Evaluating Adaptive Algorithms for Music and Speech Processing in Hearing Aids

Understanding Collaborative Approaches Among Audiologists, Manufacturers, and Users to Improve User Acceptance

A Thesis Prospectus
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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

In the United States, around "30 million people are exposed to hazardous noise at work," and those who attend live concerts, nightclubs, and use personal music players are at risk for noise-induced hearing loss (NIHL) (Fiedler & Krause, 2010, p. 1-2). "Hearing loss has been found in over 52% of classical musicians and 30% of rock and roll musicians," and "over 80% of musicians, if tested just after their performance had temporary music induced hearing loss" (Chasin, 2010, p. 30).

Hearing aids, which are electronic devices that are worn in or behind the ear, are common treatments that help individuals with hearing loss hear conversations and music better by amplifying surrounding sounds. They often require assistance from audiologists to have their hearing aids fitted and adjusted, ensuring the devices comply with the user's hearing loss severities and lifestyles (Venema, 2016). However, as shown in Figure 1, many hearing aid users have reported experiencing difficulties when listening to music through their devices.

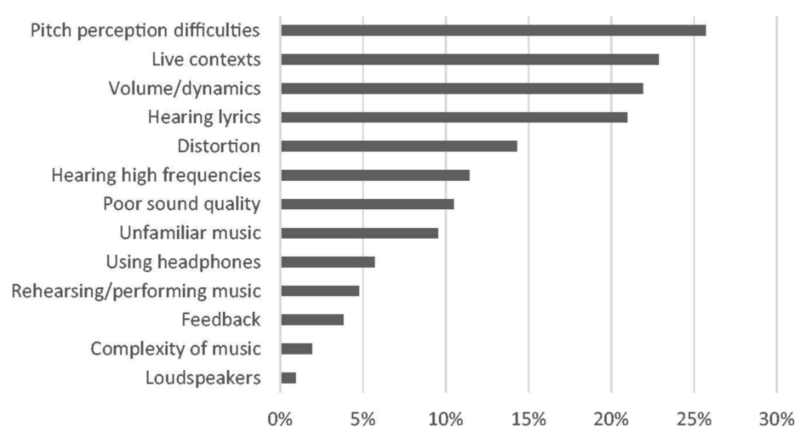

Figure 1. Common Issues Faced by Hearing Aid Users While Listening to Music
The most significant issues experienced by hearing aid users were pitch perception, which involves difficulties distinguishing between different notes and tones, challenges in live contexts like concerts or live performances, issues with volume dynamics, and issues with hearing lyrics. (Greasley, Crook, & Fulford, 2020, p. 5).

Hearing aid settings can be adjusted by audiologists to better process music, but "music is not a required part of any audiology curriculum" (Greasley, Crook, & Beeston, 2019, p. 16). Therefore, it is recommended for musicians to seek out audiologists experienced in adjusting hearing aids for musical settings, but those specialists may not be widely accessible to everyone.

Consequently, a study by Greasley, Crook, and Fulford (2020) showed that difficulties listening to music with hearing aids on have been shown to negatively impact people's quality of life. This is shown in Figure 2 as it shows the responses from hearing aid users who were asked whether difficulties with listening to music using hearing aids negatively affected their quality of life.

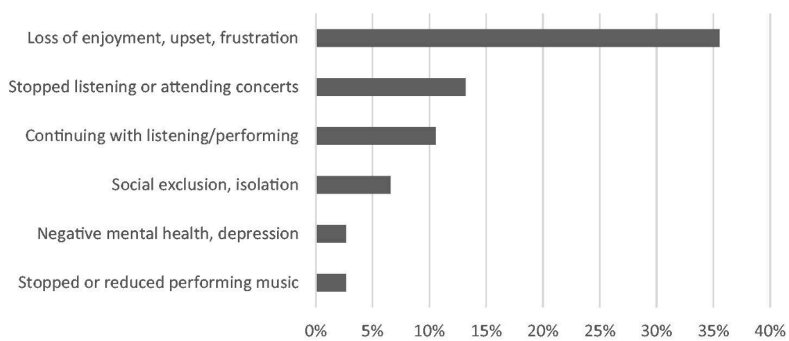

Figure 2. The Effect of Difficulties with Listening to Music on Quality of Life
The most common response was a loss of enjoyment and feeling upset and frustrated (Greasley, Crook, & Fulford, 2020, p. 5).

