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Improving Speech Recognition during Phone Calls in Noisy Environment through the Use of Wireless Audio Streaming in Hearing Aids

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Abstract

Objective: To investigate the improvement of speech recognition for phone call listening by using wireless audio streaming hearing aids in noisy environments. Methods: 30 subjects who were diagnosed as symmetrical, sensorineural hearing loss (SNHL), no middle ear problem, good aided speech recognition and able to speak Mandarin were selected in this research. Speech recognition scores for the phone call between aided with wireless mode-on and aided with wireless mode-off in quiet and noisy environments were statistically analyzed. Results: For word recognition score, subjects with the wireless mode off and on in quiet condition were 85.7% ± 13.6% and 96.0% ± 7.2% ($P < 0.05$), respectively. In noisy conditions, subjects with the wireless mode off and on condition were 27.3% ± 21.2% and 88.7% ± 18.5% ($P < 0.05$). For sentence recognition score, subjects with the wireless mode off and on in quiet conditions were 84.7% ± 13.3% and 92.7% ± 10.1% ($P < 0.05$), respectively. In noisy conditions, the sentence recognition score for subjects with the wireless mode off and on condition were 11.0% ± 13.5% and 89.0% ± 11.8% ($P < 0.05$), respectively. Conclusions: In quiet environments, individuals with hearing loss who use non-wireless audio streaming hearing aids have achieved high speech recognition during phone calls. However, using wireless audio streaming hearing aids can further enhance this experience. In noisy environments, speech recognition during phone calls may decrease when using non-wireless audio streaming hearing aids. Wireless audio streaming hearing aids can still maintain a high level of speech recognition, effectively addressing the challenge of phone call accessibility for individuals with hearing loss. Therefore, wireless audio streaming hearing aid technology can greatly improve speech recognition.

Subject Areas

Audiology

Keywords

Wireless Audio Streaming Hearing Aid, Phone Call, Noisy Environment, Speech Recognition

1. Introduction

The usage of mobile phone calls has become increasingly prevalent across populations, leading to an increase in frequency and time spent on mobile communication. Studies have shown that individuals with hearing loss may still experience difficulties when using hearing aids with mobile phones, particularly in noisy environments. According to Bentler *et al*., hearing aids are capable of delivering a clear and high-quality sound experience in quiet environments, they may compromise the quality and intelligibility of speech when background noise is present [1]. Research has indicated that speech recognition in noisy conditions is a primary issue contributing to decreased satisfaction with hearing aids. Some individuals with hearing loss express dissatisfaction with the sound quality and clarity of speech when using hearing aids to listen on mobile phones, especially in noisy environments [2]. Additionally, a significant number of patients (94%) have reported experiencing significant difficulties in phone conversations due to background noise [3]. Individuals with moderate to severe hearing loss may still struggle to hear clearly when using conventional hearing aids with mobile phones. This is primarily due to the transmission of sound to the hearing aid and subsequent amplification, which can introduce distortion. Furthermore, the presence of environmental noise can further diminish clarity. This perception has led some patients to purchase hearing aids but not use them due to concerns about their compatibility with mobile phones [4].

The use of simple acoustic coupling between mobile phones and hearing aids can be challenging as it often leads to feedback when the phone receiver is in close proximity to the hearing aid. Despite advancements in feedback reduction algorithms, feedback continues to be a challenge, particularly for individuals who need substantial amplification [4]. Consequently, the current focus of hearing aid technology development is on enhancing speech recognition in noisy listening conditions and optimizing the signal-to-noise ratio (SNR) in scenarios where distance, noise, and reverberation may pose challenges [2] [5]. Individuals with SNHL require a higher signal-to-noise ratio (SNR) compared to those with normal hearing in order to effectively communicate, even with sufficient amplification provided by hearing aids. Studies have demonstrated that when the SNR reaches or falls below 5 dB, the ability of individuals with SNHL to recognize speech in noisy environments significantly declines [6] [7]. Enhancing speech

audibility is an effective approach to assist individuals with sensorineural hearing loss in challenging listening situations [6]. Research has indicated that a 1 dB increase in SNR can lead to a 6 to 12 percentage improvement in speech recognition when background noise is present [8] [9].

