insects may also vary due to weather conditions, as some types of insects prefer high-humidity climates, for example. Bird activity is governed by migration patterns, which can impact whether the participants are exposed to these sounds at all. With bird migration, the spring migration for most birds returning to Denmark for the summer is between the end of March and the middle of May (Air Command Denmark, 2021). There are no concentration areas for returning birds within 30km of Eriksholm's campus. This is illustrated in Figure 12, which compares Eriksholm's location to the National Danish Natura 2000 bird conservation sites, where more bird activity is typically expected. As a result, bird activity is expected to remain relatively stable throughout the soundwalks.

Figure 12

Natura 2000 Danish Bird Protection Zones (Denmark, 2018)



Note. The ERC is indicated with a black pin on the map and is not in any of the areas of protection, indicating a lower or average bird population

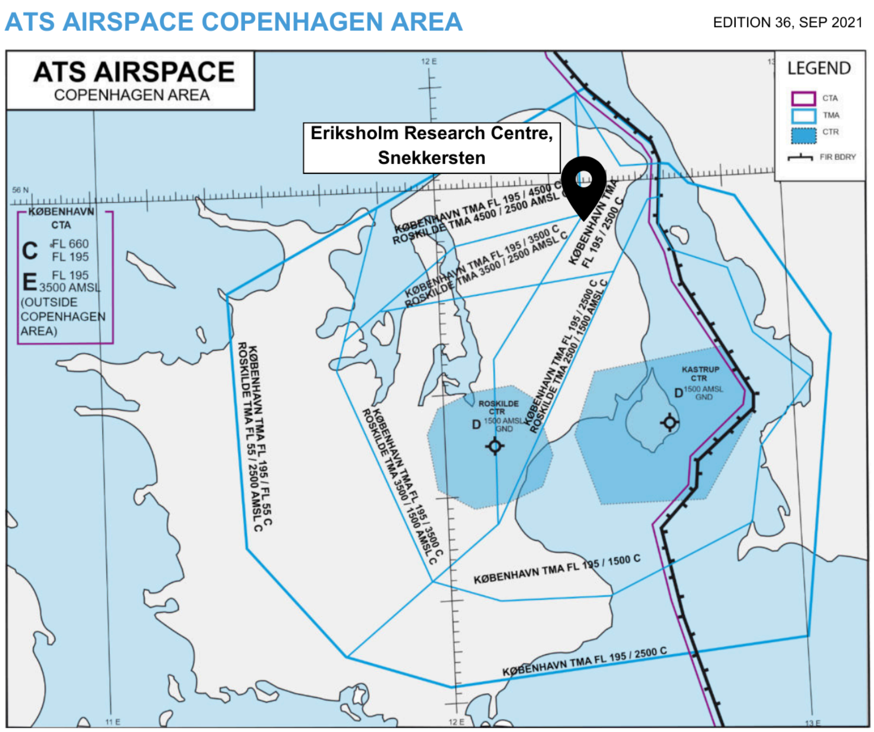
3.6.3 The Campus

The experience of Eriksholm's campus could vary from participant to participant due to the various activities occurring on the grounds. The groundskeeper often had maintenance work to complete, resulting in some participants hearing machines, like an electric saw, while others heard none. I attempted to mitigate this by coordinating the soundwalks to avoid conflicts with scheduled activities, such as the weekly lawn mowing; however, it was inevitable that some activities would still overlap. As mentioned in Section 3.3.3, lunchtime was an important activity to consider as it occurred close to the courtyard, stop number three. Unfortunately, one participant was exposed to these sounds. Some coordination was needed to ensure no tours happened when participants were doing their walk, as that could lead to other sounds like footsteps and chatter that other TPs were not exposed to. This was successfully managed, and no participants encountered any tour activities on campus.

Finally, Figure 13 shows the location of the Eriksholm campus within the Copenhagen flight area. Of note, the closest airport is around 20km away, and the Copenhagen International airport is about 50km away (Air Command Denmark, 2021). Although not located near the Copenhagen International Airport, planes often fly to that airport over Eriksholm, particularly given its proximity to the Swedish border. For this reason, some participants did hear planes during the study. Due to the timing limitations mentioned in Section 3.3.3, it was not possible to ensure that every participant did or did not hear this feature.

Figure 13

Flight Map of Copenhagen



Note. Eriksholm is indicated with a black pin on the map and is surrounded by a Terminal Maneuvering Area (TMA), which means high levels of airplane traffic due to the Copenhagen International Airport

3.6.4 Traffic

Traffic levels will never be identical for each participant, but maintaining time slots for the soundwalks is intended to take advantage of regular daily traffic patterns. However, the uncontrollable variable is the types of cars to which participants are exposed. For example, are they seeing any electric vehicles? Are there any sirens active? Are there any big trucks or buses passing by? Some participants were indeed exposed to sirens, but not all of them. This is also an issue when considering the traffic exposure at each location. Traffic is not static, and the levels can vary at each location. Given the general amount of traffic on the road next to Eriksholm, all participants heard at least one commercial truck, an electric car, and a standard gas car. The other exposure to traffic that needed to be mitigated was cars travelling through the Eriksholm parking lot. Given the timing of the stops and staff awareness of my study, no cars entered or exited the Eriksholm parking lot during the recording time.

3.6.5 Cultural Influence in Soundscapes

The overall position of Eriksholm's campus in relation to the nearest city and within the country is essential to consider to understand the expected soundscapes. There are various aspects of a location that are specific to its climate, flora, fauna, and lifestyle of its citizens, all of which can impact a soundscape (Hu et al., 2024). It is important not only to contextualize the results of this study but also to explore future areas of research by comparing how hearing aid users experience different environments based on their workplace or residence. Some of these differences are addressed in Sections 3.6.1-3.6.4, as soundscapes vary locally by season, traffic, and flight patterns; however, there are many other important factors that affect the final results. I will consider the soundscapes from Denmark in comparison to my home in Ontario, Canada.

One example of the countries' differences that I found prevalent was the absence of some animals. Denmark has few squirrels or chipmunks native to the country, so a common source of sound in Ontario, Canada, is not often heard (*Squirrel Population by Country 2025*, 2025). This is also true of the bugs present outdoors (Health Canada, 2024; *Mosquito | Kongeåen*, n.d.) and other creatures like birds with unique calls. One participant, visiting from the United States, commented that they were unfamiliar with the bird calls in the area. One interesting line of future research could be to investigate whether birds native to specific regions generally have higher or lower frequency calls, and if this affects the satisfaction of HA users, particularly if they are able to hear them more clearly in their local area. The area where Eriksholm is located is home to a deer family, rabbits, and a stream that runs through the wooded area, which is also inhabited by ducks. While participants were never taken inside the forest itself, the density of the trees and the presence of these animals and features all influenced the particular soundscape the study participants encountered.

Landscape features can also influence the soundscape of an area, like mountains in Canada that are not found in Denmark. Mountains can create unique echoes, and Denmark is known for being a flat country, with its highest elevation being 170m (Ejer Bavnehøjs Venner, 2022), compared to Canada's 6000m (Government of Canada, Statistics Canada, 2021b). Canada also experiences a notably different winter season, necessitating winter tires with a distinct sound profile compared to summer tires (Gorzelanczyk et al., 2021). Snow has a unique sound-dampening effect (Conrady et al., 2018) that is not seen to the same extent in Denmark, whose winter climate is primarily rainy (Baron & Petersen, 2014).

In terms of lifestyle, urban versus rural soundscapes exhibit major differences due to the presence of man-made sounds, such as traffic and construction, which are more prevalent in highly developed areas. However, the general social attitude towards things like public transit and cycling can also strongly influence the soundscape of an area. For example, Denmark prioritizes public transit and has multiple metro and train lines (*Getting Around*, 2025). My hometown of Ottawa does not have streetcars and relies mainly on an extensive bus network (*Service Types*, 2025). Denmark is also known as being one of the most bike-friendly countries in the world, and the sounds associated with biking are much more present than in cities like Ottawa or Toronto. There, cyclists are often limited by snow in the winter and may use electric bikes, as the distances to travel between places are much greater (Buehler & Pucher, 2020).

3.7 Measurement and Recording Methods

This section details the recording setup used to capture the sounds experienced by the participants in the unique moment they were stopped to listen. These recordings are valuable for understanding the variables present during each stop and for comparing the written survey answers with the recordings in cases of uncertainty. This project does not analyze the recordings due to timeline constraints; however, the details are included here, as they were a significant part of the data collection process. It is intended to be shared for future studies to provide a clear understanding of how to replicate my study.

3.7.1 Ear Canal Simulator Setup

The ISO document ISO/TS 12913-2:2018 (E) outlines the established methods for creating binaural acoustical measurements. The recordings were taken for future analysis, but will not be analyzed in depth for this thesis project due to the project timeline and scope. This ISO procedure was followed, with some variation, given the equipment available and the physical environment in which the study took place. The measurements were taken using an ear canal simulator nicknamed “Klangfinder” (see Figures 14a and 14b). An ear canal simulator was used instead of a simple binaural microphone setup because it would allow Klangfinder’s model ears to replicate the participant's listening experience with greater authenticity (Yellamsetty et al., 2021). The other benefit is that Klangfinder is designed for use in testing hearing devices, which means the hearing aids programmed to each participant could be fitted to the model and used as a more accurate simulated recording rather than post-processing the recordings through a similar audio profile to each participant.[4] Klangfinder’s head system complies with ITU-T P.58:2013, 5.2 and ANSI/ASA S 3.36:2012 standards, as required by ISO (2018).

[4] This unfortunately is what will need to happen with the recordings due to a mistake in selecting the ear canal channel on the Klangfinder. This meant that all recordings were taken without the hearing aids influencing the sound. This will be discussed further in Section 5.7.

Figure 14a

Front View of Ear Canal Simulator "Klangfinder"

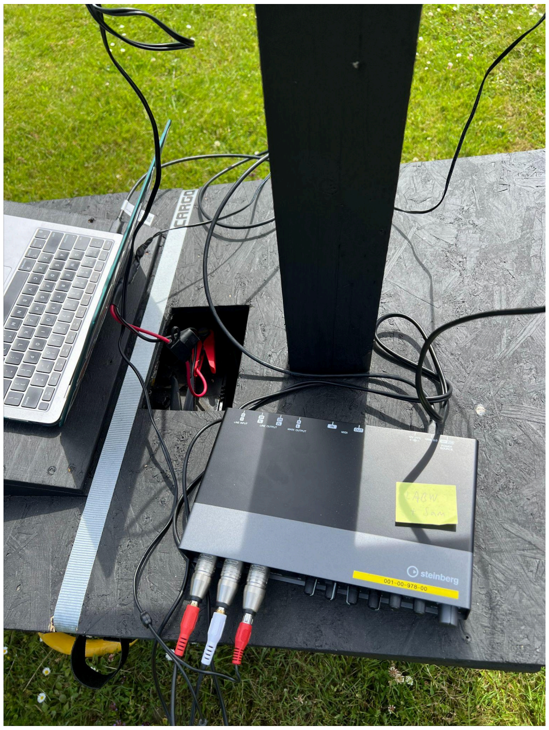
Figure 14b

Side View of Ear Canal Simulator "Klangfinder"

To ensure accurate recordings and alignment with ISO's regulations and other studies, Klangfinder was mounted at a height of approximately 1.45 metres. This could not be adjusted to match the height of each participant due to the setup and timing of the study, so there will be minor discrepancies in the recordings versus the true experience, which is relatively insignificant for this project and in accordance with the practice of other soundwalk studies which also maintain a consistent recording height (Sun et al., 2023). Klangfinder was always facing the same way as the participant, and locations were chosen so that the model would be at least one metre away from any reflective surfaces (such as building walls). To achieve the required height, Klangfinder was mounted to a wooden post affixed to a plywood sheet. As there were multiple locations involved, the fixture was strapped to a wheelbarrow that was weighted with rocks to counterbalance the heavy ear canal simulator. This setup also allowed for the placement of a computer and sound card on the plywood sheet, as seen in Figure 15.

Figure 15

Computer and Sound Card Placement on Measurement Device



3.7.2 Capturing the Recordings

A sound meter was strapped to the base of Klangfinder to obtain a third (and monaural) recording for comparison with the ear canal recordings. For the HA cohort, this also provided an unprocessed sound signal for comparison. All these devices were powered by a car battery housed inside the wheelbarrow (See Figure 16). The final location, the tower, was only accessible through a narrow stairway, so this location was treated more as a bonus and was not recorded. However, I did measure the sound pressure level (SPL) to compare it with the other locations.

The sound meter used was a Brüel and Kjær model BK 2250 Light SLM. Before the start of every soundwalk, the sound meter would be calibrated at the recommended 94 dB using a special calibration device specifically made to fit this sound meter. The device itself is IEC compliant 61672-1, which satisfies the ISO requirements from 2019 on data analysis, as it was written in tandem with the International Electrotechnical Commission (IEC).

The recordings were captured through a sound card connected to a MacBook Air M1 running Audacity. This software was chosen due to my familiarity with it from my bachelor's thesis work and because it is free to use and effective for recording multiple channels. The following steps were completed before each soundwalk to capture the recordings:

3.7.2.1 Steps for recordings

1. Open a new Audacity file (one file per test person).
2. Calibrate the SPL meter using the calibrator at 94 dB.
3. Plug the Klangfinder and sound meter into the sound card, and then connect the sound card to my computer.
4. Ensure appropriate gain by adjusting knobs on the sound card as needed.
5. (For HA users) Ensure the hearing aids are turned on.
6. Hit record.

The measurements were collected statically, as both the participants and the model remained in place and facing the same direction for the duration of the stop and recording. While recording, the input was uncompressed, with a sampling rate of 44.1 kHz and a bit depth of 24, in accordance with the 2019 ISO standard. Each stop and associated recording was three minutes long. This is the minimum duration specified in the ISO guidelines and is also used in other soundwalk studies (Mancini et al., 2021). This number was chosen to ensure the study was not too long, given the pre-survey and interview in addition to the walk. The shorter time also allowed for more locations to be visited, thus providing more areas for comparison and variability in the traffic-to-nature ratio.

Figure 16

Recording Setup for Soundwalk

Note. This is the final setup with all the required quantitative measuring equipment, including Klangfinder, a sound card, a computer, a sound meter, and a car battery (housed inside the wheelbarrow)

3.7.3 Other Quantitative Measurements

The weather was measured at the first location using the Weather Underground website at the beginning of each soundwalk. This particular weather source was chosen based on recommendations from colleagues due to its larger network connected to personal weather stations (*PWS Network Overview | Weather Underground*, n.d.). Since the ERC campus is not located near a major city, having a weather station closer to the campus to obtain the most accurate readings was important. The measurements taken using Weather Underground include temperature, humidity, wind speed, and a general description of the conditions (e.g., fair, cloudy, sunny). These values were collected based on the ISO data collections 2018 standard D7.d for soundwalks.

While the majority of ISO's recommendations were followed, one was thoughtfully excluded. Despite the recommendation, I did not use windshields because the ear canal mimics what the participants were exposed to. It would have been more appropriate if the microphone I used had been more exposed, but this was not the case since the microphones were inside the Klangfinder's ear canals.

There were many challenges with creating and maintaining the recording setup. The primary concern was ensuring the gain was consistent and avoiding clipping during the recording process. Since the recording system needed to be re-established for each soundwalk, it was difficult to maintain a satisfactory balance. It will likely need some post-production tuning to compensate for this challenge. This will not impact the results of this thesis. The other issue with the wheelbarrow setup was the weight. It was quite heavy and needed to be moved to each location, including down a hill. As stated in Section 3.3.2, this was a factor in changing the location order. Despite that difficulty, I would still use a similar setup for future studies, as it was feasible with a carefully planned soundwalk itinerary.

