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Improving TV-Watching Speech Recognition for Hearing Aid Users through Wireless Audio Streaming in a Household Setup

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Abstract

Objective: Television viewing is one of the most frequent yet acoustically challenging listening situations for individuals with hearing loss in daily life. Conventional hearing aids rely primarily on environmental microphones, which are susceptible to the adverse effects of listening distance, room reverberation, and household background noise, often resulting in reduced speech intelligibility and increased listening effort. Wireless audio streaming technology, which delivers television audio directly to hearing aids, has emerged as a promising solution to these challenges. The present study aimed to systematically compare speech recognition performance during TV watching with wireless audio streaming enabled (Wireless-ON) versus disabled (Wireless-OFF) among adults with moderate-to-severe sensorineural hearing loss (SNHL) in a simulated household setup, and to quantify both objective benefits and subjective listening experiences associated with this technology. **Methods:** Sixty native Mandarin-speaking adults with bilateral symmetrical moderate-to-severe sensorineural hearing loss were evaluated, recruited from Hui'er flagship clinics. They were mixed-gender with a male predominance, aged 6 - 84 years, and had pure-tone thresholds ranging from 36.25 to 85 dB HL. Aided speech perception, measured as percent correct, was assessed under two conditions: Wireless-ON (wireless-enabled) and Wireless-OFF. Scores ranged 50% - 100% for Wireless-ON and 20% - 100% for Wireless-OFF, with most participants showing improved performance in the Wireless-ON condition. Testing was conducted in a simulated household environment, with TV speech calibrated to typical household levels and common background noises presented. Sentence recognition tasks used 4 adapted Mandarin lists (20 sentences per set, 5 - 9 syllables) scored verbatim. Wireless TV audio transmitted via a 2.4 GHz digital path, while standard hearing aid processing features remained active; fitting was verified using real-ear measurements (REM) and NAL-NL2 targets. Paired t-tests (parametric) and Wilcoxon tests (non-parametric) in SPSS 27.0 compared the two conditions, and regression analyses examined moderation by age and hearing loss. **Results:** Speech recognition performance during TV watching was significantly better in the Wireless-ON condition than in the Wireless-OFF condition. Mean sentence recognition scores increased from 0.72 ± 0.16 in the Wireless-OFF condition to 0.86 ± 0.12 in the Wireless-ON condition ($p < 0.001$). The average improvement (Delta = Wireless-ON score − Wireless-OFF score) was 0.14 ± 0.11, indicating a consistent enhancement in speech recognition across participants. Paired-samples t-test results confirmed a statistically significant difference between conditions ($t = 7.588$, $df = 59$, $p < 0.001$), with a large effect size (Cohen's dz = 0.98). Consistent findings were obtained using the Wilcoxon signed-rank test ($Z = -5.726$, $p < 0.001$), yielding a large effect size ($r = 0.74$). These results demonstrate that the observed improvement is not only statistically robust but also clinically meaningful. Multiple linear regression analysis revealed no significant moderating effects of age or hearing loss severity on the magnitude of improvement associated with wireless streaming ($R^2 = 0.021$, $F = 0.605$, $p = 0.550$), suggesting that the benefits of wireless audio streaming are broadly applicable across different age groups and degrees of moderate-to-severe hearing loss. Subjective outcome measures further supported the objective findings, with participants reporting significantly higher ratings for speech clarity, listening comfort, reduced listening effort, and overall satisfaction in the Wireless-ON condition compared to the Wireless-OFF condition (all $p < 0.001$). **Conclusion:** The present study demonstrates that wireless audio streaming significantly improves speech recognition during TV watching in a household setup for adults with moderate-to-severe SNHL. The large effect sizes observed indicate clinically meaningful benefits, attributable to the direct transmission of TV audio to hearing aids, which minimizes signal degradation, environmental noise, and room reverberation. These benefits were consistent across age groups and degrees of hearing loss within the moderate-to-severe range. Wireless audio streaming therefore represents an effective and practical intervention for addressing TV-watching difficulties in everyday life and should be considered an integral component of contemporary hearing aid rehabilitation strategies.