Wireless audio streaming technology has emerged as a valuable solution in the hearing aid industry, addressing challenges related to phone communication with reduced interference [10]. From traditional telecoil solutions to the latest 2.4 GHz technology, wireless audio streaming has become an integral part of hearing aid usage, offering numerous benefits in everyday situations such as answering phone calls, online classes, and streaming audio from televisions or mobile devices [11]. Wireless technology converts the sound collected by microphones into radio waves and transmits them through a transmitter. The receiver, built into the hearing aid, then receives these radio waves at the same frequency and converts them back into audio signals, allowing the hearing aid user to hear the sound [2]. Hearing aids now incorporate built-in wireless receivers, significantly improving their cosmetic appearance and convenience. Wireless audio streaming technology has emerged as a valuable solution in the hearing aid industry, addressing challenges related to phone communication with reduced interference [7]. Through the utilization of wireless technology, the audio signal is transmitted via radio waves, effectively mitigating the adverse impacts of background noise, reverberation, and other factors on sound transmission. This technology has the potential to enhance the speech recognition capabilities of hearing aids in noisy environments, allowing users to perceive phone conversations with greater clarity. This wireless technology provides the capability for hands-free communication on mobile phones by allowing sound to stream directly into hearing aids. It has the ability to automatically reduce environmental noise, enabling users to focus more on phone conversations, as mentioned in reference [12]. Furthermore, the wireless audio streaming technology can stream the phone signal to both hearing aids simultaneously. This leads to improved speech recognition performance and enhanced listening comfort and ease through binaural streaming, compared to monaural listening with hearing aids that lack with wireless technology, as discussed in reference [13].

Previous studies have demonstrated that the wireless connectivity between telephones and hearing aids can greatly enhance the speech intelligibility of individuals with hearing loss [13]-[17]. Multiple studies have indicated that wireless hearing aids can enhance the speech recognition abilities of individuals with hearing loss who speak English or Korean in noisy environments [1] [5]. Additional research has indicated that Bluetooth accessories, remote microphone HATs, and streamers can also improve speech recognition performance in difficult listening environments [4] [6] [18]. However, there are limited studies comparing the advantages of hearing aids with and without wireless audio streaming for mobile phone calls among individuals with hearing loss who

communicate in Mandarin Chinese. It motivates us to investigate the extent of improvement in speech recognition that can be achieved through the use of wireless hearing aids. By examining this, we aim to determine the potential benefits that wireless technology can bring to individuals with hearing loss.

2. Methods

2.1. Participants

We enrolled 30 SNHL patients (8 female and 22 male) from Hui'er flagship hearing clinic. All individuals in this study were native Chinese. Patients who were with symmetrical hearing loss, no middle ear problem, aided speech recognition score above 60% in quiet environment and able to speak and understand Mandarin were selected in this research. The age of subjects ranged from 29 to 86 years old. The mean age was observed to be 64.03 ± 16.73 years old. According to the World Health Organization (WHO) 2021 hearing loss classification criteria, among the 30 subjects, 1 had moderate hearing loss, 14 had moderate severe hearing loss, 13 had severe hearing loss and 2 had profound hearing loss, as shown in Table 1 [19]. Figure 1 showed the average pure-tone hearing thresholds

Table 1. Degree of hearing loss in the study.

Severity	Number of patients
Mild (20 - 34 dB HL)	0
Moderate (35 - 49 dB HL)	1
Moderately severe (50 - 64 dB HL)	14
Severe (65 - 79 dB HL)	13
Profound (80 - 94 dB HL)	2
Deaf (≥95 dB HL)	0
Total	30

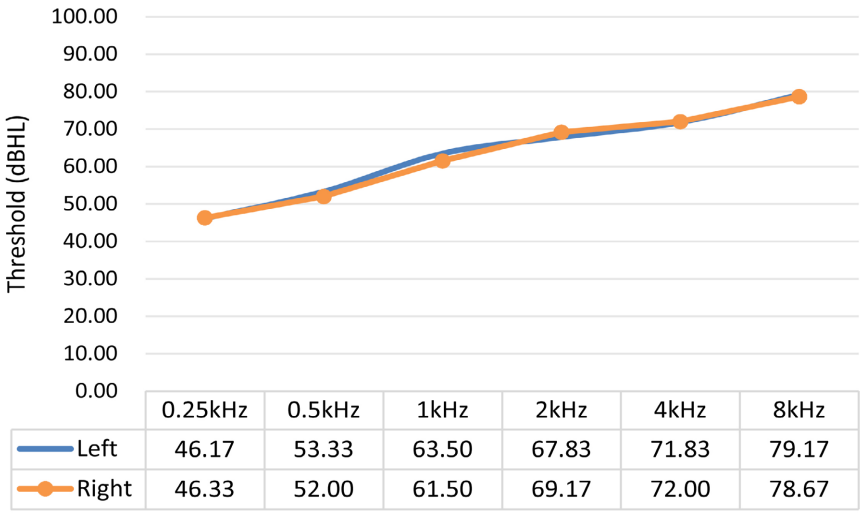

Figure 1. Average pure-tone hearing thresholds of all participants.