3.8 Coding Process

As detailed in the ISO guidelines for method C data analysis in ISO/TS 12913-3:2019(E), this study employs grounded theory to derive insights from the interview transcripts of each participant. Grounded theory has three stages of coding: open, axial, and selective (Turner & Astin, 2021). Open coding consists of reading each transcript, highlighting key phrases, and generating a series of codes that begin identifying some themes. For this study, the open coding stage was completed using an iPad with a digital pencil, where key phrases were marked in yellow and notes were written in the margins of the transcript. I chose this method over using coding software like Dedoose due to its flexibility and portability, as working on this project in both Denmark and Canada resulted in a lot of travelling over this project's timeline.

After this step, I began phase two: axial coding. This step involves synthesizing some themes from open coding and finding commonalities among the transcripts. I completed this method using an Excel sheet, identifying specific quotes and the exact insights gained in a quotes and codes table format. For example, one TP said, "Leaves rustling, number two is because that's nice to hear. It’s not inconvenient.” The initial codes I drew from this phrase were: Natural sounds, sound: leaves rustling, "nice to hear", sound as not inconvenient, sound rating. I noted which words were coming up frequently and used the spreadsheet to tally this information.

The final stage of grounded theory is called selective coding, where the codes from the previous two steps are cyclically combined to form larger picture themes from the content. This also combines the codes from every transcript, getting an overview of themes across participants rather than the detailed individual view that the first two steps take. This was broken down into several steps, as the data from axial coding can be applied through different lenses and thus can be processed in various ways. For example, when I was looking at the frequency of the codes, I put all the codes into a spreadsheet and tallied how often they appeared. When searching for higher-level themes within the codes, I began by removing duplicates and grouping codes into similar categories (e.g., sounds, locations, feelings). These codes can then be compared across participants to identify similar themes and determine which aspects of each theme were discussed. All of this information is then put into a visual format for data representation.

3.9 Generalizability and Trustworthiness

This study is heavily based on the ISO soundwalk standards, which have been established for over five years and have a reputation in the field of research standards (*ISO Standards*, n.d.). The standards allow for some researcher interpretation and flexibility, especially in the interview portion of the study. Therefore, as I combined all three methods, there may be less generalizability compared to the strict, prescription-based, and validated ISO methods. However, given that many soundwalk studies also employ a similar combination method (Mascolo et al., 2024; Aletta & Kang, 2019), I am confident that the procedure used in this study maintains the integrity of the ISO standards.

The participants in my study have contributed to numerous other research projects at ERC and were selected to have a similar demographic profile as possible to eliminate some barriers that may influence hearing aid experience and satisfaction. However, the general approach of this research project is not to derive insights from statistics, but instead to examine each participant’s experience as a unique perspective that should inform the final results. As such, these findings are not intended to be generalized across the entire hearing aid industry, but rather to raise awareness about the issues that hearing aid users encounter when trying to experience natural soundscapes.

4.0 Findings

The following section shares the findings from this study. The results are divided into two of the most commonly discussed sounds: bird song and traffic noise. These two sounds represent the urban and natural aspects of the study best, as they are quite different in average frequency and appreciation. Given the sharp divide between traffic and nature that Eriksholm's campus had simply from the proximity to a major thoroughfare, these two sounds embody the experience of the soundwalks best, especially as the stops were devised to highlight these differences. The findings compare the two cohorts' ability to describe sound and contextualize themselves in space using sound. The majority of the data analyzed for this thesis is from the coded post-soundwalk interviews and the rankings from the pre-survey results. While I attempted to maintain the exact wording of each participant for any quotes used throughout this paper, some language may have been altered to provide clarity or brevity (e.g. removing repetitions, correcting grammar, and adding context).

4.1 Characterization of the Soundscape

Table 4

HA Cohort Soundwalk Conditions

Participant	**A1**	**A2**	**A3**	**A4**	**A5**
Soundwalk date	May 22	May 22	June 3	June 3	June 13
Weekday	Wednesday	Wednesday	Monday	Monday	Thursday
Time slot	Morning	Afternoon	Morning	Afternoon	Afternoon
Temperature	70F	74F	59F	63F	57F
Humidity	58%	48%	76%	64%	63%
Windspeed	2mph	9mph	0mph	0mph	5mph
Weather conditions[b]	Sunny, partly cloudy	Sunny, windy	Cloudy	Mostly cloudy	Partly cloudy

[b] Results recorded from Weather Underground (*Weather Underground*, n.d.)

Table 5

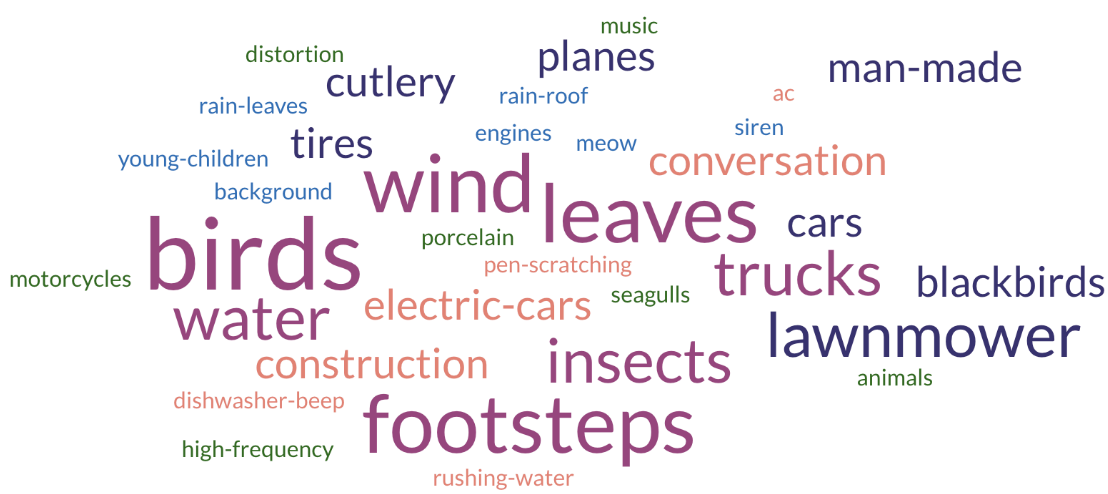
Non-HA Cohort Soundwalk Conditions

Participant	**U1**	**U2**	**U3**	**U4**	**U5**
Soundwalk date	June 4	June 4	June 12	June 13	June 21
Weekday	Tuesday	Tuesday	Wednesday	Thursday	Friday
Time Slot	Morning	Afternoon	Morning	Morning	Morning
Temperature	63F	65F	53F	55F	64F
Humidity	61%	56%	81%	71%	63%
Windspeed	0mph	0mph	8mph	9mph	5mph
Weather conditions[c]	Partly cloudy	Sunny	Cloudy, rain	Mostly cloudy, rain	Some sun, risk of rain

[c] Results recorded from Weather Underground (*Weather Underground*, n.d.)

Figure 17

HA Cohort: Sounds Discussed in Interviews



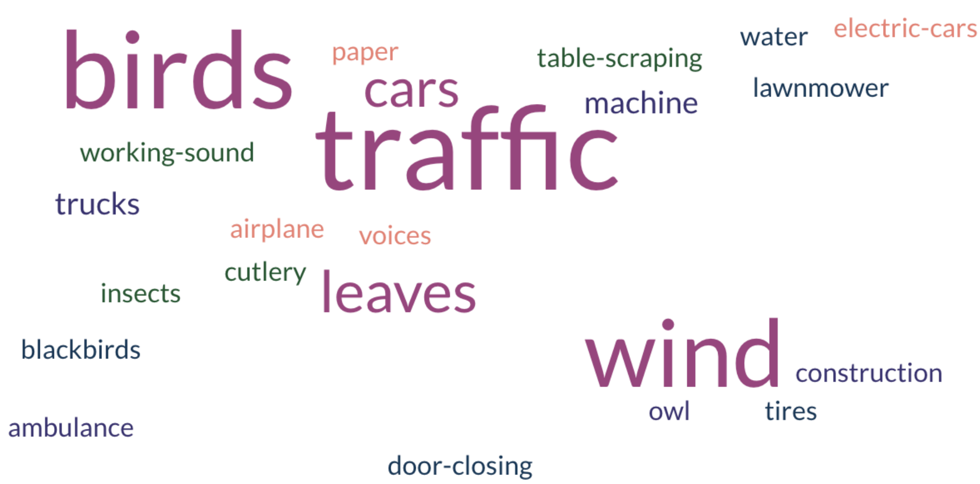
Note. The indicated sounds are represented in a word cloud, where the largest words reveal the most frequently referenced

Figure 18

Non-HA Cohort: Sounds Discussed in Interviews

Figure 19

HA Cohort: Sounds From Soundwalk Questionnaire



Note. These sounds were written during the soundwalk and are an amalgamation of every stop

Figure 20

Non-HA Cohort: Sounds From Soundwalk Questionnaire

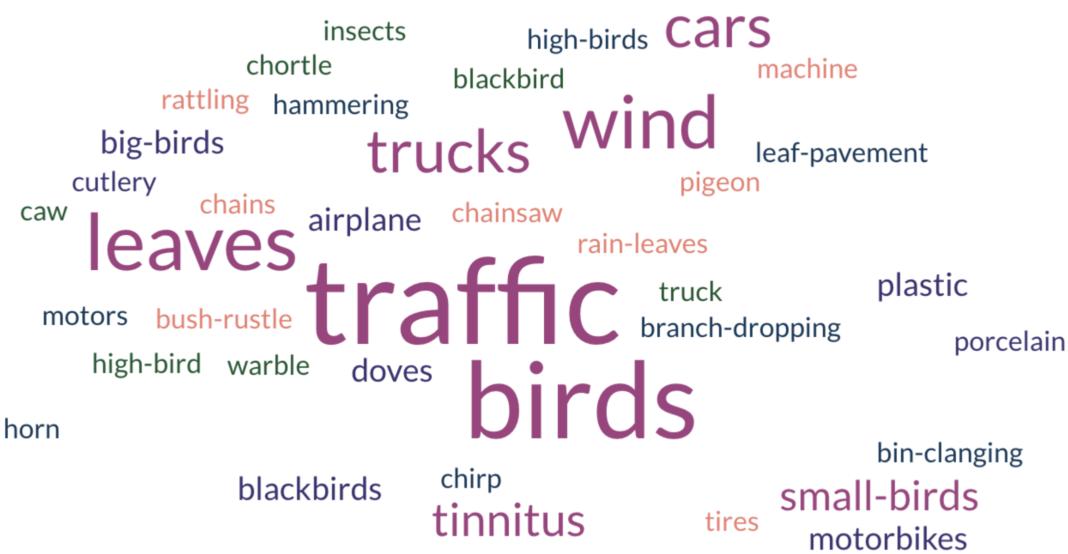


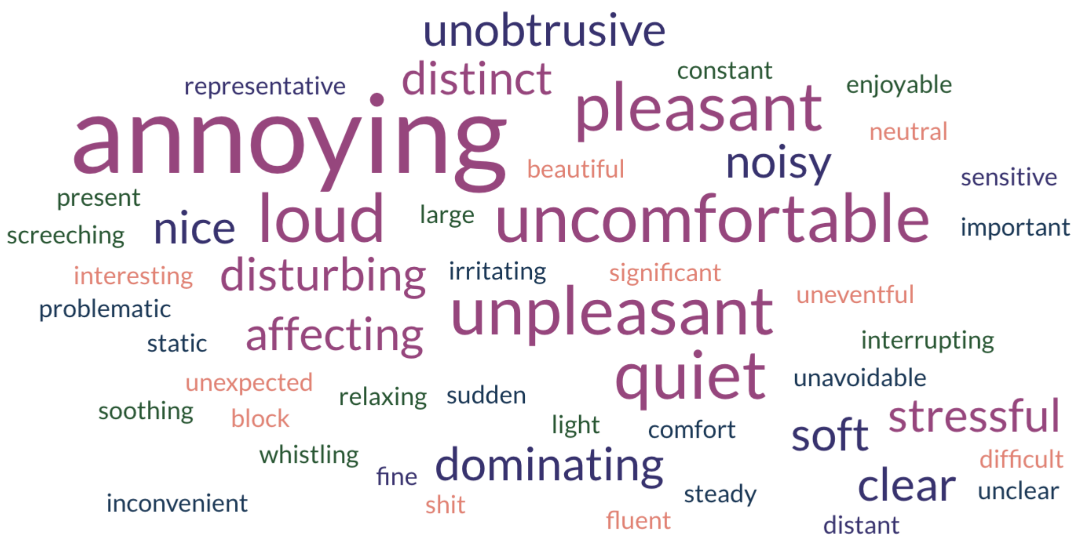
Figure 21

HA Cohort Sound Descriptors

Note. A word cloud of words used to describe sounds that participants used in the interviews and wrote in their questionnaires

Figure 22

Non-HA Cohort Sound Descriptors

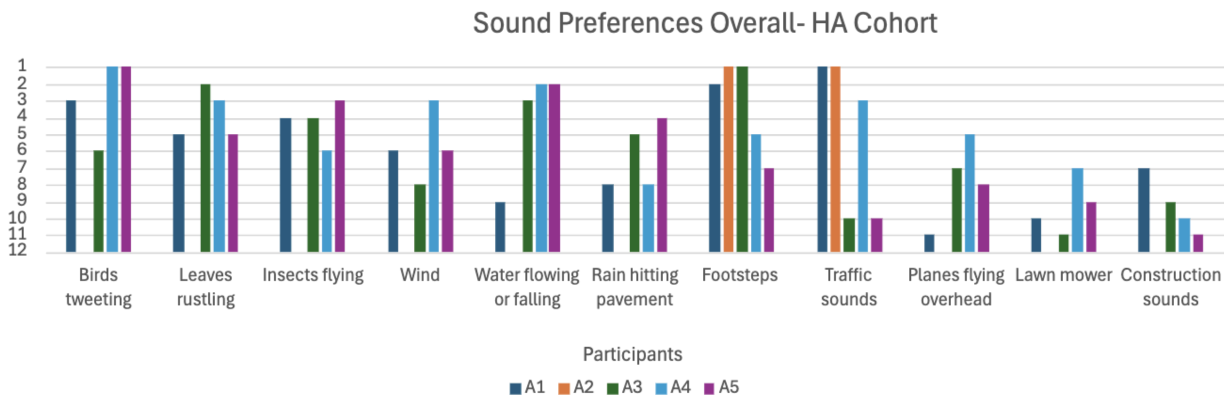


4.2 Summary of Results

The findings for this study are first divided into participants' feelings about bird sounds and traffic sounds, as these were the two most frequently discussed topics. The hearing aid cohort has an additional section on device satisfaction, as this was an important factor to consider in the overall listening experience, but does not apply to the non-HA cohort. The common themes gleaned from the findings are discussed in more detail in Section 4.5 and revolve around the role of contextual cues, the importance of natural sound environments, the impact of electric cars on traffic noise, and how visual cues influence sound experiences. The biggest difference in experience between the cohorts was at the forest corner, with significantly lower enjoyment ratings from the HA cohort. The impacts of this insight are explored further in Section 5.0.