This technical project aims to evaluate and improve Yin and Chen's (2023) adaptive hearing aid algorithm called PEM-WNPVSS, which is a proposed algorithm that can simultaneously process music and speech. This algorithm can be implemented into hearing aids that can be used by both professional musicians and casual listeners, and can automatically adjust to its environment in real-time, addressing the main difficulties of current hearing aids, which are pitch perception performance in live settings, managing volume dynamics, and improving lyric clarity.

This STS project analyzes existing research to identify the primary concerns of manufacturers, audiologists, and hearing aid users, in order to uncover effective collaboration strategies to enhance the music listening experience for hearing aid users.

Evaluating Adaptive Algorithms for Music and Speech Processing in Hearing Aids

Sandgren and Alexander (2024) explain that current hearing aids are primarily designed with a default speech setting to enhance speech clarity in daily communication, using Wide Dynamic Range Compression (WDRC) to minimize background noise. However, this can cause issues when listening to music because WDRC compresses both soft and loud sounds into a narrower volume range, reducing the detection of dynamic and subtle tones in music (Sandgren & Alexander, 2024). Chasin (2009) explains that to optimize hearing aids for music as opposed to speech, the main differences to consider are that music has a more varied long-term spectrum and a wider range of intensities compared to speech, which is more uniform. Music also has a higher crest factor, meaning it has moments of high peak levels compared to its average waveform levels, which can be created from a burst of loud sounds from a percussion instrument.

Consequently, many hearing aid manufacturers have incorporated an additional music setting to improve music sound quality by modifying or deactivating features like WDRC. However, these hearing aids often require users to manually switch between default speech settings and music settings, which can be inconvenient, especially for live performers. Live performers need hearing aids that can adapt to both speech and music during performances and offer clear communication and music enhancement simultaneously (Greasley, 2017). In addition, despite many users finding that hearing aids with music settings are capable of processing recorded music, in live settings, they are less effective in understanding lyrics and processing individual instrument sounds (Greasley, Crook, & Beeston, 2019).

Yin and Chen (2023) proposed an algorithm that can process both music and sound without the need of changing from a speech default setting to a music setting. In hearing aids, sound enters through a microphone, is amplified, and then emitted by a speaker. However, there are times when the emitted sound coming out of the speaker re-enters the microphone, creating a feedback loop and causing howling noises, which is often referenced as feedback. Yin and Chen (2023) propose the Prediction Error Method - Weighted Nonparametric Variable Step Size (PEM-WNPVSS) algorithm. The PEM component predicts potential errors within the inputted signal before it impacts the output and adjusts the adaptive filter settings ahead of time to correct distortions in sound signals coming into the microphone. The WNPVSS component then weights the error signal of the adaptive filter adjustment and adjusts its step size based on the severity of the signal to respond more accurately and effectively in dynamic environments.

This allows the hearing aid to adapt to different environments and can process both speech and music without requiring users to manually switch between speech versus music settings or adjust the volume. Figure 3 shows how the PEM-WNPVSS algorithm compares with four other algorithms in processing speech and music using the Perceptual Evaluation of Speech Quality (PESQ) score to measure the algorithms’ ability to preserve the clarity of the inputted speech and music signals.

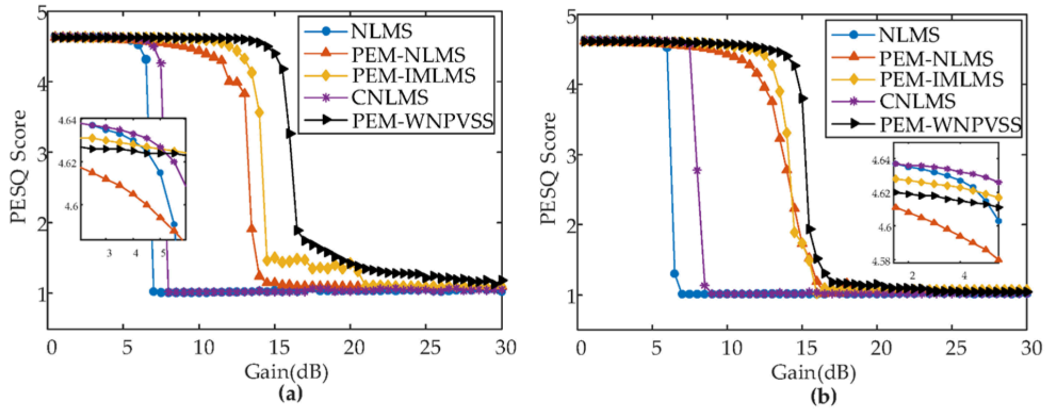

Figure 3. PESQ score of five algorithms when the inputs are: (a) speech signal; (b) music signal
The PEM-WNPVSS algorithm, compared to the other four algorithms, maintains a higher PESQ score as the frequency gain increases and has a slower decline in sound quality, showing that the algorithm produces less distortion and more accurately preserves the clarity of speech and music signals as frequency gain increases. Therefore, this algorithm is more effective at addressing issues in volume dynamics and lyric clarity (Yin & Chen, 2023, p. 11).