of all participants. The mean of pure tone average (PTA) threshold at frequencies of 500, 1000, 2000 and 4000 Hz of left and right ears were 63.73 and 63.62 dB HL respectively.

2.2. Hearing Aid Fitting

All subjects were fitted with Hui'er ITC Charm K830-W bilaterally based on their latest pure tone audiogram; their hearing aids are fine-tuned according to the best fitting of the tuning program. All subjects were wearing In-the-Canal (ITC) customized hearing aids according to each individual's ear canal size. Feedback cancellation was activated to avoid feedback that will affect the sound quality when answering phone calls.

2.3. Test Equipment and Materials

Speech recognition tests included two test contents: "word" and "sentence" and two acoustical environments: "quiet" and "noise". We were using two Hui'er ITC Charm K830-W hearing aids, Apple iPad 9th generation to play the test files, and Grason-Stadler AudioStar ProTM-audiometer to play the wide-band white noise. The word recognition test material utilized Mandarin Speech Test Materials (MSTMs)-bisyllabic Mandarin words. The material consists of 10 lists, each containing 20 words in each word list. The standardized sentence was derived from the Mandarin version of the ones from The University of Western Australia supported by Widex for speech audiometry. The bisyllabic Mandarin words and sentences were imported to the iPad.

2.4. Test Environment

According to Figure 2, speech recognition tests in quiet and in noise were carried

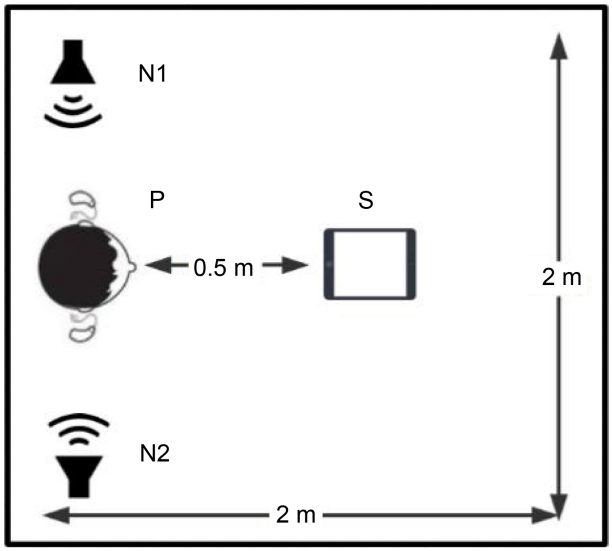

Figure 2. Two speakers (N1, N2) were used for playing noise and located at 0˚ and 180˚ azimuth to patient's ear level. The speech was presented by iPad 0.5 meter in front of the patient. The noise placed in the two corners (N1, N2) of the soundproof room.

out in a 2 m × 2 m × 2 m soundproof chamber in Hui'er Clinic, with background noise <35 dB A. The subject was seated at P. Two speakers (N1, N2) were used for playing the noise. The two speakers were set at ear level and located at 0˚ and 180˚ azimuth of the subject, respectively. Wide-band white noise was utilized simultaneously at a calibrated noise level at 65 dB A played by Grason-Stadler AudioStar ProTM-audiometer. The examiner presenting speech signals (S) by using iPad were located 0.5 m directly in front of the subject. By setting the distance to 0.5 meters, we can simulate the typical distance between the speaker and the hearing aid microphone during a phone call or while listening to audio content. This distance setting helps replicate the acoustics and sound quality that individuals with hearing aids experience in real-life situations. It takes into account factors such as sound propagation, attenuation, and background noise, which can significantly impact the user's ability to hear and understand the speech. This approach aims to provide a more inclusive and accessible experience for users who rely on hearing aids, allowing them to engage in phone conversations and enjoy various audio contents with enhanced clarity and understanding.