Figure 23

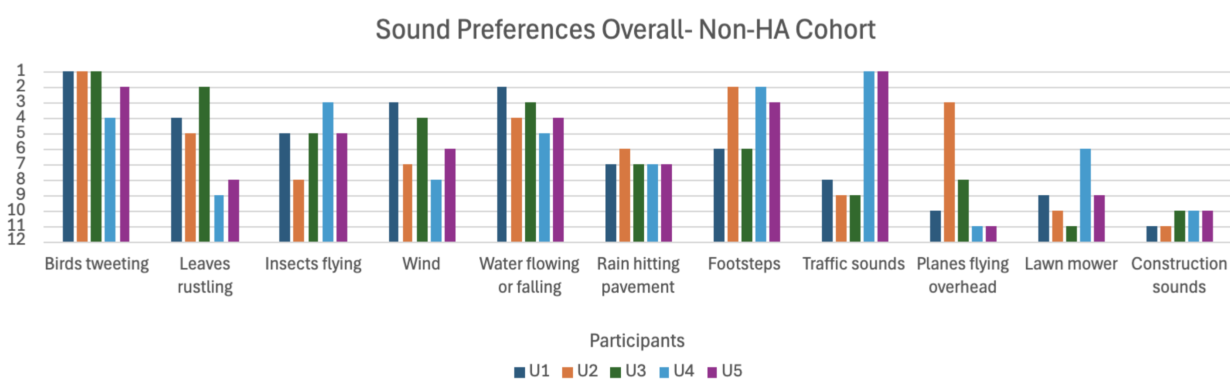
HA Cohort: Overall Sound Preferences from the Pre-Survey



Note. TP A2 did not provide rankings for every sound, which is why there are only four participant rankings for most sounds in the HA cohort

Figure 24

Non-HA Cohort: Overall Sound Preferences from the Pre-Survey



4.3 Hearing Aid Cohort

4.3.1 HA Device Satisfaction

To open the results gathered from the hearing aid participants, I would like to highlight the successes my participants shared regarding how their hearing aids had positively impacted them. I make it clear throughout this paper that hearing aids are not perfect devices; however, I also want to emphasize that they are still valuable tools that bring joy to many of their users. Throughout the conversations I had in May and June of 2024, I heard many beautiful stories about how hearing aids had positively impacted the wearers I was working with. It is important to take a moment to reflect on these successes as well; even if there are differences in the listening experience of hearing aid and non-hearing aid users, this work is and continues to bring a lot of good to millions of people. This only deepens the need to continually improve hearing aids, as sound has the potential to evoke such profound feelings of joy and connection.

TP A4 shared during the interview that they were very content with their HAs, stating, "I am very happy to have my hearing aids, even though I think maybe I am one of the borderlines that can get along without them, but especially [...] for presentations and stuff like that. Oh, I'm so happy." They shared a lovely story with me about a sailing trip where they had an experience they would not have had without their devices. TP A4 fell asleep wearing their hearing aids and woke to a unique bird call. They followed the direction of the calls to see a seawall with kingfishers (a type of seabird) scattered throughout. They noted the value of this scene when they said, "I mean, that was really significant, and it stands in my mind forever. I would never have seen it if I had not had my hearing aids on."

TP A2, who has been wearing hearing aids for the majority of their life, said this latest iteration of the Oticon hearing aid "sounds compared to what you could hear when you're younger. Actually, with the new ones here, many situations where I smile, because I get a sound where I just say what was that." They highlight the improvement from past devices, showcasing the importance of their continued development when they shared that they felt the Oticon Real HAs were "100 times quicker now to react than for just three years ago. And that's a big help." Finally, in hearing those sounds, sometimes for the first time since they experienced their hearing loss, they noted that they often pause, "and then I listen again. And then I smile because this was what I had 30 years ago."

4.3.2 Thoughts on Birds - HA Cohort

All of the participants had a lot to say about the different birds on Eriksholm's campus. As this study occurred in May and June, the birds were quite active throughout the ERC. There are three key questions to consider when looking at the participants' reactions to hearing birds. Are the birds present, are they distinct, and are they important to hear/does it elicit any feelings? Each participant from the HA cohort contributed to answering these questions. While everyone acknowledged that they could hear the birds at one point or another throughout the soundwalk, some shared that they had more difficulty. TP A2, affected by the strong winds during their session, noted that "When the wind was very hard, the birds [were] not there." They said this was particularly noticeable at the bus stop, saying, "I don't know when we were standing with the bus place if there was any birds saying anything because I couldn't hear anything [but] the wind and the traffic." They also articulated that this was a "minus," indicating that they wanted to hear the sounds of birds. TP A2 further expresses this desire when they later say, "The one of the thing, which gets me happy, that's when we are in the forest or something and you hear the blackbird." This last statement highlights that they are familiar with the call of a blackbird, but they did not note hearing it during the soundwalk, despite the majority of other participants saying they did.

Participant A4 acknowledged both the presence and distinction of bird sounds when they said, "Yes, there [were] very many birds. But I did hear a blackbird." They further indicate the importance of hearing these bird calls by using “my birds” to indicate a sense of possession: "But the most important thing when I'm wearing these is my birds.” TP A3 shared the hearing aid's impact on their life by saying, "Before I started out with a hearing aid, I never heard a bird, couldn't hear them." Not only was TP A3 able to identify the presence of birds with hearing aids, but they were also able to distinguish between different calls. However, it is unclear to what extent: "I cannot tell which type they are, but that's because of my poor, poor knowledge about birds. But I can tell that it's different sounds."

TP A5 shared a similar sentiment about how their hearing aids had given them the ability to hear birds again when they stated: "[Without my hearing aids] I wouldn't hear the birds. The amount of birds, some of them are weak and some of weren't, but I wouldn't hear all of them." However, their ability to distinguish bird calls was not entirely restored by their hearing devices as they noted sometimes confusing bird calls with insect sounds: "Some places I heard the wind, but I could see there must be some wind noise, and some insects and birds, maybe it can be kind of it can be difficult to know if it's birds or insects." Here, TP A5 also notes that they look for visual cues to help understand what a sound might be. This idea will be further explored in Section 4.6.3.

Finally, participant A1 indicated that they could “discriminate that [there] were different birds,” but they also stated: "I don't think I heard any black birds because that's very significant." It is unclear whether any blackbird calls were present during their soundwalk. However, TP A2 conducted their soundwalk on the same day and also did not note any blackbird calls, despite their familiarity with them. In this situation, referring to the recordings has the possibility to clarify whether this particularly identifiable call was present. It is also possible that since these two soundwalks occurred in May, with the next one following nearly two weeks later, some changes in the natural soundscape occurred due to the variables discussed in Section 3.6.2.

4.3.3 Thoughts on Traffic - HA Cohort

The most discussed sound from this study was the level of the traffic that came from the road directly across from the ERC. These traffic sounds brought up feelings of irritation and annoyance. Still, some participants also listed traffic as a necessity to hear, as it provides a sense of safety, knowing where a car might be approaching. These contrasting feelings are displayed in Figure 25, which compares the ranking preferences of bird sounds versus traffic sounds. Following the approach of observing the birds, the results will indicate whether a participant experienced the presence of traffic, how distinct that presence was, and how they felt about it. One specific aspect of traffic, electric cars, will be explored further in Section 5.2, as most participants had unique thoughts on their presence compared to the standard wheels on pavement noise associated with typical traffic.

Starting with TP A3, they specifically noted that at the bus stop, “You could hear the difference from the size of the car, how speedy they were” and contrasted this to how the traffic sounded in the courtyard, saying “it was one long, continuous car noise, like a waterfall.” They also noted that the forest corner was their favourite stop because their back was to the traffic, thus reducing those noises in favour of more natural sounds from the forest. TP A5 also noted that "There were differences between a truck or little car” at the bus stop, indicating that being that close to the street did allow for successful distinction between vehicles. They also shared their feelings about traffic, saying the sound is “...uncomfortable and [that] traffic is often like a curtain in the background, who hides the speech, for instance, or other sounds I want to know... to hear.” This word “curtain” was used to describe traffic from many participants in both cohorts, along with similar words like “constant,” “hum,” and “dominating.”

Participant A1 was an outlier in sharing their experience of traffic being dominant even at the forest corner location. They also noted that "the bus stop is very close to discomfort. Because of the very heavy traffic." They clarified that this discomfort was caused by the volume of the noise rather than the type of noise itself. Most notably, TP A1 shared that they think “all locations are very similar because of the traffic.” This particular statement is compared to other TPs' thoughts in Section 4.6.1. It is clear from this participant’s perspective that traffic was indeed present, but they do not elaborate on the distinctiveness of these traffic sounds, only highlighting “one very noisy heavy truck” at the bus stop. This could perhaps indicate that the traffic sounds were not appropriately distinguished when the hearing aid was trying to filter out the noise, but it could also indicate the influence of the participant’s tinnitus, as they did state that it was particularly noticeable at the bus stop and tower due to the high volume.

TP A2 was similarly nondescript when stating that they heard traffic, simply writing “traffic or car noise” for each stop. However, similarly to TP A1, they did say that they were able to distinguish between trucks and cars at the bus stop location specifically. This participant felt that hearing traffic was important to their well-being because they were active cyclists. They even shared a strategy to help with the inability to distinguish where a car was coming from while they were cycling, stating that they use a digital system with a sensor that visually indicates when a vehicle is approaching. They state that this system helps prevent the shock that comes with having cars narrowly pass them while they are unaware of their presence until they can feel that closeness. TP A2 did not rank all of the sounds provided in the pre-survey, so it is not possible to directly state how important they feel hearing traffic is to them, however, based on what they shared with me in their pre-survey, they made it evident that it remains important for them to maintain awareness of their surroundings.

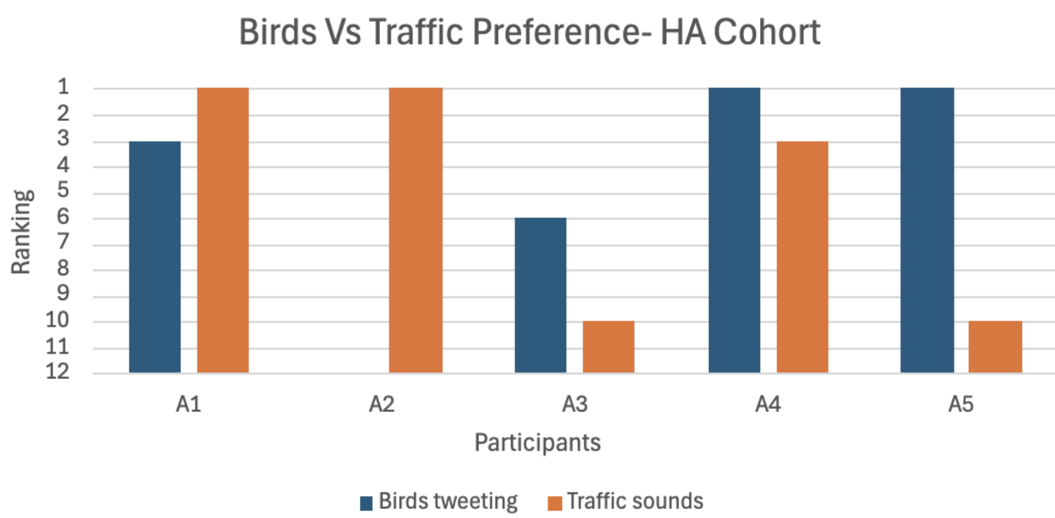
Finally, TP A4 spoke of how traffic sounds were overwhelming them during bike rides:

> Sometimes when I do a bike ride, then sometimes I take them out, but I do like to have them on if it's not too much traffic. Because there is so many sounds that you can enjoy when you also bike but traffic is always in the way.

Here, they are stating that traffic sounds can be so loud that they would rather remove their HAs than listen to that sound. This is in spite of their ranking of traffic as one of the top three most important[5] non-speech sounds. Throughout the soundwalk, this participant noted that the traffic was “annoying” and even said they would prefer to move somewhere else when asked to comment on the disliked sounds at the bus stop. TP A4 was the only participant in either cohort able to identify electric cars as a unique sound at the bus stop and was the best in the HA cohort at distinguishing between cars and trucks.

Figure 25

HA Cohort: Bird Versus Traffic Sound Preferences



Note. See Figure 23 for rankings of all sounds listed in the pre-survey

4.4 Non-Hearing Aid Cohort

4.4.1 Thoughts on Birds - Non-HA Cohort

The non-hearing aid cohort also had much to say about the presence of birds throughout the study. As will become evident in the following quotes, there is a general trend among participants to be more descriptive in reference to these bird calls, even specifying the location in space from which the sounds originated. This is something that is not seen from the HA cohort. Further speculation on this particular observation will be presented in Section 5.3. These participants’ statements will also be considered from the perspective of presence, distinction, and importance.

The first participant to consider is TP U1, who self-identifies as a “bird-watcher.” Blackbirds again come up with this participant, who describes them as "[sticking] out because...

5 This participant, TP A4, put “wind”,” traffic” and “leaves rustling” all as the third most important sound, indicating that they are of equal importance to them.

they have such a long song." They also note that they mostly listen to blackbirds due to this distinction and say they have heard a blackbird on the forest path, at the bus stop, and on the tower. In their written survey responses, TP U1 distinguishes between birds by labelling them as “bigger” or “smaller” and describing their calls as “warbles,” “chortles,” or “chirps.” They also indicated their preference for hearing bird song, as noted in four out of the five locations, where they wanted to hear more bird song during those listening stops.

TP U5 made specific reference to where the bird calls were coming from, saying that "the birds were easy to identify where they were, if it was to the left, to the right, or high or low." While TP A3 from the HA cohort wrote that they heard birds from “all directions,” it was only participants in the non-HA cohort, such as TP U5, TP U2, and TP U3, who specifically referenced being able to identify the direction from which the bird sounds were coming. TP U5 also described the call of a blackbird, stating that it was “very high [and] its sound is very sharp. It takes over the room.” Note the use of more precise descriptors as well. Finally, TP U5 also indicated a preference for bird sounds, saying, "I like the birds tweeting."

The next participant, TP U2, who also noted the directions from which bird calls were coming, shared that:

> ...with the birds I did hear, you know, separate birds, solo birds, and also from different directions. So I would say the birds were generally very distinct. Depending a little bit, depending on exactly where we were at, but quite distinct and clear. I heard them very clearly. - TP U2

This participant indicates both the presence and distinction of the bird calls in this quote, emphasizing the clarity with which they heard these bird calls. TP U2 states their explicit preference for the sounds of bird calls when they said, “You know that I like when I'm outdoors. Birds tweeting is very... it's a beautiful sound to be aware of the surroundings and be outside. …that's a part of being in nature." This statement aligns with the broader trend of participants appreciating nature, which will be further explored in Section 4.6.4.

TP U3, like TP U1, indicated an interest in bird identification: "I often listen to the birds, because I've always taken interest in that so I can depict what bird is, just by listening to it." Interestingly, TP U3 commented numerous times on how prevalent but unexpected the bird calls were during each stop, noting, “I didn't expect to hear so many birds here, up [on the tower], as we actually did." They later commented about the courtyard location that

> Even though we are behind the castle, that takes a lot of the traffic noise away, I would not have expected myself to be able to pick up the birds from the distance… But again, I would have thought that it would have been the traffic, even though it was behind [us in the courtyard], [that] the cars that would take the scene, but actually the birds were more [present] than I expected. - TP U3

This participant also wrote their answers about what sounds they use, specifically referencing the direction from which they heard the bird calls (and other sounds present in the soundscape). This was unique, and when I asked for their reasoning, they said, "It was just so distinct," further confirming their keen ability to distinguish specific sounds and, in the case of this analysis, bird sounds.

Finally, TP U4 demonstrated their ability to identify the presence of and distinguish between different bird calls. While they discuss the bird sounds they heard during the study more in passing, being more concerned with the amount of traffic noise they experienced, TP U4 is able to identify specific bird calls, like a dove. They do not indicate such evident distinction as other members of this cohort, as they only note the different kinds of calls in the forest corner, otherwise opting for simply noting "bird song" on the list of sounds they heard at each stop. They indicate their interest in bird song when they wrote in the survey, "Being such a huge fan of bird song, the birds singing," in response to which sounds they would like to hear more of. While all but one of the quotes from participants in either cohort about birds mentioned the tower (just TP U3), it is still important to note that TP U4 did not complete the tower stop due to the weather conditions on the day of their soundwalk. This means they did not experience, nor have the chance to comment on, the birds at that location.

4.4.2 Thoughts on Traffic - Non-HA Cohort

The feelings of irritation experienced by the HA cohort in response to traffic noise were also present in the non-HA cohort. There was a common theme among participants in this cohort: being surprised at how loud the traffic noise was during the soundwalk, considering they worked at the ERC every weekday. This cohort also had similar mixed opinions on the importance of traffic, with rankings varying from 1 (most important) to 10 (out of 11), as shown in Figure 26. This could be in part due to their own interpretations of the word important, but the descriptions of the traffic by multiple TPs in this cohort as stressful, extreme, or inescapable indicate the negative influence that the level of traffic noise had on each participant (Figure 22).