However, the PEM-WNPVSS algorithm was initially tested on a dummy in a soundproof room using simulations of speech, an orchestral piece, and sounds from a gas stove ignition to represent noise (Yin & Chen, 2023). These simulations were tested separately, not simultaneously, which may not accurately predict the algorithm's performance in real-world scenarios where speech, noise, and music occur together. To ensure these hearing aids can effectively be used by concert goers or musicians who are performing live, a functional hearing test can be used. Functional hearing tests can provide a more accurate representation of the algorithms' efficiencies because they "assess some aspect of real-world hearing (e.g., speech perception) under simulated real-world conditions (e.g., noisy environments)" (Russo, 2009).

Therefore, I propose a study that compares Yin and Chen's (2023) proposed PEM-WNPVSS algorithm with the other four algorithms in their research study, and put them through simulations that closely replicate real-world environments, including various music genres, various instruments, and simultaneous playbacks of speech, music, and noise. Under varied acoustic conditions and varied frequency gains, the dependent variables will be the same ones used in Yin and Chen's research, such as PESQ, misalignment (MIS), which measures the algorithms' ability to accurately model and adapt to an unknown system, and additional stable gain (ASG), which measures how much additional amplification the algorithm can provide before feedback occurs.

The primary challenge of this project is to create simulations that mimic real-world conditions within a controlled setting. This could potentially be achieved by using high-quality speakers to play the simulations in a soundproof room, similar to the audio system used in movie theaters.

The proposed study aims to show the algorithms' ability to manage feedback, reduce distortion, adapt to dynamic environments, and reproduce accurate pitches, providing insights as to how effective Yin and Chen's proposed PEM-WNPVSS algorithm is at addressing the main concerns of hearing aids for music, which are pitch perception, volume dynamics in live contexts, and lyric clarity.

Understanding Collaborative Approaches Among Audiologists, Manufacturers, and Users to Improve User Acceptance

Studies show that although "67% of hearing-aid users reported some degree of difficulty listening to music, 58% of hearing-aid users had never discussed music in a clinic" (Greasley, Crook, & Fulford, 2020, p. 1), showing that there is a high percentage of users who are dissatisfied with how their hearing aids perform while listening to music, but there is a lack of willingness to ask their audiologists for better music adjustments.

Additionally, "age-related hearing loss is an increasingly important public health problem affecting approximately 40% of 55–74 year olds," however, "the majority (80%) of adults aged 55–74 years who would benefit from a hearing aid, do not use them" (McCormack & Fortnum, 2013, p. 1). McCormack and Fortnum (2013) found that the main issues were that their hearing aids did not provide enough benefit and were uncomfortable. This can be due to audiologists not getting the training they need to effectively adjust hearing aids for enhanced music processing, since “63% of practitioners reported having no training in terms of fitting hearing aids for music” (Greasley, Crook, & Beeston, 2019, pg. 16).

Also, Sataloff R. and Sataloff J. (2009) highlight that there is a stigma around hearing loss, and many view it as an embarrassing sign of aging or infirmity, which discourages many from seeking necessary medical assistance. “Many deny and tolerate hearing loss for a considerable period of time before being coerced by a family member to seek medical care” (Sataloff R. & Sataloff J., 2009, pg. 1). The stigma around hearing aids raises uncertainties in the likelihood that audiologists will be informed about a patient’s need to be recommended hearing aids specifically for music, which raises concerns about the societal demands on newly-developed hearing aids that are designed with better music processings.

Moreover, when deciding which hearing aid brands to recommend, audiologists often work with a variety of hearing aid manufacturers and select hearing aid devices based on the product quality and customer service (Johns Hopkins Medicine, 2024). However, a difficulty audiologists face among commercially available hearing aids is that different manufacturers use different hardware components and their digital algorithms are proprietary technology (Sandgren & Alexander, 2024), making it difficult for audiologists to identify which frequency ranges to adjust for different hearing aid brands. Figure 4 shows the key factors that hearing aid manufacturers focus on to ensure their products meet both user needs and audiologists’ quality standards.