2.4.1. Test Procedure for Speech Recognition in Quiet

Subjects were fitted with Hui'er ITC Charm K830-W on both ears. Instruction had been addressed to them before the test. They were instructed to repeat the words they heard. The examiner was standing 0.5 meter directly in front of the subjects, and presented the Mandarin Speech Test Materials (MSTMs)-bisyllabic Mandarin words through iPad. In the wireless audio streaming mode-off condition, examiner adjusted the volume of the iPad (recorded as V1) until the most comfortable loudness to provide good clarity of speech [20]. Examiner increased or lowered down the volume according to the subject's correct or incorrect response of the test [6]. The word recognition score results were recorded by percentage. After with the wireless audio streaming mode off condition, we turned the wireless audio streaming mode on by connecting the hearing aid with iPad through the setting-accessibility-hearing devices. Examiner had to adjust the volume again (recorded as V2) so they could hear the word at the most comfortable level. The word recognition score was recorded again. Another sentence recognition test was performed to imitate someone answering phone call in daily life. We would still test the subject in both wireless mode off and wireless mode on condition by using same iPad volume respectively. They were instructed to answer the questions they heard. The sentence recognition score was recorded.

2.4.2. Test Procedure for Speech Recognition in Noisy

We tested the subjects in the noisy condition after compared with the test in quiet condition. As we mentioned above, the wide-band white noise was presented at 65 dB A at both sides of the subject by using Grason-Stadler AudioStar ProTM-audiometer. Different word lists and sentences were presented by the speaker of the iPad (wireless mode off) or directly audio streaming to the hear-

ing aid (wireless mode on). We would like to remain the same volume of the iPad to V1 and V2 for both wireless mode off and on conditions, respectively, the same as that in the quiet condition. The speech recognition score was recorded.

2.5. Statistical Analysis

The data was inputted into Excel and statistical analysis was conducted using IBM Statistics Package for Social Science (SPSS) Statistics 25. Percentages of word recognition score and sentence recognition score in each condition of wireless mode off and mode on were evaluated using paired Wilcoxon signed-rank tests. When the data within groups do not follow a normal distribution, a paired Wilcoxon signed-rank test can be used to compare two samples between groups. The statistical level of significance was defined as a *P* value of less than 0.05.

3. Results

3.1. Improvement in Speech Recognition Performance

3.1.1. Word Recognition Test

Improvement in word recognition performance was observed in both quiet and noisy environments with wireless mode on and off, as indicated in **Figure 3**. According to **Figure 4**, in quiet environment, the average word recognition score for participants with the wireless mode off and wireless mode on condition were 85.7% ± 13.6% and 96.0% ± 7.2% ($P < 0.05$), respectively. In noisy environment, the average word recognition score for participants with the wireless mode off and wireless mode on condition were 27.3% ± 21.2% and 88.7% ± 18.5% ($P < 0.05$), respectively. The word recognition score for participants with the wireless mode on was approximately 60% higher compared to wireless mode off condition. Wireless mode on demonstrated outstanding performance in word recognition and the results were statistically significant ($P < 0.05$).

3.1.2. Sentence Recognition Test

According to **Figure 5**, there was a noticeable enhancement in sentence recognition performance in the wireless mode on compared to the wireless

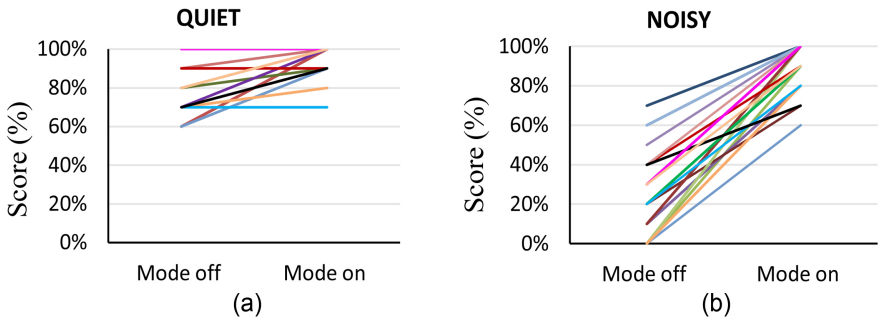

Figure 3. The word recognition score of 30 subjects with wireless hearing aid mode off and mode on in both quiet and noisy environment. (a). Quiet environment; (b). Noisy environment.