The participant, TP U5, reported the most negative experience of the bus stop, citing its high volume of traffic noise, in this cohort. Interestingly, they had ranked traffic as the number one most important sound in the pre-survey. This participant shared:

> I believe it is felt more and if the [volume of the traffic noise] is higher, [then] you are under pressure. My heartbeat actually also started. I felt it more at the bus stop. So my full body was actually in a stressful situation.

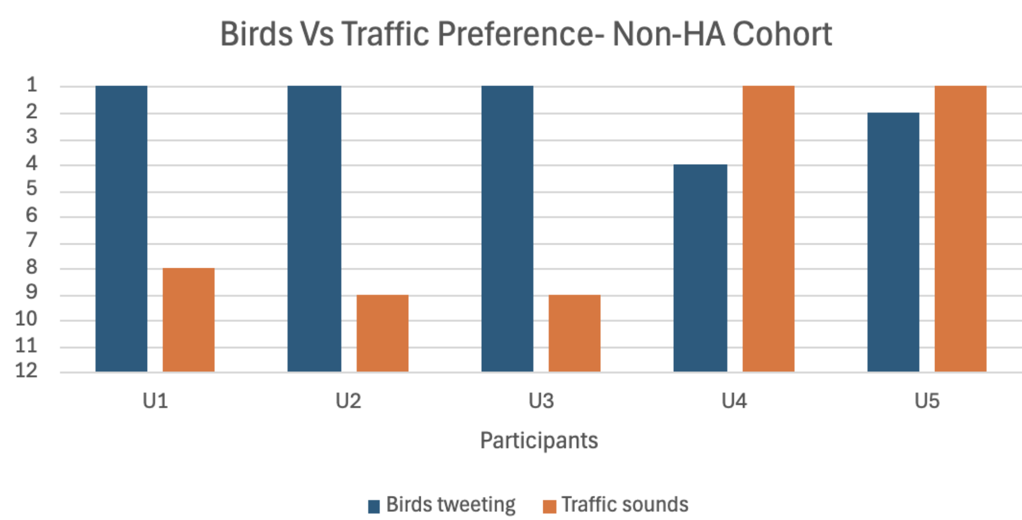
This participant described the traffic at the bus stop as being varied, with the ability to distinguish between smaller cars and trucks compared to the tower. They described the difference as the tower being "like a block of noise." However, they were still able to distinguish trucks, cars, and even motorcycles at that location. They did not say the tower caused the same physical stress effects as the bus stop.

TP U1 noted the "blend" of traffic sounds but also said, "When you're close to [the road], you can't help but [hear] the different kinds of sounds." This is shared with the HA cohort, who, in their interviews, mentioned that the bus stop had distinct vehicles rather than those in the courtyard or the forest corner. This TP also labelled the traffic as "annoying" and wished that it was gone for most of the stops. They also highlighted that the volume of traffic was unexpected and that they felt surprised by how loud it was. TP U2 shared this surprise, saying, "I mean, there was really nowhere we got, that I got rid of the traffic noise, which was a bit to my surprise." They also noted that the courtyard was louder than they had expected, recalling their frequent lunches there throughout the summer months.

TP U3 expressed the differences between the locations as going from "one extreme to the other" when they said "from like the bus stop down to the forest corner [...], they were very distinct differently, because the traffic noise was either extremely prominent in one of them and not very prominent [in the other]." This participant later explained that the traffic was impossible to get "rid of," even at the forest corner. This is a sentiment shared by TP U4 who stated that "the road is just taking over every experience [they're] trying to have […] listening to other things."

Figure 26

Non-HA Cohort: Bird Versus Traffic Sound Preferences



Note. See Figure 24 for rankings of all sounds listed in the pre-survey

4.5 Comparison

4.5.1 Differences in Enjoyment Ratings

In the questionnaires that participants filled in for each soundwalk stop, there was a question asking them to rate their preference on a scale of 1-7 for how enjoyable that stop was. At the beginning of this paper, I hypothesized that the HA cohort would have lower enjoyment ratings due to the known disparities associated with experiencing sound with hearing aids. This hypothesis was mostly correct, as the HA cohort ranked some locations significantly lower than the non-HA cohort. However, there were some unexpected values within these rankings as well. Given the preference for low traffic levels, the location with the highest enjoyment rating would be the forest corner, and the lowest would be the bus stop. While that prediction did come to pass, the bus stop was actually rated slightly higher in enjoyment for the HA cohort, which was unexpected. The difference between the average ratings among the cohorts is only 0.2, which is not significant enough to indicate that one cohort truly preferred the location over the other. However, it is interesting that the values are so close. See Figures 28 and 29 for the specific values.

Given the overwhelming traffic noise at the bus stop, it would seem logical that hearing aids might exacerbate the situation by overamplifying the noise; however, this does not appear to be the case with the participants in this study. This suggests that the WHS and other noise removal programs are effective in extremely noisy scenarios. Traffic is also a semi-dynamic sound, but it is mostly constant in effect. It can thus be handled predictably by a hearing aid, unlike background speech that hearing aids might be able to decipher meaning from and thus focus on inappropriately. Background speech is currently known to pose the greatest challenges to hearing aid developers in determining what speech to focus on, so the hearing aids may be better equipped to handle this less complex background noise.

The forest path was one location that the non-HA cohort preferred significantly more than the HA cohort. Since the forest path and courtyard were halfway between the back of the campus and the road, I was uncertain how participants would feel about them. Since the courtyard has buildings shielding some of the traffic noise, it is likely the more preferred location compared to the forest path. However, the dramatic differences in preference across the forest path and courtyard locations were unexpected. The non-HA cohort preferred the forest path more than the courtyard, whereas the HA cohort had the opposite preference. The ratings from each cohort varied the most within the cohorts themselves, for the non-HA cohort rating between 2 and 6 and the HA cohort between 2 and 7. For the forest path, the difference in the average enjoyment ratings between the cohorts was 1.4. To put this into context, all other ratings differed by less than one, highlighting how much more the non-HA cohort preferred the forest path specifically.

The difference in preference for this specific location is unclear, though, given what is known about how hearing aids process sounds, it can be inferred. Because the forest path was a unique stop, with participants facing one ear towards traffic and the other towards a natural environment, it is possible that the traffic noise was amplified across both devices, overpowering the natural soundscape. Since HA participants had primarily symmetrical losses, no difference can be attributed to that; however, the non-HA cohort had a participant with left-sided hearing loss, the same side facing traffic. One could expect that the rating for that location would be abnormally high compared to the others due to the diminished traffic sounds from the hearing loss, but this is not the case as that participant (TP U1) ranked their enjoyment for the forest path as a 5.5, the same as TP U3 and close to the six that TP U2 and TP U5 gave. This further confirms that the lower enjoyment ratings are likely due to the listening experience provided by the hearing aids.

A final notable difference is that HA participants gave the forest corner a lower overall rating compared to the non-HA cohort. The HA cohort ranked the forest corner an average of 4.7, unlike the 5.4 from the non-HA group. There were two participants, one from each cohort, who experienced (unexpected) construction noise at this location, and they both gave approximately the same rating. There were also two participants, one from each cohort, who experienced high levels of wind at the forest corner, with gusts of 9 mph; however, both participants rated this location the same. Excluding those four participants with comparable values, there are distinctly lower ratings from the HA cohort, which relates to the experiences they shared with me in the final interview. For example, TP A1 rated the forest corner a four, which is understandable given that their experience was hindered by their tinnitus and potential overamplification of traffic, as discussed in Section 4.3. Since the remaining participants from each cohort's ratings cannot be explained by external influences that occurred for their specific listening situation, this provides further indication that hearing aids were not providing an equivalent enjoyable listening experience to that of the non-HA group.

Figure 27

Average Enjoyment Rating: Comparison Between HA and Non-HA Cohorts

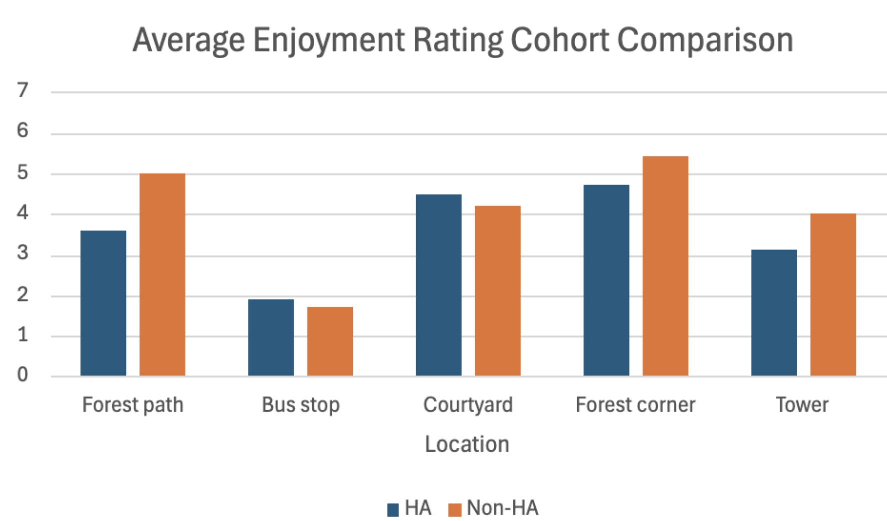


Figure 28

HA Cohort: Enjoyment Ratings by Location

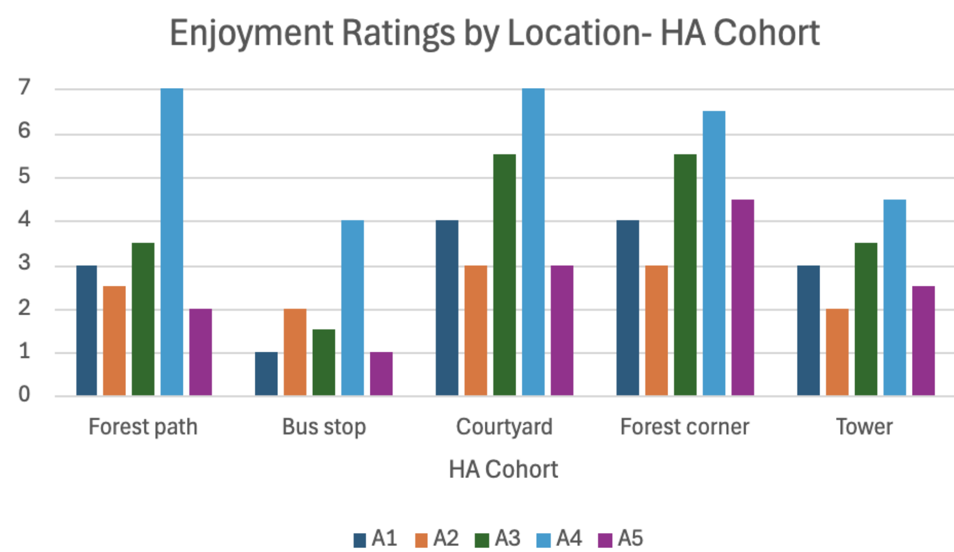
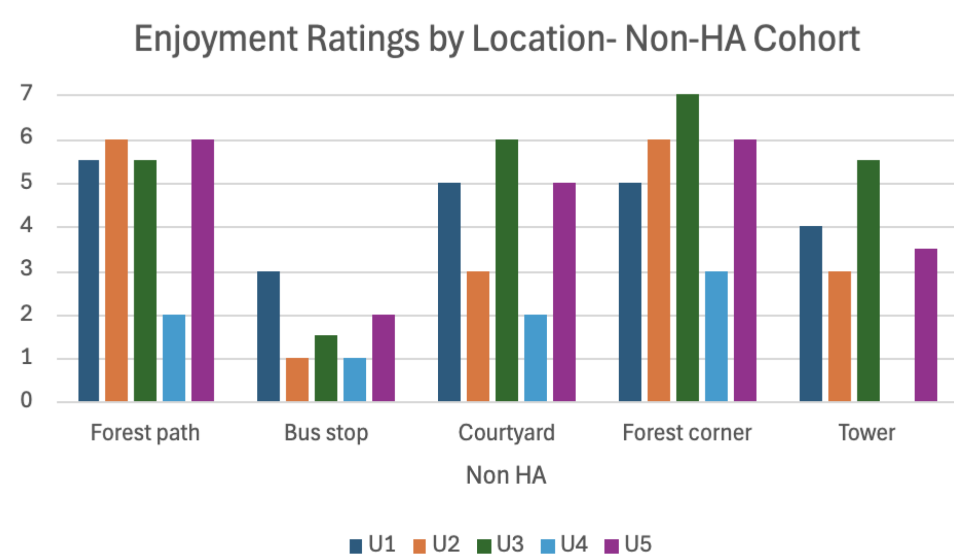


Figure 29

Non-HA Cohort: Enjoyment Ratings by Location



4.6 The Influence of Specific Interests

Throughout the study, participants shared with me their unique interests that influenced their perspective on their surrounding soundscape. It became evident that these interests played a role in how the participants ranked sounds in terms of importance and described sounds they had a particular interest in. As discussed further in Section 5.3, there is a strong possibility that participants with a vested interest in certain sounds would be more descriptive, having been exposed to and more familiar with these sounds in their daily routines. While the interest in birdsong may have been the most common, some more unique interests can explain some of the more distinct rankings in the sound preferences pre-survey.

Many participants ranked the airplane sounds below the halfway mark as least preferred sounds (see Figure 30), but TP U2 ranked it as their third most preferred sound. When I inquired about this in the interview, they said:

> I'm a bit of a plane nerd. I like to observe planes. So I usually like the sound. I mean, they're usually, by this, I mean not, loud planes, but just, you know, distant sounds from planes. I always identify and look up to see them.

This particular interest explains why TP U2's ranking was so different from that of the other participants. Others thought plane sounds were mostly unnecessary, with TP A3 sharing, "Planes flying away… that I don't need, but it's ok," and TP U1 saying, "Planes overhead, I think I generally try to just ignore. They're not interesting to me." While a plane did not pass by during TP U2's soundwalk, it did during TP U5's, however, they did not notice it. TP U5 speculated that it was likely because they had their eyes closed, referencing again the importance of visual cues. The other explanation they gave was that the sound was "less or the least, yeah, the least important to me, thinking of Corona[virus], we had no planes for a long time." This suggests that, given their limited interest in planes and minimal exposure to them during the pandemic, TP U5 was less likely to notice them, whereas TP U2 was due to their interest.

The most descriptive participant was TP U3, who shared interests in bird calls, trees, and motorcycle engines. This participant was responsible for twelve unique words to describe sound and was a part of the non-HA cohort, a longtime ERC staff member. As such, they were very familiar and comfortable with the campus, in addition to having unique interests in particular sounds. This participant described themself as "a little forest nerdy" as they were aware of all the different tree species present on campus. This led to detailed descriptions of leaves, so rather than most participants saying they heard "leaves rustling," TP U3 said:

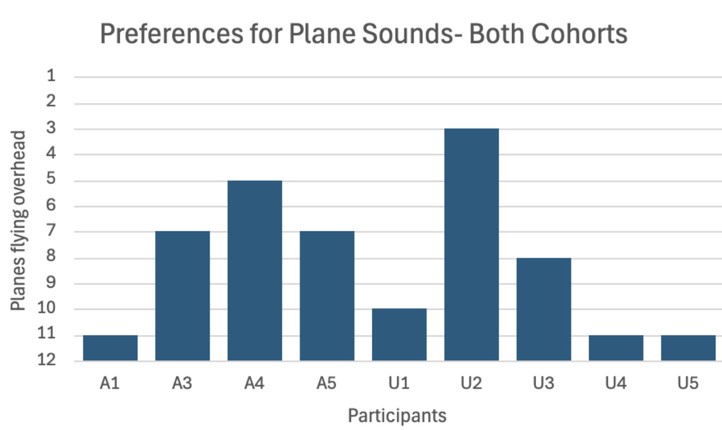
> "We do have some, some special type of willow tree. [...] Very tall, and the leaves are like, like, this size on a very short twig or a very long twig, means that it rattles a lot. And you can actually hear on a very long distance, and I could easily pick that up immediately when I came down."