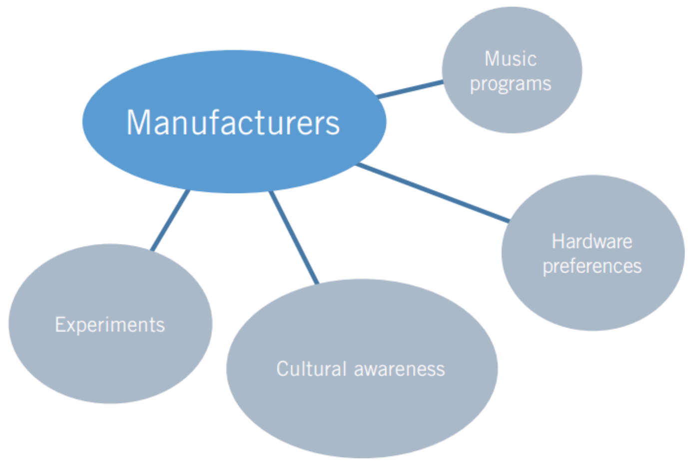

Figure 4: Key Focus Areas for Hearing Aid Manufacturers
Hearing aid manufacturers are recommended to focus on collaborating with audiologists to refine music programs, understanding user preferences for hardware, enhancing cultural awareness about the challenges of music perception, and conducting experiments to verify the effectiveness of hearing aids in real-world music scenarios. (Greasley, Crook, & Beeston, 2019, p. 25).

The study by Greasley, Crook, and Beeston (2019) also provides key focus area models for other influential actors within this sociotechnical system of hearing aids, which include manufacturers, audiologists, hearing aid users that are musicians, and hearing aid users that are casual music listeners. Analyzing the relationships in the diagrams can show interdependencies among hearing aid manufacturers, audiologists, and users. For example, manufacturers depend on audiologists to enhance their understanding of the technical specifications of music programs (Greasley, Crook, & Beeston, 2019). Also, this analysis can uncover potential conflicts, such as human actors having a difference in priorities or having misunderstandings about technical requirements, which could hinder the successful integration of new hearing aids. Understanding these actor interactions is essential for addressing challenges in the development and adoption of new hearing aids.

Uncovering ways to improve how audiologists adjust hearing aids for music, encourage more open communication about hearing concerns in regards to music, and increase transparency from manufacturers about their products could help alleviate the ongoing issues with hearing aids' music processing capabilities. If users remain unsatisfied with their hearing aids' performance and comfort, and stop wearing them, they can miss out on the health benefits that listening to quality music can offer. Research shows that "active musical participation can lead to beneficial effects on both cognitive and psychosocial functioning" (Viola et al., 2023, p. 1)

My STS topic will examine the collaboration and interactions among key actors involved with hearing aids for music, building on research from Greasley, Crook, and Beeston (2019), which offers insights and recommendations for hearing aid users, audiologists, manufacturers, and researchers on improving music satisfaction among hearing aid users. Analyzing the interactions between these actors can allow hearing aid developers and manufacturers to anticipate the user's reactions to their proposed designs. This approach can offer insights into how willing users and audiologists are in adopting newly-developed hearing aids and what the manufacturers can do to ensure audiologists and users will adopt and be pleasantly pleased with the proposed hearing aid designs.

Challenges in this study include researching ways to overcome the stigma associated with the use of hearing aids among those with hearing loss, and the anticipated deliverable is an analysis that outlines how key actors can effectively collaborate to enhance music processing in hearing aids.

Conclusion

The anticipated deliverable of my technical project is an analysis of the PEM-WNPVSS algorithm's performance in simulated real-world settings, that musicians and concert goers will often experience, and depending on the results of this study, the PEM-WNPVSS algorithm may be refined to better suit practical uses of musicians and concert goers, aiming to enhance their listening experience while ensuring the design is user-friendly. The anticipated deliverable for my STS research is an analysis of how manufacturers, audiologists, and users can collaborate effectively to design and integrate new hearing aids that meet user needs.

If these deliverables are successfully completed and appropriately implemented, hearing aid algorithms can be enhanced to address common issues such as poor pitch perception and unclear lyrics in live settings. An enhanced hearing aid design can be effectively integrated within the existing audiologist practices and can potentially make hearing aids more appealing and beneficial to hearing aid users who are professional musicians or casual listeners.

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