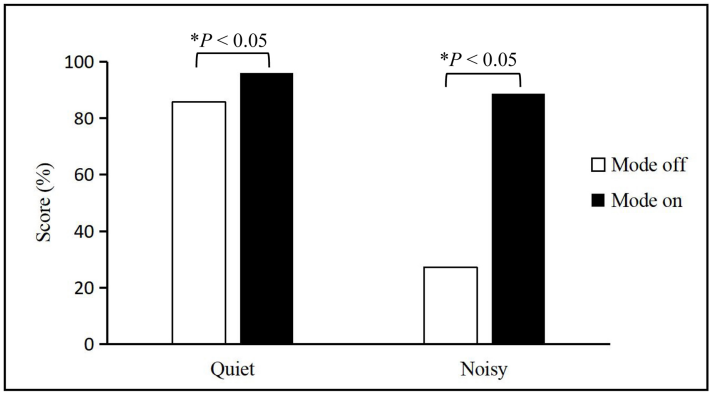

Figure 4. The average of word recognition score with wireless hearing aid mode off and mode on in both quiet and noisy environment.

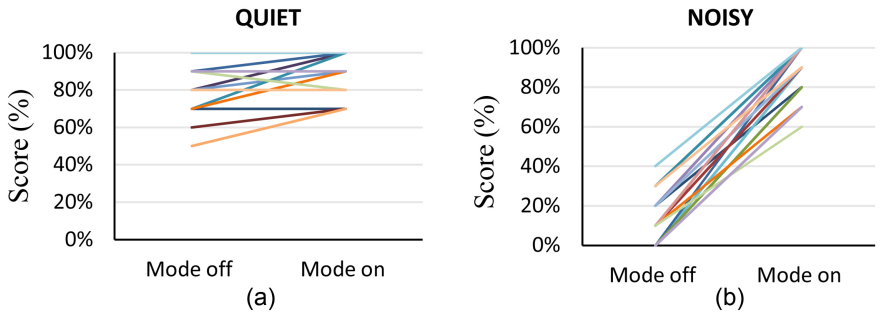

Figure 5. The sentence recognition score of 30 subjects with wireless hearing aid mode off and mode on in both quiet and noisy environment. (a). Quiet environment; (b). Noisy environment.

mode off in both quiet and noisy conditions. Figure 6 illustrates the average sentence recognition score for subjects with the wireless mode off and wireless mode on condition were 84.7% ± 13.3% and 92.7% ± 10.1% ($P < 0.05$), respectively in quiet environment. In noisy environment, the average sentence recognition score for participants with the wireless mode off and wireless mode on condition were 11.0% ± 13.5% and 89.0% ± 11.8% ($P < 0.05$), respectively. The sentence recognition score for subjects with the wireless mode on was approximately 70% higher compared to wireless mode off condition. The wireless mode demonstrated superior performance in sentence recognition and the results were statistically significant in noisy environment ($P < 0.05$).

4. Discussions

Answering mobile phone calls can pose greater challenges for individuals with hearing aids compared to face-to-face conversations. The process of transmitting speech through mobile phones involves various transformations, often leading to interference [15] [20]. Mobile phones can sometimes cause interference or feedback with hearing aids, resulting in buzzing or whistling sounds. This interference can make it difficult for hearing aid users to hear the conversation clearly. In everyday communication, individuals with hearing loss rely heavily on cues

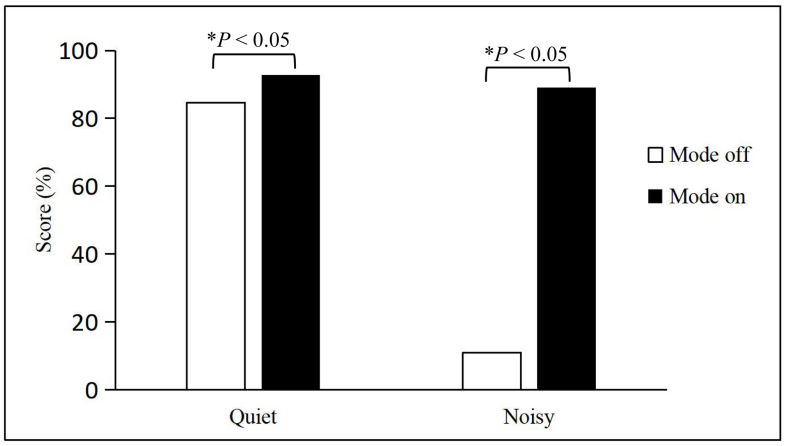

Figure 6. The average of sentence recognition score with wireless hearing aid mode off and mode on in both quiet and noisy environment.

such as lip reading, facial expressions, and body language to comprehend speech effectively [21]. When an individual is unable to visually perceive the speaker, they miss out on crucial information conveyed through facial expressions, lip reading, and body language, leading to added complexity in phone conversations [16]. It is worth noting that the clarity of speech during mobile phone calls is typically poorer compared to face-to-face conversations.