TP U3 provided the most sound descriptors, but not by a significant amount compared to others in their cohort. They only had three more than the next closest participant in the non-HA cohort. However, this is a significant difference from the HA cohort, as there were six additional words compared to the next closest in that cohort and twelve words fewer than the participant who provided the least amount of descriptors. One interesting thing to note is that the participant with the fewest descriptors for sound, TP A2, provided the most descriptors for their feelings. This is worth further exploration in future projects related to Section 5.3, as it highlights another challenge that participants with hearing loss face in describing sounds specifically.

Finally, while the participants in the hearing aid cohort did not mention many specific interests tied to sound, there is one particular participant worth highlighting. TP A5 was registered in a class that taught students to become more aware of the sounds in their surroundings. This seemed to be a mix of a mindfulness exercise and a form of aural rehabilitation, the latter of which the participant was keen to access. They said, “I haven't practiced a lot, and it was, it was not because of my hearing ability, but I thought it would be nice to try. It might help the hearing ability to train the listening to surrounding sounds.” TP A5 had only attended the first two to three sessions out of a much longer course (around eight weeks), so they felt that they had had the opportunity to develop their listening skills to a lesser extent. However, it may have still had an impact on their experience of the soundwalk study. They said, “I think it’s the training… it had made me more aware of the sounds in your surrounding, that’s why I should be aware.” This ties back to the value of contextual cues, but interestingly, it does not align with ranking traffic or footstep sounds as more important. This could be due to their interpretation of the word important, or another unknown influence. It would be interesting to conduct this study in tandem with the hearing awareness course and evaluate any differences in participants’ ability to notice and describe soundscapes from the beginning to the end of the course.

Figure 30

Both Cohorts: Preferences for Plane Sounds



4.6.1 Thoughts on Soundwalk Stops

The first test person who participated in my soundwalk, a hearing aid user, spoke to me throughout the stops and during the interview about how every location was dominated by traffic. This was shared during the post-interview with this thought: “I think all locations are very similar because of the traffic” - TP A1. Because it was my first soundwalk of the study, I became concerned that the locations across Eriksholm were not differentiated enough, as indicated by this participant. The next test person, TP A2, also reported that the wind dominated any sounds not related to traffic, making it challenging to identify other sounds, such as birds. They said, "It was a pity because [the wind] was so constant in the test all the way." However, after further thought and discussion with colleagues, I realized that this TP’s experience is not necessarily indicative of the study locations, but rather of how much their hearing aids were amplifying the traffic noise. Soon after that first soundwalk, TP A4, another hearing aid user, mentioned unprompted, "I think you did a good job on picking different places where the different sounds were present."

When comparing these experiences to the non-hearing aid cohort, they echo TP A4’s thoughts:

> But some of [the locations] were more different than others, like from one extreme to the other, from like the bus stop down to the forest corner, you call it in the backyard, they were very distinct differently, because the traffic noise was either extremely prominent in one of them, and, and not very prominent. - TP U3

> Oh, I think the different places sounded very different, in that the level of the traffic with respect to the other sounds varied quite a bit. So that was the biggest difference, is how much or how loud was the traffic noise. - TP U1

These participants indicated that the traffic noise was limiting in what other sounds they could experience, but ultimately noted that this noise was how they were able to differentiate between each location. This reaffirms the original purpose of selecting each location based on its varying level of traffic noise and distance to the main road. It is also interesting to note that none of the non-HA cohort participants commented on the similarities between locations, unlike the two HA cohort participants. This could indicate a difference in the listening experience due to the use of hearing devices, which can over-amplify wind and traffic noise.

4.6.2 The Importance of Contextual Clues

A frequent discussion that I had with my participants was around sounds that provided context; this could be context for where someone is in space, or where someone else is in reference to yourself, or what other things might be around you. The most debated sound for desiring it for context, but also finding the sound itself unpleasant, was traffic. Each participant’s thoughts on traffic are covered in depth in Sections 4.3.3 and 4.4.2 for the HA and non-HA cohorts, respectively. However, some clear contradictions can be observed between the discussions and the various rankings provided. TP U4 summed up their thinking around what sounds they considered necessary when they said

> And especially those two [footsteps and traffic], I think differ from all of the rest, by containing information that concerns me, where birdsong or rain or also wind, they wouldn't direct all the other sounds would not direct attention to me, right? Or maybe require my attention, but those two would potentially, that's why I did prioritize them that way.

TP A3 commented that they felt being able to hear footsteps was “necessary… because it gives you security.” However, unlike most other participants in the HA cohort, they said that they “don’t need” traffic sounds, ranking it a ten out of eleven of least importance. Later, TP A3 said, “There's also the risk of not hearing the traffic these days, where we have all these electrical cars, I cannot hear them. And that's a problem for me. That's a problem for you” perhaps indicating that traffic sounds are still important for providing context. This could indicate that this participant interpreted the traffic sounds they were asked to rank as simply road noise they would typically hear from their house or workplace, for example.

TP A1, who also ranked traffic a ten out of eleven, stated that general traffic sounds, like those experienced waiting on the side of the road at a bus stop, are not important. However, they stipulated that traffic sounds while they are driving are very important to them. So this ranking, similar to TP A3, still demonstrates a need for traffic sounds to provide situational awareness in specific scenarios. TP A1 did rank footsteps more highly, sharing that they wanted to hear “if somebody was coming up from my back.” TP A4 found footsteps less useful and more annoying, saying, “It sort of annoys me when I can hear myself walking around in the house.” TP A5 also shared the sentiment that footsteps are not so important, ranking it a seven out of eleven, the lowest of all the participants.

Many of the non-HA cohort spoke to the importance of footsteps for providing contextual clues. TP U2 ranked it the second most important, stating, “I like to be aware of other people around me, so therefore I appreciate the sound of footsteps.” TP U1 noted that leaves rustling can also provide context, as it could be associated with the sound of footsteps, and ranked that as the fourth most important sound, with footsteps in sixth place. They thought that both footsteps and leaves rustling were “useful for sort of knowing there are others around you.” TP U5, who ranked footsteps in the top three but traffic as the most important, expressed similar feelings about the importance of both sounds for providing context. They said, “I like to hear if somebody is approaching; footsteps, maybe I can feel that another person is in the room or but still, I think it's important to hear the footsteps compared to not hear them.”

4.6.3 The Impact of Visual Signals

Many participants shared the need for visual cues, but the HA cohort spoke to its necessity more. A visual cue is referencing anything that participants saw that might have indicated that something was making a noise or where that noise was coming from. For example, TP U1 commented: “I could see the leaves were blowing, but I couldn't hear them for a while, and I thought, Wow, I'm not even gonna be able to write that down. But there was enough, I guess the wind picked up and I was able to hear it.” They saw the leaves moving and knew they were creating sound, but they were unable to hear it over the traffic noise.

TP A3 spoke the most about relying on visual cues. This makes sense given their history of hearing loss, as they became hard of hearing as a child and likely developed heightened visual acuity to compensate (Alencar et al., 2019). They stated the importance of visuals and how that can impact the overall soundwalk experience: “[at the forest path] you look into the forest, if I would have turned around and I could see the traffic, it might have been different. It's also something to do with the visual.” When asked about the quietest sound they were able to hear, this participant relied on their visual sense to pick it up, saying, “It’s only because I could see it was there.” Furthermore, this participant noted the amount of listening effort they put in at each location:

> If you look at the trees and you see that there was a little wind out there, and you see the leaves, then you can hear the sound [and] concentrate on it. If I couldn't see it, most likely I wouldn't say it. So that's very common. It’s the visual things.

TP U5 tried concentrating as TP A3 did, but closed their eyes in an effort to focus solely on their auditory sense. However, this led to them missing an airplane that flew overhead. They speculated that they missed it because they closed their eyes, again indicating the importance of visual cues for identifying different sounds. After personally reviewing the recordings, it was hard to tell if the plane was audible, emphasizing the need for visual confirmation. TP A2 also spoke of intensely concentrating, but instead felt that it helped them identify more sounds, saying that they only noticed the sound of the groundskeeper working due to this focus: “It was only because I was really concentrated because otherwise I wouldn't notice that at all.”

Seeking out visual confirmation of a sound is a common behaviour among humans (Recanzone, 2009). It is especially important for Deaf and Hard of Hearing individuals, as they rely on captions, lights, or sign language —a visual language — to navigate the world. When I was a co-op student working for a hearing aid company in 2020, I wrote about the importance of this topic for the UX Collective based on my direct observations after interviewing people with hearing loss (Faulkner, 2020). This continues to inform my current work, providing a written copy of the interview questions for participants to reference, for example. It is also inherently part of the soundwalk experience, where participants are strategically positioned to face certain directions as part of controlling both the auditory and visual scenes (Aletta & Kang, 2016; Jeon et al., 2013).

When participants experienced a quiet sound that they were not able to confirm visually, they expressed uncertainty and a desire to find its source. There is a small stream running through the forest beside Eriksholm's campus, with its most active section just through the trees at the forest corner location. I had hoped to make it a more prominent feature during the soundwalk, but its location was inaccessible, surrounded by a steep embankment and a lot of fallen trees and other debris. To my surprise, three participants identified this feature despite the distance and ever-present traffic sounds. TP U5 was not even sure if it was water, only after I confirmed that the stream was there did they say, "the water, I would say [was the quietest sound I heard], because I wasn't aware if it was just the faraway traffic or it really was the water running." TP U1 also felt uncertain to the point where they thought they were "fooling [themself]" as it "could have been a fan or something." One of the first questions they asked during the discussion about the survey results was whether there was a stream, as they were still wishing for confirmation of what that sound had been.

There was even one participant from the HA cohort who heard the water as well. They said, "It's really funny because it was right at the end. I don't know if it was a frog that leaped or… I just heard a little water sound." This particular insight led them to reflect on their hearing ability, speculating: "I wonder if that little water sound, if I would have heard that without my hearing aid." No other participants from the HA cohort identified a water sound, but it poses an interesting question as to whether they would have been able to see the stream if they had identified the water. Multiple participants stated that the traffic in the forest corner sounded similar to rushing water, so it is possible that the sound of rushing water was mistaken for traffic.

4.6.4 Appreciation of Nature

Another, more implicit question to be addressed by my research is to gauge the desire for improving the listening experience of non-speech environments. While previous studies have already articulated the benefits of listening to natural soundscapes, it is worth noting that many participants in this study directly commented on this benefit, sharing how they often sought out opportunities to be in nature and listen. Because hearing aid companies typically focus only on speech comprehension, it is essential to emphasize the value that non-speech scenarios bring to individuals' lives. Most participants from both cohorts shared the importance of being active outdoors, either through walking or cycling, and the value that natural sounds brought while doing those activities.

TP U4 most profoundly stated that natural environments are important to experience because "To me, nature is confirming tomorrow. Some things are recurring and that's nice, also springtime. So life confirming." TP U2 shared their value of nature, describing natural environments as "soothing": "And if I get the impression of being in nature, then, you know, that's very soothing. [There] are other things [like] water trickling or something like that, that gives me the same feeling." The value rankings of natural sounds that participants shared can be further examined in Figures 31 and 32. These charts look at how natural sounds were ranked in direct comparison to other sounds, such as traffic, construction, and lawnmowers. As previously discussed in both cohorts' thoughts about traffic (Sections 4.3.3 and 4.4.2), there are still non-natural sounds that are deemed important and thus preferred by the participants.

One participant, TP U3, shared a unique revelation they had when reflecting on the influence of natural sounds in their life. They are an avid runner and shared that they had previously tried listening to music while out on their runs, but quickly decided against it. They said:

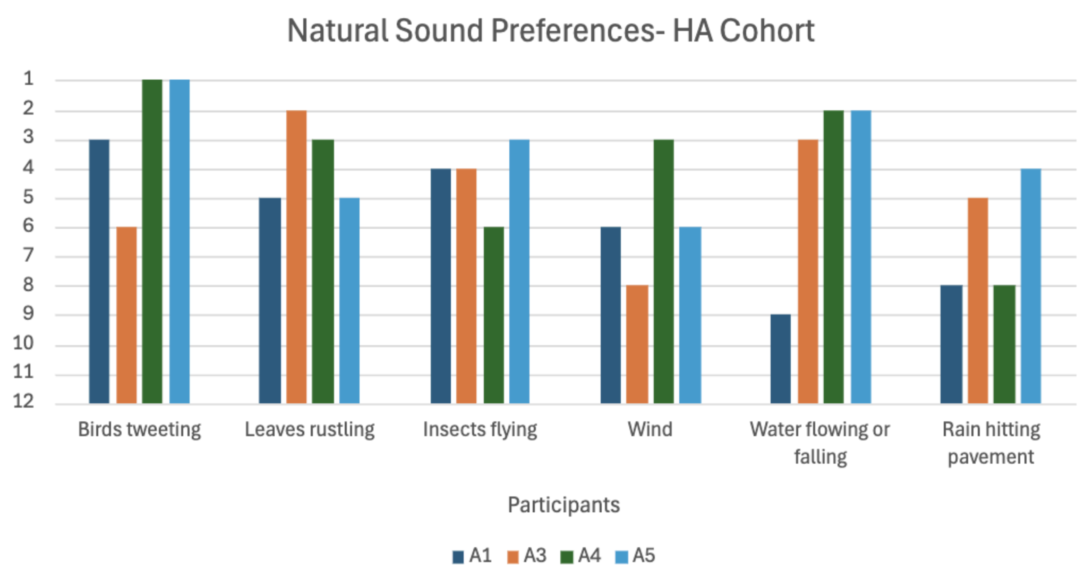
> I actually think that one of the reasons why [I don't listen to music when I run] is also because I actually enjoy, even though I'm running, I'm enjoying to listening to the nature around me. [It is] actually stressing [to listen to music when I run], to be honest, and I think that's just a realization that, that the sound of the nature is more important to me than anything else.

Not only did they find that they did not like listening to music while running as a general sentiment, but they later understood that the reason behind that feeling was the desire to experience the natural soundscape around them in its entirety. They later concluded this sentiment when they said, "So nature sounds [are] important to me, and I appreciate them."

Participants from the hearing aid cohort also shared their lifestyles, actively seeking natural environments, with TP A2 explaining that they often went on walks to improve their mood: "I have problems, I go alone [to] walk in the forest alone, just to feel what I can feel. Of course [when I am] exercising, being free in the nature … when I come home again, I'm still happy." TP A4 shared that they often also go on walks, specifically sharing that they wear their hearing aids: "I do a lot of walks… I really like to have my hearing aids with me [when I walk]. For the most part." This same participant also said they actively seek out notable natural sounds, such as when it rains: "But if I open the door, you know, the rain hit the leaves. It is everything." The passion with which TP A4 shared that statement struck me, as it was evident in the interview and later, when playing back the recording, that the participant extremely valued this particular experience.

Figure 31

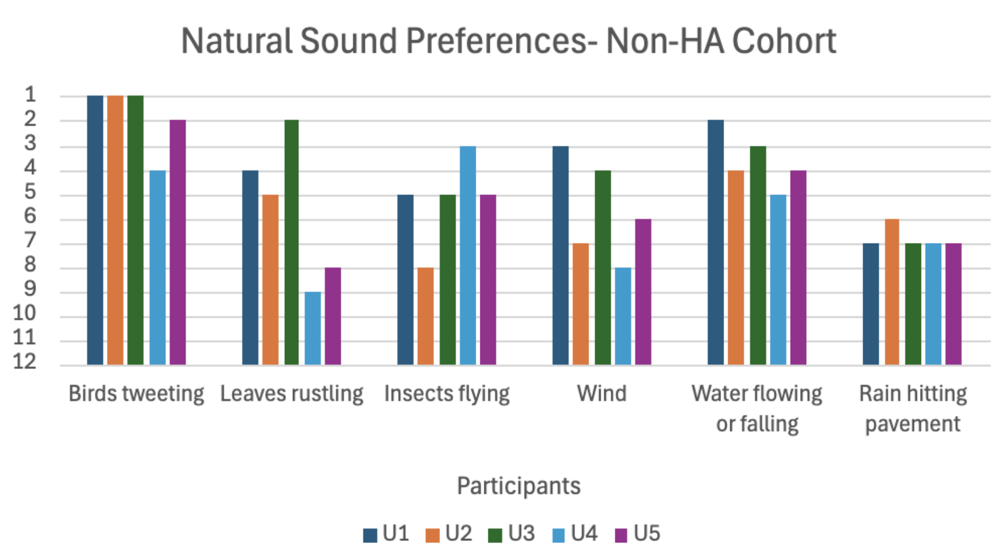
HA Cohort: Natural Sound Preferences



Note. TP A2 did not provide any rankings for natural sounds, which is why there are only four participants in Figure 31.

Figure 32

Non-HA Cohort: Natural Sound Preferences



5.0 Discussion

The following section aims to address research question one: How do the listening experiences of hearing aid users compare with people without hearing loss in more specific detail? It will then try to answer the secondary question: How might any differences in listening experience between the two study groups be addressed? This will be achieved by examining the various factors that affect the listening experience, including tinnitus. Differences across the cohort will then be analyzed in more detail before proposing a model to influence future hearing aid research and design.

5.1 Mitigating the Impact of Tinnitus

Before the study began, I spent some time considering where tinnitus fit into this research. People with hearing loss are more likely to experience tinnitus and experience it more intensely (Oosterloo et al., 2020), which could impact their ability to perceive a soundscape beyond what their hearing aids are capable of processing. TP A5 confirmed the presence of their tinnitus as “always there” when listening to nature. However, this same participant also stated that their hearing aids helped reduce their tinnitus because they provide access to sound, which can mask the tinnitus. The Oticon Real HA does have a tinnitus masker feature available; however, none of the participants had this activated.

There was one participant from the HA cohort who experienced intense tinnitus throughout the study, TP A1. They were the participant who led me to change the order of the soundwalk locations after that first study because of how the bus stop had triggered their tinnitus so much that it influenced the entire rest of the soundwalk. Notably, this is also the participant who told me that all of the locations sounded almost the same. When they told me this, they believed it was because the traffic was equally loud at each location. While this is possible through over-amplification of certain frequencies or simply a difference in listening ability, tinnitus may still have had a significant influence on their survey results.

This issue of tinnitus, despite typically being associated with hearing loss, also impacted TP U5 from the non-HA cohort and their listening experience. They wrote that it was present at every stop, typically listed as the second or third loudest sound they noticed. Unlike TP A1, TP U5 was able to identify more differences between locations. This could again point to specific hearing aid challenges for TP A1, but it is impossible to compare the two participants’ levels of tinnitus to determine the actual impact it had on them.

As tinnitus can impact the experience of a natural soundscape, future research should carefully factor it into the soundwalk design, due to its ability to mask natural sounds. Future research could also examine the use of a tinnitus masker during soundwalks to see whether it is able to improve the overall experience. This would be interesting to explore with the non-HA cohort, as they also experienced tinnitus that impacted their listening experience.

5.2 Thoughts on Electric Cars

Electric cars came up during multiple interviews, much to my surprise. While only one participant specifically mentioned it in their survey questions, which they noted during the bus stop location, it still came up in interviews without any prompting from me. This could be because the word ‘traffic' encompasses all types of cars, and electric cars are newer and thus more front of mind (Van Wee et al., 2012). Most interestingly, electric cars were often mentioned in a concerned manner, as participants who felt that traffic sounds were provided important contextual cues worried that they would be unable to hear the engineless cars. As quoted in Section 4.3.3, TP A3 emphasized the problem:

> There's also the risk of not hearing the traffic these days, where we have all these electrical cars, I cannot hear them. And that's a problem for me. That's a problem for you. You don't know if they're right behind you or... Just like when you have ambulances or other things, it can be difficult to find out which direction to come from.

TP U5, from the non-HA cohort, also believed that electric cars increased the risk to pedestrians when they said, “We have a lot of electrical cars, and the sound from these, I believe I have heard it's added, because we were totally quiet, and you couldn't hear them, and then you had all the accidents.”

TP A4 spoke to the coping strategy of being especially vigilant for electric cars around car traffic: “There was a lot of electric cars there [where I lived for ten years]. And when I came back, you know, I was looking around all the time because I was used to looking for the electric cars.” However, TP A4 and TP U3 both commented that, even though electric cars do not make as much noise, the sounds the tires make on the road are still audible. Because tire sounds are mostly audible above 45km/h (Shi et al., 2025), and the road near where the study was conducted was a highway with a speed limit well above that minimum, the fact that participants still had trouble hearing electric cars is perhaps indicative of the need for the cars themselves to make sound.

On the other end of this issue, for hearing aid users, car noise is often a significant challenge when trying to communicate while driving. Electric cars, however, provide a much quieter interior, making it easier to engage in conversation. TP A2 spoke to this issue when conversing with their partner in the car:

> In the car when my [partner] is beside me saying the first word in a [sentence], I couldn't hear the first word because the hearing aids should first recognize that oh, now they're coming speech in between the noise. And then it wakes up but before it does that, you lost the beginning of a speech.

TP U3 commented on the benefits of the quiet car, despite having an interest in motorcycle engine sounds, sharing “I also enjoy riding my electrical car...which is pretty quiet, which I think is really nice, something that I appreciate almost every day when I'm driving, if I don't listen to anything.” This benefit can be quite meaningful, as some participants spend a lot of time in their cars travelling for work; however, many countries are mandating that electric car manufacturers add artificial sound to address concerns about low audibility and thus increase awareness of electric cars. It is unclear if this benefit of quieter car interiors is mitigated by the addition of artificial noise, at least at low speeds.

Although the exact risk of the silence of electric cars remains unclear, preliminary studies have suggested an increased likelihood of pedestrian-car collisions involving hybrid and electric vehicles (Pardo-Ferreira et al., 2020; Ashmead et al., 2012). This issue has been under debate for over fifteen years, when a notable and often referenced study, dating from 2009 on hybrid and electric vehicles was published (Robart & Rosenblum, 2009). From my research, it is clear that participants feared the risk, regardless of whether the risk has increased as electric models are becoming more popular.

This concern is shared with blind and low-sighted individuals who rely on their hearing to navigate streets safely (Kim et al., 2012). Thanks to the strong advocacy of organizations representing blind and low-vision people, electric cars are easier to hear now than they were when they were first released on the market. Still, it is essential to consider how hearing aids process these new sounds, as they are unfamiliar and often vary between car models (Government of Canada, Canada Gazette, 2022). More research is required to ensure that hearing aids can reliably react to the sounds emitted by this new generation of cars, in order to alleviate the concerns that my participants, and likely many other HA users, experience.

5.3 The Use of Descriptive Language

The non-hearing aid cohort was generally more descriptive in their sound observations, using more precise words to describe what they were hearing, as seen in Figures 18, 20, and 22. This can be observed in Section 4.4.1, which compares bird calls, as well as in Section 4.4.2, which discusses traffic. The HA cohort’s descriptors can be seen in the word clouds featured in Figures 17, 19, and 21.

There are several possible explanations for this difference, which will be addressed in turn. The first is the differences in language ability between the two cohorts. The non-HA cohort was both more proficient in English (on average) and, as employees of the ERC, potentially more primed to use sound descriptors compared to the HA users. Having a higher language proficiency would allow for more precise language to be used, for example, “birds” versus “tweeting, warbling, chortling.” The second possibility is that the non-HA cohort had more participants with an interest in specific sounds, like birds, trees, planes, and engines. TP U2, TP U3, and TP U1 all indicated their keen interest in identifying birds and their associated calls. Having this interest could mean that these participants were already advantaged over others in providing more descriptive sounds for those areas of interest. One thing to ponder, from which nothing can be concluded from such a small sample size, is why no one from the HA cohort had an interest in birds. TP A3 even described birds as “annoying.”

Finally, the most intriguing explanation, which certainly warrants further study, is that perhaps the HA cohort was less descriptive because they lost some of their ability to describe sound at some point in the progression of their hearing loss. Increasing research is emerging on the connection between hearing loss and cognitive decline, which may also contribute to this relationship (Babajanian & Gurgel, 2022; Uchida et al., 2018). It is important to note, however, that all participants in the HA cohort had completed and passed a Montreal Cognitive Assessment (MoCA) screener, indicating no cognitive decline. In a 2016 paper, Castiglione et al. noted that cognitive testing scores from the participants in their study improved after regular use of their hearing aids, providing further justification for pursuing this line of inquiry. It is also plausible that hearing aids and hearing loss result in a restricted set of frequencies being available to an individual, making sounds less nuanced. A 2021 study noted that participants with hearing loss were less able to identify "sound textures," defined as sounds related to wind, water, insects, and other natural phenomena. The study clearly states that hearing loss overall negatively impacts an individual's ability to perceive environmental sounds (Scheuregger et al.). These thoughts are the most promising line of questioning that resulted from this study. Should a link between hearing loss and the ability (or lack thereof) to describe sound be discovered, this could introduce a whole new area of aural rehabilitation as people aim to rebuild their lost language.

5.4 Improving the Experience of Hearing Aid Users

The goal of this study is ultimately to benefit HA users, so it is necessary to consider what can be done to enhance the benefit of hearing aids to their users in non-speech environments. Beginning with the differences observed in the experiences between the HA and non-HA cohorts at each location, it is evident that some overamplification may be occurring for traffic and wind noise. Based on the sound rankings and the participants' preferences for how much each provides necessary context, wind is not so important, but traffic is to some. While the Oticon Real has an improved WHS, it may need to be adjusted to improve non-speech-related sound processing, as it is currently optimized for speech (Gade et al., 2023). To truly understand the current available technology for WHS, a similar study using the Oticon Intent hearing aids would be necessary, as this model represents the next and current generation of Oticon's WHS.

The development of electric cars and determining the sounds they emit at low speeds is also an area that can benefit current and future HA users. Working with people who have hearing loss and associated advocacy organizations, such as the Canadian Hearing Society, has the potential to improve the sense of safety that HA users have in car-centric areas. There is potential for audiologists to educate their clients about the risks associated with not hearing these types of cars and to provide strategies to mitigate that risk. For example, when a client receives a hearing aid for the first time, the audiologist could suggest being more deliberate in areas with cars to ensure the client visually confirms a vehicle and is not relying solely on their hearing.

Another area that has the potential to improve the experience of HA users is external to the device technology and instead related to the differences observed in this study around the ability to describe sounds. This would require future follow-up studies, as this insight was an unexpected finding that my study was not designed to explore in full depth. While my research has yielded preliminary findings on a HA user's ability to describe the sounds around them, various intervention methods can be explored in future research. For example, there is the possibility that offering a class similar to one that one of my study participants was enrolled in to become more aware of their surroundings may provide some benefit in addressing the potential loss of language. How this also ties into cognitive ability and hearing loss's impacts on dementia is yet another possible area that could improve the quality of life of individuals experiencing cognitive decline from age. While the most significant improvement for hearing aid technology will be the implementation of artificial intelligence, this research suggests a need to explore other solutions to enhance the experiences of HA users.

5.4.1 Applying the COM-B model

The COM-B model stands for Capability, Opportunity, Motivation, Behaviour, and is a behavioural science method applied when trying to change individual engagement with a particular habit. Companies typically use this model to gain a deeper understanding of the factors that influence a client's decision to use or not use their product. Hearing aid companies would strongly benefit from using this model to best serve their users, as it ensures all their needs are being met in a way that naturally leads to the desired behaviour of wearing a hearing aid.

The primary issue that hearing aid companies currently face is the low adoption rate of the devices (Simpson et al., 2018). There is still a significant stigma and numerous challenges associated with Bluetooth connectivity, high prices, and unrealistic expectations that prevent the majority of people who could benefit from a hearing aid from wearing them (McCormack & Fortnum, 2013). The research from this study helps to understand the motivation behind hearing aid wearers, informing where to target marketing and product development. The user's listening experience is crucial in maintaining and motivating the behaviour of wearing the hearing aid, which provides the benefits of improved cognitive function and a reduced risk of cognitive decline.

Current hearing aid development does not emphasize using HAs for enjoying nature, instead focusing on speech. Preliminary research has shown that environmental sound awareness and speech recognition are related (Harris et al., 2017), indicating the need to consider both issues in device development. The issue with focusing intently on speech is that it can then lead to a detriment in non-speech sound processing. However, this study successfully established that HA users do have a desire to hear natural sounds. In addition to the value of contextual cues, natural sounds serve as a good motivator that could potentially increase the uptake of new devices. HA users experience both speech and non-speech environments every day, hearing more non-speech-related cues simply by going through the world as is. If their hearing aids are not optimized to process those sounds, then a significant part of the device experience is diminished.

Four of the HA cohort participants had been wearing their hearing aids for over twenty years and were committed to the devices, not only out of necessity but also out of habit. But the fifth participant, who had only been fitted four years prior to the study commencing, showcases the importance of motivation. This participant, TP A4, got their hearing aids because they wanted to be able to listen better to university lectures. The second reason was that they wanted to hear the sounds of birds. They were motivated to wear their HAs because they often went on solo walks and wanted to engage with the sounds of nature.

The concern shared about electric cars also highlights the capability portion of the model, as HA users do not have the hearing ability to identify electric cars and therefore feel more at risk of the dangers of being in proximity to those cars. When considering the application of COM-B for hearing aid uptake, capability mostly references the ability of someone who could benefit from a HA to be able to purchase it and physically wear it (Oosthuizen et al., 2022). But when considering the desired behaviour as engaging with the HA (to *best* benefit from it), capability can be around what abilities the HA users achieve from the devices. The motivation may be to engage with speech environments better, but long-term satisfaction and recommendations to their friends and family relies on the whole experience, specifically in non-speech environments.

TP A2 shared a story with me that highlights the impact of positive device experiences and their potential to encourage more device uptake. TP A2 was the longest HA user in the HA cohort and shared a lot about their feelings related to their devices. They told me that they had a friend who needed HAs and had purchased them, but did not want to wear them. The friend felt it was too hard to adjust and too difficult to set up. So TP A2 spent a weekend setting up the HA app and working with their friend to get more comfortable with the devices, and now the friend uses them regularly. TP A2 was likely more motivated to help their friend because of their own improved listening ability with their hearing devices. They also said that when they go on walks, sometimes they can hear things that reminds them of when they were younger and their hearing loss had not progressed as much. This was specifically in reference to non-speech sounds like birds and leaves rustling. It brought them great joy to have those experiences.

> When you make a noise from your shoes, the wind comes, when the birds are singing, when the wind takes the blades… and so it's what you remember from when you were younger. [...] Actually, with the new ones here, many situations where I smile, because I get a sound where I just say 'What was that?' And then I listen again. And then I smile because this was what I had 30 years ago.

I learned of this model from Sylvia MacSpaden, a fellow OCAD graduate who presented on COM-B at the Blend Design Conference in 2025. While my project does not delve into the specifics of a new HA user's journey or explore the multitude of reasons why someone chooses to wear a hearing aid, I felt it was essential to introduce this model to non-speech sound prioritization in HA development as it is typically used in the HA user's journey (Oosthuizen et al., 2022). Hearing aid uptake is ultimately beyond the scope of this project, but it does intersect with this project when considering why users choose to wear the devices or not, as sound quality and device satisfaction are huge indicators of success (Bannon et al., 2023; Kaplan‐Neeman et al., 2012). As such, future HA research should consider this model when investigating the benefit of optimizing devices for non-speech environments, as the greatest benefit may be realized by attracting new users. I think following the mapping exercises created by designers to better understand consumer motivation and its ties to behaviour and product engagement could shift the future market. While there is still much to overcome in terms of stigma and high prices, the introduction of lower-cost OTC products and a surge in Bluetooth earbuds will quickly transform the industry landscape.