In addition to the factors mentioned earlier, background noise is a significant interference that can cause difficulties for individuals when listening to someone in a conversation. Research has indicated that speech recognition in noisy environments is a major challenge that can lead to decreased consumer satisfaction with hearing aids [2] [22]. Numerous studies have demonstrated that while hearing aids can provide clear and high-quality sound experiences, they can struggle to maintain speech signal quality and intelligibility in the presence of background noise. According to research, approximately 71% of hearing aid users reported dissatisfaction with their hearing aid performance in noisy environments [17].

Wireless audio streaming technology is extensively utilized in various real-life scenarios, facilitating wireless communication between electronic devices. Wireless technology converts the sound collected by microphones into radio waves and transmits them through a transmitter. The receiver, built into the hearing aid, then receives these radio waves at the same frequency and converts them back into audio signals, allowing the wearer of the hearing aid to hear the sound [2]. Through the utilization of wireless technology, the audio signal is transmitted via radio waves, effectively mitigating the adverse impacts of background noise, reverberation, and other factors on sound transmission. This technology has the potential to enhance the speech recognition capabilities of hearing aids in noisy environments, allowing users to perceive phone conversations with greater clarity.

In the context of this study, the implementation of wireless audio streaming in

hearing aids has shown potential benefits for enhancing speech recognition. The results indicate that utilizing wireless audio streaming hearing aids can lead to an approximate improvement of 60% and 70% in word recognition test and sentence recognition test, respectively. When faced with a noisy environment, directly answering phone calls using a mobile phone may not be an optimal solution. However, leveraging wireless technology can provide significant assistance in such situations.

Numerous studies have investigated the positive impact of wireless audio streaming technology for mobile phones and hearing aids on speech intelligibility and speech recognition. Wireless hearing aids are designed to separate speech signals from background noise and transmit only the speech signal for amplification [20]. This technology can automatically reduce environmental noise, allowing users to focus more on phone conversations [12]. By activating the wireless mode, the hearing aid microphone is suppressed, resulting in reduced ambient noise levels and an enhancement in the signal-to-noise ratio (SNR) [18] [20]. Research has demonstrated that enabling the wireless mode can result in an approximate 5dB enhancement in SNR, leading to better speech recognition performance [18].

In this research, binaural fitting was utilized. Binaural hearing is one of the advantages of wireless streaming technology. Hearing aids equipped with wireless audio streaming technology can directly stream phone signals to both hearing aids simultaneously. Wireless hearing aids eliminate the need for transmitting sound from the speaker of a mobile phone to the microphone of the hearing aids. This bypasses potential distortion and interference, allowing for the direct streaming of natural audio input to the hearing aid amplifier. This results in enhanced speech recognition performance and improved listening comfort and ease through binaural streaming, as opposed to monaural listening with a single hearing aid [13]. Users no longer have to struggle to hear conversations through their mobile phones.

Wireless audio streaming hearing aids offer several benefits, including improved clarity in phone conversations and enhanced sound quality. With these hearing aids, users no longer need to place their mobile phones close to their hearing aids when answering calls. Speech signals can be directly transmitted to the hearing aids, eliminating acoustic feedback and reducing speech distortion without compromising the intensity of the signal [23]. This allows users to focus on and clearly listen to speech.

5. Conclusion

In quiet environments, individuals with hearing loss who use non-wireless audio streaming hearing aids have achieved high speech recognition during phone calls. However, using wireless audio streaming hearing aids can further enhance this experience. In noisy environments, speech recognition during phone calls may decrease when using non-wireless audio streaming hearing aids. On the

other hand, wireless audio streaming hearing aids can still maintain a high level of speech recognition, effectively addressing the challenge of phone call accessibility for individuals with hearing loss. Therefore, wireless audio streaming hearing aid technology can greatly improve speech recognition.

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Conflicts of Interest

The authors declare no conflicts of interest.

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