5.5 Implications of the Research

The outcomes of this project can be applied to numerous solutions directly impacting the experience of hearing aid users today. The primary takeaway should be that hearing aids are not fully restoring the ability to hear natural sound environments, and hearing aid users want and prioritize non-speech sounds as key contextual and emotional experiences. This project can be applied to artificial intelligence solutions, as detailed in Section 2.2.5, but can also be applied to another, more niche area of remote device fitting. Currently, the majority of prescription hearing aids are fit in an audiologist's office (Polonenko et al., 2010), completely isolated from natural sounds. Considering how much of a priority it is to hear these sounds for wearers, and the lack of optimization and utilization of existing features, such as WHS, in current HA programs, evaluating the device in environments the user experiences in their daily lives could lead to a better and more personalized program. Given the rise in remote programming due to the COVID-19 pandemic, this is an interesting application of soundscape research that warrants further investigation in future studies.

A secondary implication of this research relates to the methodology itself. This study was done following a combination of ISO soundwalk methods. This was a successful methodology that I would personally continue to use for future studies. While there were aspects of the data collection process that could have been improved upon in my study, having standards to follow ensured a higher-quality procedure and mitigated many potential issues with the study, given my early stage of development as a researcher. Future research into the combination of these methods and their success as a technique for working with HA users would be beneficial to HA development.

5.6 Contribution to Inclusive Design

This project is being completed in partial fulfillment of the requirements of the Master of Design—Inclusive Design program at OCAD University. Although it does not follow the traditional inclusive design research methodology of co-design, it remains pertinent to the field. While disability studies and, consequently, studies on hearing loss are integral to inclusive design, this project also incorporates other aspects of the field.

This study was designed within an inclusive design context, as I was actively involved in inclusive design education at the time of its creation. This results in some differences compared to if I had come from, for example, a background in acoustics engineering or artificial intelligence and machine learning research. The inspiration for this study was to explore non-traditional hearing aid sound environments, partly due to my understanding from prior interactions with HA wearers that they often find themselves in many different acoustic situations that simply are not accounted for in current device development. This requires seeing HA wearers as whole, complex individuals with different interests and uses for their HAs beyond conversations (particularly in restaurants, as HA designers typically focus on). It also means the research was constructed from the beginning with the wearer in mind, rather than the technology. What is most important in this study is looking at how hearing aids contribute to an individual's sense of safety in their surrounding environments, as well as the joy that they can get from having certain frequencies restored.

5.7 Reflections on the Research

This study would have benefited from a pilot due to the flexibility of the interview questions from ISO and the cultural and language differences amongst the cohorts. As a result, there are some changes to the existing study questions in Appendices A to E and study logistics that would improve future research. Some of these changes would improve the participant experience by making things clearer. Other changes would be more beneficial for data collection, making things more relatable and thus easier to articulate. I was also very flexible throughout the study process, which is, of course, important, as nothing will run smoothly every time; however, there are some things that I should have tried to collect instead of dismissing them. The following are a collection of suggestions for future research based on what I learned during my study:

5.7.1 Interview and Survey Questions

1. Changing the ranking of the pre-survey to make "rain hitting pavement" more relatable. Two participants commented that pavement was not relevant in Denmark, as the streets are primarily made of brick, and suggested that rain hitting leaves or the roof of their house would be a more effective question. Most participants placed this "rain hitting pavement" sound in the middle of their rankings and did not comment much about it. This further indicates the lack of relatability to the sound and potential improvement by changing the wording. The following quotes are relevant to this particular issue:
    a. "It's funny the rain hitting pavement is an interesting one. And to me, that's sort of a neutral sound. Rain hitting the roof or the windows, I think is a pleasant sound, but rain hitting the pavement, I don't know why... to me that's sort of more neutral." - TP U1

   b. "But on the pavement, you know, there's no pavement anywhere." [reference to me asking about rain hitting pavement] - TP A4
2. The pre-survey would have been better as a formal interview before beginning the soundwalk, given the challenges participants faced in writing their answers and the benefits of a discussion in building trust with the participants before starting the walk. Having the TPs write their answers in silence led to some awkwardness and did not start the study on the best note.
3. The pre-survey question asking if participants would get a complete sense of their surroundings was useful, but the wording led to short yes/no answers. This meant I had to prompt them to explain more during the interview, losing the opportunity to understand their thoughts in the moment and potentially leading to them changing their reasoning after completing the study. Rephrasing this question to prompt a more detailed response and incorporating it into a pre-interview (see point 2) would have remedied this issue.
4. Adding a question in the pre-survey about which program the HA participants were actively on before beginning the soundwalk would have cleared up some confusion and is a necessary change for any future projects involving HA participants listening with their devices. There was at least one participant who, after the soundwalk, we realized may have had the program on that lowers the volume for surrounding sounds, which could have impacted their experience during the soundwalk. While this participant did not seem to have a different experience compared to the other hearing aid users, knowing this for sure would reinforce a higher quality of study.
5. The questionnaire given to participants to evaluate each soundwalk location would have benefited from clearer demarcations of one to seven rather than just having tick marks to indicate those values. Participants tended to respond in half-steps or use the scale as a slider, rather than providing absolute values, which made interpreting and comparing the data among cohorts more challenging.
6. The questionnaire asked participants what sounds they would like to hear more or less of. Since every participant responded "traffic" for less and "birds" for more, it was not very insightful from a researcher's perspective. To remedy this, I think having a question that asks for specific descriptors of sounds they like the most or least could address some of the issues with uncertainty around language ability and prompt more unique answers from participants.
7. The ISO recommendations for method C (interviewing) focused on collecting an understanding of the participants' home listening situations. I chose not to do this as asking questions about previous activities can lead to a lot of bias in response and misrepresentation. However, looking back at the interviews, having more questions in the pre-soundwalk discussion about common environments in which participants find themselves would have been beneficial. This would allow for

more accurate sentiments around being in nature, as they would not have been primed to appreciate the most natural environment (by having just been out at the forest corner stop).

8. I spent a considerable amount of time considering the impact of tinnitus on participants, but I found that the actual questions I asked did not quite address what I was hoping to learn. From the initial participant profiles I had on the HA cohort, they had rated their tinnitus as "bothersome/not bothersome," but those often did not align with what I was told in the interviews. I had been recommended the Tinnitus Handicap Inventory, a standard industry tool to collect participants' feelings, but I did not use it due to an oversight. Having this tool would have given me more confidence in the answers I received from participants about their tinnitus. For future research, I would certainly utilize this tool to gain a better understanding of tinnitus's role in participants' perception of their sound environments.
9. A clear definition of how participants could or could not move their heads or bodies when seeking sound sources would be necessary for future iterations of the study. While I was clear to participants where they needed to be facing, some participants turned their bodies or heads in response to a specific noise. In contrast, others did not, as they interpreted my instructions as not allowing that movement. I tried to get everyone to face only in the pre-determined direction, but I did not stop people from moving. Given the importance of visual cues in the final results, having more consistency among participants would be crucial to ensure similar experiences at each location.
    a. Additionally, the first few participants did not seem to understand that they needed to remain in place for the entire three minutes, regardless of whether they felt they had finished taking notes. Towards the end, I changed the way that I explained the requirement and reminded participants at each location to stay until I instructed them to move. This was more successful, but for future projects, it should be emphasized from the beginning.

5.7.2 Study Logistics

1. Some sessions had to be cancelled or modified due to the rain. After cancelling two sessions only for it not to rain for very long, I decided to forge ahead, but then encountered delays and missed locations due to the rain. Had I had more time and availability, I would have booked participants closer together, as there was a long stretch of really nice weather in which I only ran two surveys.
2. I realized early on that it was impossible to create identical sound environments for each participant, so I needed to focus on mitigating differences rather than trying to control every detail. For example, during two soundwalks, an ambulance passed by. So the sound

of a siren blaring is only going to be noted by those two participants. The number of variables that could impact the soundscape is covered in Section 3.6, but it became clear quickly that those variables needed to be seen as enhancing a participant's experience rather than discrediting the differences. Soundscapes are inherently uncontrollable due to the many aspects that compose them, thus requiring the ability to be patient and work with what is available in the moment.

3. In the first five soundwalks, participants were given questionnaires to take notes on that were not double-sided. This meant they could flip the first page on their clipboards and immediately see the next page. The following five participants had a double-sided sheet, requiring them to flip the entire sheet over, which made it less obvious that there were more questions on the back. While I was there to prompt the participants and remind them of the second side, I think having each sheet individually available on a clipboard outside was the more effective method.
4. The tower was physically challenging to navigate, as it required climbing a steep set of stairs. While it provided an interesting comparison to the bus stop location given its height, for future studies, I think the benefit derived did not seem to outweigh the inability to get the recording and the time it took to get there. Especially with all the changes I would make to the pre-survey and extending the interview, that time would be more beneficial spent elsewhere. I think five locations were a good amount overall, and had the forest itself been more accessible for walking, I believe being surrounded by the trees would have provided just as valuable, if not a more valuable, listening experience than the tower location.

5.7.3 Technical Issues

1. There were some difficulties with the sound meter as it had an auto-shutoff feature that I was initially unaware of. I always noticed the issue quickly, so I would just extend the recordings to the amount of time it was originally turned off for. After the first three studies, I realized that the best way to prevent this issue was to conduct a clap test before asking participants to start actively listening. This just meant that after I connected all the devices, I clapped a few times to evaluate whether the sounds were being registered in each channel. This resolved any further issues, and I believe it is good practice in conducting future recordings.
2. The Klangfinder was not set to the correct ear canal for the hearing aids, meaning all the hearing aid participants did not have recordings through their hearing devices, as was intended. This was a disappointing revelation given all the hard work everyone put into ensuring the hearing aids were programmed on time and fit accordingly. However, the recordings remain useful since they still capture the listening experience at an approximate adult height through two simulated ear canals.

5.7.4 Research Successes

1. The construction of the wheelbarrow, complete with all the necessary equipment and made mobile, was a great success. It was especially wonderful that the setup consistently worked, such that I had very few issues connecting and beginning recordings across all the different soundwalks. Given the numerous pieces that needed to be coordinated, this was quite a feat, made possible only through the collaboration of the wonderful staff at Eriksholm.
2. Despite the aforementioned changes that I would have made with the study questions, there was still a very evident difference between the HA and non-HA participant answers. This bolsters the need for this project in the first place and will hopefully inspire future research in this field of study.
3. While the order between locations was changed after the second participant, the final path that was worked out was ideal for navigating the wheelbarrow around campus and for the starting and ending locations being close to the interview rooms. It also made it physically easier to navigate the heavy wheelbarrow more independently by avoiding going up the large hill on campus during the study.
4. One participant needed sitting breaks, and there were ample spots around my locations where they could rest and take notes between locations. This was semi-intentional, as I knew there were seating areas at the majority of the locations. Had I been more purposeful in creating sitting areas, I would have added one closer to the bus stop, as that was the farthest stretch without anywhere to sit.

6.0 Conclusion

6.1 Revisiting Goals and Objectives

This project began with the goal of comparing listening experiences, leading to a primary research question that was broadly defined, but quickly shifted to focus on non-speech environments, specifically natural versus man-made environments. Throughout the project, the dichotomy of birds and traffic as representations of rural and urban environments highlighted how HAs handle these sounds differently, evoking specific emotional reactions from the device users. There is also a clear need for personalization when it comes to creating the ideal hearing aid, as individual interests can influence a person's listening experience.

To answer the first research question, I originally hypothesized that HA user satisfaction would be higher in soundscapes with minimal background noise. Based on the locations selected for the soundwalk, the preferred location order would be the forest corner, and the most disliked location would be either the bus stop or the tower, due to exposure to traffic noise. This was true with the forest corner being ranked as the most preferred and the bus stop being ranked as significantly less preferred. The average difference in preference between the two stops is quite significant for both cohorts, further reinforcing this conclusion.

My second hypothesis was that non-HA participants would generally have higher satisfaction rates than HA users. Interestingly, this hypothesis was not true across all locations. Participants in the HA cohort ranked the forest path and forest corner significantly lower overall in enjoyment than the non-HA cohort (see Figure 27), but ranked the bus stop and courtyard as slightly more enjoyable. The potential reasons behind this discrepancy are explored in Section 4.5.1; however, the difference is so small that it is not statistically significant. While this does not definitively prove the hypothesis, it still aligns with the overall theory that HA participants experienced lower levels of satisfaction. This is due to the significant differences between the forest path and forest corner, in addition to the near-matched ratings for the other locations. The tower location cannot be fairly compared because one participant in the non-HA cohort did not complete it.

6.2 Future Research

To begin, this research would generally benefit from more cohorts. The ISO recommendation is to have twenty participants and to do the walks in a group setting. While it made sense for my study to have one-on-one soundwalks and interviews, future studies working with soundscapes and HA users could benefit from the group method. Future research would also benefit from conducting the study in the participants' native language to avoid potential miscommunication and provide more clarity on the effect that hearing loss might have on language ability.

Given that one of the primary concerns of participants in this project was about electric car awareness and traffic safety, future research should continue to build on the global understanding of the risks of electric cars. This would provide an opportunity for public safety campaigns or the incorporation of safety discussions in audiology clinics to ensure the risks and fears are being appropriately addressed. This research could also be applied to other populations that may be at higher risk from traffic dangers, such as individuals with intellectual disabilities, children, and newcomers unfamiliar with electric cars. Electric cars were not yet available in 1970, when the World Soundscape Project began. As acoustic ecology is a practice for assessing changes in soundscapes in specific locations, soundscape research must continue as future innovations are introduced, altering the soundscapes of everyday life. Not only is there a cultural aspect to different soundscapes, but there is also a temporal aspect.

Another potential area of research to explore is working directly with cyclists to improve how HAs function in that unique soundscape. Denmark would be an ideal country to continue this research, given its extensive public cycling infrastructure and culture, which ensures a large testing population. Other countries, such as the Netherlands and Germany, would also be great places to continue this work. Multiple participants from this study noted the challenges of cycling as a HA user, which is something worth mitigating from both a comfort standpoint and a safety and awareness of traffic standpoint.

As I mentioned traffic and the necessity of future research with electric cars, I also want to explore bird song and calls, given their importance in my study and to my participants. When I presented my bachelor's thesis in 2023, an attendee visited me afterward and shared an idea for noise reduction that would highlight bird sounds. In this particular example, they stated that the noise reduction algorithm I was evaluating in that project could be trained to isolate specific bird calls, thereby enhancing the sonic experience of bird-watching. I found this interesting and remembered it when I started hearing the study's participants describe the bird sounds and how pleasant it was to listen to. At the same time, one participant found bird noises annoying, so they would not value it or want it to be specifically filtered and emphasized in the same way as another participant with an interest in birds. With sounds causing negative experiences, we need to consider not just how to emphasize the desired sounds, but also how to reduce the unwanted sounds based on the device user's needs. This is particularly relevant in the case of traffic sound, as traffic is seen as vital for situational awareness, but can also be irritating and overwhelming.

It is also important to note that in the year since this project began, the implementation of artificial intelligence and the expansion of the collective understanding of how HA users experience natural soundscapes have already grown immeasurably. This rapidly evolving field is expected to continue growing with the future integration of artificial intelligence. The application of AI may lead to greater advancements in improving the experiences of HA users in natural soundscapes, as discussed in Section 2.2.5. The most promising development in this field of soundscape research is the use of AI models to classify the sound scheme of an environment in real-time and make adjustments accordingly. HAs primarily use a set of heuristics (see Section 2.2.4), unique to the company, platform, and device model, in order to determine how to filter the incoming sound signal at any given moment. I hope that future iterations of these models are trained on more non-speech sound scenarios, allowing them to learn how to make the appropriate adjustments to the incoming signal to better meet the needs of the HA user. This would be unique to their type of hearing loss and the associated fitting prescription, but can be informed by research, such as this study, to guide the prioritization of important sounds.

One of the big takeaways for me as a researcher is the cultural aspect of sound environments. While I discuss this topic in Section 3.6.5, I was really only able to scratch the surface of how culture factors into listening experience and HA device satisfaction. Given how many cultural differences and variables exist in soundscapes, future research needs to explore the relationships between culture, sound, emotional experience, listening ability, and the use of hearing aids. Considering that most HA companies have non-profit branches that provide HA fittings and devices to low-income households (Cook, 2024), it is worth understanding those unique sound environments and further catering HAs to those communities' specific needs. It is also important to work with communities that are not close to major urban hubs, as people living in rural areas are also exposed to dramatically different soundscapes and may have other device needs as a result. One of my participants actually drove three hours to attend the study. They came from the mainland of Denmark to Zealand, taking a six-hour round trip, because they felt this research was so important and they wanted their voice to be heard. This alone indicates the need for this type of research and the necessity to continue expanding our understanding of HAs and non-speech environments.

My own future research will continue to build upon soundscapes and infrequently studied sound environments for HA wearers. I am pursuing a PhD in hearing health rehabilitation science with a focus on pediatric sports and hearing aid wearers. I plan to apply the recording techniques and ISO standards from this project to my future endeavours. I look forward to working with a different participant base, while maintaining a continued focus on HA device optimization through programming or, in the case of helmet sports, physical shape. Remote fitting applications can also be applied to this future research, along with the construction of a sound corpus, which can then be used in future studies to make testing with infrequently used sounds, such as those found in sports environments or natural environments, more accessible.

I plan to apply the knowledge to how access to non-speech sounds impacts the affect of HA users, especially in infrequently examined environments. Many of my research participants used strong words to explain what their ability to hear meant to them. I think future research could benefit more from this approach rather than from using prescription targets alone. Devices will soon be infinitely more customizable, and the industry will have to change the way it fits hearing aids to meet those unique needs. Sports environments are a good place to start because they encompass a wide range of sounds that contribute to the emotional experience of an athlete. Understanding how hearing aids influence that experience is key to better serving athletes with those devices and their connections with the space, the sport, and their team. The next step in my journey will be to start working with youth who wear hearing aids and participate in sports, which will help me better define the direction of my PhD research.

I became interested in this topic at the beginning of my graduate degree, when I had a project that explored the built environment and examined ways to make spaces accessible for HA users. Beyond the issue of HAs being mostly designed for speech, is that the devices are also tested by a very particular community. There is little testing done with people under the age of 50, and even less with individuals who may have other disabilities like Down Syndrome or Autism (Danyluk & Jacob, 2023). While part of this challenge arises from the difficulties in receiving ethics clearance, I think they are also excluded from testing because of the common corporate goal of catering to 80% of the market (*Virtuous Tornado | the Inclusive Design Guide the Inclusive Design Guide*, n.d.). What I truly hope to achieve through my future research and career in hearing science is to serve the 20% who are not receiving the attention they deserve.

Now that I have completed this project, I am better equipped to continue research in this domain with a greater understanding of the impact that non-speech environments have on the overall listening experience of HA users. I remain grateful to my study participants who provided such meaningful insights for this project. This project would not exist without them. I remain hopeful that non-speech sounds will become prioritized in future hearing aid development as the industry's understanding of the importance and value of natural soundscapes grows.

Appendices

A: Questions Given During the Soundwalk

***Note that participants in both cohorts were given a total of five sets of the same questions, one for each location.**

1. List the most noticeable 8 different sounds you are hearing over the next 1-2 minutes. If possible, list them from most to least noticeable.

2. Are there any sounds that cause discomfort or feel overwhelming?

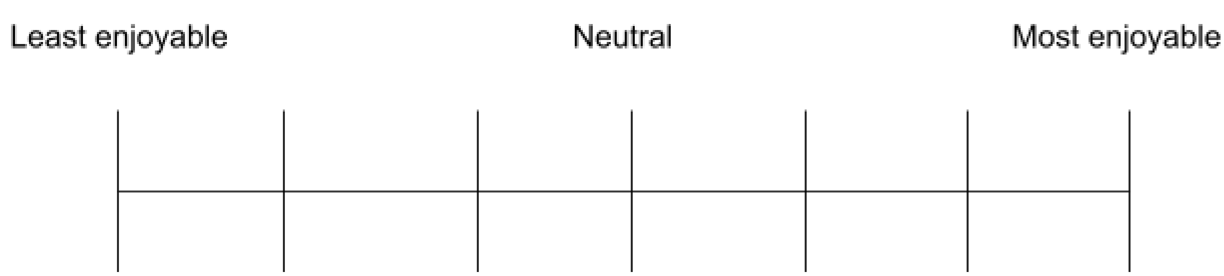
3. Are there any sounds that are particularly pleasant?

4. Do the sounds you heard match your expectations of the area? Why/why not?

5. Are there any sounds you want to hear <u>more</u> of? Please indicate which.

6. Are there any sounds you want to hear <u>less</u> of? Please indicate which.

7. How enjoyable was this listening experience on a scale of 1-7, with 7 being the most enjoyable?



8. Is there anything else going through your mind? Please use this space for notes or any observations.

B: Interview Questions: HA Cohort

Participants are not expected to disclose their health information at any time.

1. Have you ever reflected on your sound environment before? Was this walk a familiar experience or completely novel?
    a. Why have you/haven't you reflected on this previously?

2. Do you experience tinnitus/how did it impact your listening experience?

3. How distinct did each sound feel? Were some sounds harder to identify than others?

4. Were there any additional sounds that you felt were uniquely available to you because of your hearing aids?

5. Was there any sound you were expecting that you felt you were missing out on?

6. You listed in the survey that _____ sound was the loudest/quietest, was this expected given the environment you were in? How did that make you feel?

7. Was there anything unique about this sound environment or were there any unexpected sounds?

8. You noted that ____ caused discomfort, can you describe what that discomfort felt like?

9. You noted that ____ sounded pleasant, can you describe what about listening to that sound felt pleasant?

10. You noted that you wanted to hear more/less of ____, can you explain why you wrote those sounds down?

Final question: Is there anything else you would like to add?

C: Interview Questions: Non-Hearing Aid Cohort

Participants are not expected to disclose their health information at any time.

1. Have you ever reflected on your sound environment before? Was this walk a familiar experience or completely novel?
    a. Why have you/haven't you reflected on this previously?

2. Do you experience tinnitus/how did it impact your listening experience?

3. How distinct did each sound feel? Were some sounds harder to identify than others?

4. Was there any sound you were expecting that you felt you were missing out on?

5. You listed in the survey that _____ sound was the loudest/quietest, was this expected given the environment you were in? How did that make you feel?

6. Was there anything unique about this sound environment or were there any unexpected sounds?

7. You noted that ____ caused discomfort, can you describe what that discomfort felt like?

8. You noted that ____ sounded pleasant, can you describe what about listening to that sound felt pleasant?

9. You noted that you wanted to hear more/less of ____, can you explain why you wrote those sounds down?

Final question: Is there anything else you would like to add?

D: Pre-Survey Questions: HA Cohort

1. How do you feel about wearing hearing aids?

2. Describe a scenario where you would feel discomfort listening to something. How would you address it?

3. What is your general comfort level with your hearing aids?

4. How many hearing aids have you worn in your lifetime?

5. Based on what's been explained thus far, what are you expecting to get out of this experience?

6. Do you think you'll be able to get a full sense of your surrounding environment during this study?

7. Do you make use of different hearing aid programs, and if so, which one(s)?
    a. In which situations do you switch programs?

8. How often do you adjust the volume on your hearing aids?
    a. In which situations do you adjust the volume?

9. Rank the following sounds in terms of order of importance for you to hear (1 being most important, 11 being least important): Importance can be considered either enjoyable or useful.

______ Birds tweeting
______ Leaves rustling
______ Footsteps
______ Traffic sounds (cars driving)
______ Planes flying overhead
______ Insects flying
______ Construction sounds (trucks backing up, drilling, etc.)
______ Wind
______ Water flowing or falling
______ Lawn mower cutting grass
______ Rain hitting pavement

E: Pre-Survey Questions: Non-HA Cohort

1. Describe a scenario where you would feel discomfort listening to something. How would you address it?

2. Do you ever feel you have difficulty listening in certain sound environments/situations?

3. In what environments do you find it easiest to communicate?

4. Based on what's been explained thus far, what are you expecting to get out of this experience?

5. Do you think you'll be able to get a full sense of your surrounding environment during this study?

6. Rank the following sounds in terms of order of importance for you to hear (1 being most important, 11 being least important): Importance can be considered either enjoyable or useful.

______ Birds tweeting
______ Leaves rustling
______ Footsteps
______ Traffic sounds (cars driving)
______ Planes flying overhead
______ Insects flying
______ Construction sounds (trucks backing up, drilling, etc.)
______ Wind
______ Water flowing or falling
______ Lawn mower cutting grass
______ Rain hitting pavement

F: Study Facilitator Guide

Goal

To learn about how people with hearing aids experience a specific sound environment (on the Eriksholm campus) and compare that to the experience of people who do not have hearing loss. This will highlight differences and similarities in the listening experience in order to evaluate the effectiveness of current hearing aid technology in restoring hearing abilities.

Supplies

- 2x clipboards (one for researcher and one for participant)
- Printed copy of Eriksholm consent form
- Printed copy of OCAD consent form
- Printed copy of participant questionnaire to be filled in both before and during the walk
- Printed copy of interview questions for participant to reference as needed
- Phone (Otter.ai recording and weather situation)
- Klangfinder with sound meter and sound card set up in wheelbarrow
- Hearing aids programmed to test participant's audiogram
- Computer with Audacity
- Interview room: Hertz Laboratory or Decibel Clinic

Test participants

- 5 hearing aid wearers from the Eriksholm test pool
- 5 participants who do not wear hearing aids and have no known hearing loss

Summary of Procedure

Participants will be briefed and give written consent before receiving a questionnaire with a couple of questions to fill in first about their expectations. Next, they will be led on a walk through Eriksholm's campus, stopping at predetermined locations for 3 minutes each to take notes and respond to the questionnaire. Participants will then return to the meeting room for a semi-structured interview on their experience during the soundwalk. Finally, they will be thanked, and the assessment will be completed.

Session Overview and Timing

The total time should be around 1-1.5 hours. The soundwalk is 40 minutes, and the interview is 45 minutes.

Agenda	**Location**	**Timing**	**Researcher tasks**

Introduction and overview	Hertz Laboratory	5 minutes	Participant receives a copy of Eriksholm consent, OCAD consent, the questionnaire, and a pencil
Pre-survey and expectations	Hertz Laboratory	5 minutes	Beginning of questionnaire will have questions to be filled in before the walk starts
Location 1	**Upper forest path** Orientation: Facing forward towards corner 5 with one ear on traffic and one ear on the forest side	*Start within 15 minutes of meeting* Walk from interview room to upper forest: 5 minutes Stop in the forest path for 3 minutes	*sound capture *measurement of key variables - *get wind and temperature from the weather underground refreshed for that minute* -notes on participant behaviour
Location 2	**Bus stop** Orientation: Facing forward towards the street	Walk to bus stop from the forest path: 3 minutes Stop at the bus stop for 3 minutes	*sound capture *measurement of key variables -notes on participant behaviour
Location 3	**Centre Courtyard** Orientation: Towards the forest (back to traffic)	Walk from the bus stop: 5 minutes Stop in courtyard for 3 minutes	*sound capture *measurement of key variables -notes on participant behaviour
Location 4	**Forest corner** (near	Walk to forest	*sound capture

	bench) Orientation: Towards the forest	corner from courtyard: 5 minutes Stop at forest corner location for 3 minutes	*measurement of key variables -notes on participant behaviour
Location 5	Top of central tower Orientation: Facing traffic (looking down)	Walk from forest corner to the tower: 8 minutes Stop at top of tower for 3 minutes	*sound capture *measurement of key variables -notes on participant behaviour
Reflection Interview (semi-structured)	Hertz Laboratory	Walk from tower back to the meeting room: 5 minutes Interview duration: About 45 minutes	*Start Otter.ai Participant receives a printed copy of the questions for reference -notes on participant response
Conclusion and thank you	Hertz Laboratory	5 minutes	

Data Capture

- Otter.ai will record and transcribe the interview
- Binaural microphone/recording set up will capture: A-weighted equivalent continuous sound pressure level $L_{Aeq,T}$; C-weighted equivalent continuous sound pressure level $L_{Ceq,T}$ as well as percentage exceedance levels $L_{AF5,T}$ and $L_{AF95,T}$, sound recording through Audacity, hearing aid recording through Audacity
- Pencil and paper for the questionnaire results that occur during the soundwalk

- Computer for the recording of the answers for interview questions (in addition to the transcript)

Test Reset Plan

- Ensure room for next session is booked
- Print more copies of consent forms, questionnaires, or interview questions as needed
- Return sound measurement equipment to storage, making sure it is ready for the next session
    - Wheelbarrow to the shed, hearing aids back to [the ERC audiology team], and Klangfinder and sound meter in the anechoic chamber lab

After the Sessions

- Listen to Otter.ai transcript and correct any typos
- Type up written responses to the questionnaire in a spreadsheet
- Type up notes from the soundwalk and interview (if necessary)
- Upload all of the sound data to the external hard drive

G: Interview Script for Facilitator

Introduction - 5-10 min

*Present participants with:
- Eriksholm consent form
- OCAD consent form
- Questionnaire on a clipboard with a pencil

*Make sure recording equipment is ready and the tower is unlocked

Hi, my name is Sam and I'm going to be conducting the session with you today. Thank you for joining me; I really appreciate you taking the time to be here. I am researching the way that people with hearing aids experience certain sound environments for my Master's thesis in Toronto, Canada. I will be taking you on a walk around the Eriksholm campus to five different locations to have you listen intently in different scenarios.

Do you have any questions before we begin?

We are going to start by having you fill in a quick pre-survey. It has some questions about your expectations going into this study and some of your sound preferences. I will give you a few minutes to fill that out, and then we can head out and begin our walk!

Pause for participants to fill in the pre-survey. Maximum of ten minutes.

Orientation - 5 min

The walk we are going to be doing today is called a soundwalk, as you are focusing on the different sounds around you as you walk. We are also going to stop at 5 key locations for 3 minutes each to get a better sense of that environment. Please follow my instructions to the best of your ability, and don't hesitate to ask if you ever feel uncertain about what should be going on.

Please use all your senses to perceive the space around you, not just your hearing. I'd like you to note sounds you hear, but also what you like or dislike about those sounds and why. The goal is to get a holistic understanding of what your experience, both emotionally and physically, during the walk. I will also ask you to position yourself in specific ways; since this can have an impact on what you hear, please stay in the same position for the duration of the 3 minutes.

There is a space at the bottom for notes, and then each location has specific rating scales and questions. Please consider your listening experience at each location, but listen intently while we walk between locations, too. Feel free to use the notes section to jot down any observations.

*Make sure recording equipment is in place before leaving
Begin walking to location 1: Forest path

Please orient yourself facing the forest with your left ear directed towards the road. We will now stand here for 3 minutes and I invite you to reflect on what you're hearing, seeing, feeling, and thinking. Don't feel pressured to take notes right away, I will give you time afterward to write down your thoughts.

*Start a 3 minute timer and ensure to hit record on recording equipment

Repeat steps for each of the following locations:
2. Bus stop facing traffic
3. Courtyard: Facing fields
4. Forest corner: Back to traffic
5. Tower: Facing traffic (below)

Interview - 45 min

*Present participants with:

- Interview questions for their reference

*Start recording using Otter.ai

Leave room for elaboration. Questions do not need to be answered in order and it is ok to go off script to follow up on particularly interesting points. Focus on overall experience from the walk and the feelings that come along with it.

Go through the pre-survey, questionnaire, and pre-set interview questions.

Conclusion - 5 min

Thank you so much for contributing to my research. You have given me some really valuable insights today. I appreciate your time. Do you have any other questions for me?

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