Keywords

Wireless Audio Streaming, Hearing Aids, Television Listening, Household Environment, Speech Recognition

1. Background

Hearing loss is globally recognized as one of the most prevalent chronic health conditions, affecting over 1.5 billion people worldwide, with its incidence expected to rise sharply in the coming decades [1]. Among all types of hearing impairment, sensorineural hearing loss (SNHL) accounts for approximately 90% of permanent cases, resulting from damage to cochlear hair cells, synaptic pathways, or the auditory nerve. Beyond reduced audibility, SNHL impairs frequency selectivity, temporal resolution, loudness perception, and binaural processing—deficits that severely hinder speech understanding, especially in complex acoustic environments [2]. A well-documented challenge for individuals with SNHL is the "cocktail party problem", which describes difficulties in perceiving target speech amid competing noise, reverberation, or spatial separation between the listener and sound source [3]. Unlike normal-hearing individuals, those with SNHL typically require higher signal-to-noise ratios (SNRs)—often 10 - 15 dB higher—to achieve comparable speech comprehension [4], making everyday activities such as telephone conversations, group discussions, and television (TV) watching significantly challenging.

Television watching plays a central role in the daily lives of middle-aged and older adults, serving as a primary source of entertainment, information, social connection, and lifelong learning [5]. Surveys indicate that adults over 60 years old spend 3.5 - 5 hours per day watching TV, underscoring its importance in their auditory experiences [5]. For individuals with SNHL, the ability to understand televised speech directly impacts their quality of life, social engagement, and psychological well-being [6]. However, even with widespread hearing aid use, TV listening remains a persistent struggle: 74% - 80% of hearing aid users report difficulties following TV dialogue, and dissatisfaction with TV listening performance is a leading cause of hearing aid abandonment [7]. A 2018 survey of 515 hearing-impaired individuals aged 50+ found that while hearing aid users watched TV for an average of 6 hours 10 minutes per day (57 minutes longer than non-users), over 39% still encountered frequent listening problems, highlighting the unmet need for effective solutions [6].

Three interconnected factors contribute to TV listening challenges for individuals with SNHL. First, signal decay: sound intensity decreases with distance, with a doubling of distance resulting in a roughly 6 dB reduction in sound energy. In typical home environments, viewing distances of 2 - 3 meters significantly weaken high-frequency speech cues critical for consonant discrimination and overall intelligibility [8]. Second, transmission distortion: room acoustics, including reflections from hard surfaces, introduce reverberation that smears temporal and spectral speech features, further reducing clarity. Individuals with SNHL are particularly vulnerable to this distortion due to preexisting impairments in temporal processing [9]. Third, environmental interference: household noises (e.g., appliances, conversations, outdoor sounds) reduce the effective SNR, often to negative or near-zero values—insufficient for adequate speech recognition in moderate-to-severe SNHL [4]. These factors collectively create a hostile listening environment that conventional hearing aids struggle to overcome.

Conventional hearing aids address reduced audibility through amplification and signal processing features such as directional microphones and noise reduction [10]. While these technologies provide measurable benefits, they are limited by their reliance on on-device microphones, which capture sound after it has been degraded by distance, reverberation, and background noise [11]. As a result, many hearing aid users continue to experience difficulty understanding TV speech even with well-fitted devices [7]. For example, a study by Gordon-Salant and Callahan (2009) found that hearing aid use alone did not significantly improve word recognition for TV content, though closed captioning provided additional benefit [12]. This limitation underscores the need for solutions that bypass environmental sound degradation at the source.

Wireless audio streaming technology has emerged as a promising alternative, transmitting audio directly from external devices (e.g., TVs, laptops, smartphones) to hearing aids via 2.4 GHz Bluetooth or proprietary radio-frequency (RF) protocols [13]. By bypassing environmental microphones, wireless streaming preserves the original audio signal's fidelity, eliminates distance-related signal decay, and reduces interference from background noise—directly addressing the root causes of TV listening difficulties [13]. Additionally, wireless streaming supports binaural transmission, delivering synchronized audio to both ears to enhance spatial perception, speech segregation, and listening comfort [14]. This binaural input is particularly valuable for individuals with SNHL, who often experience degraded spatial processing and increased listening effort [11].

Empirical evidence confirms the efficacy of wireless streaming for TV listening and speech recognition in noisy environments. Kim *et al.* (2014) demonstrated that Bluetooth-implemented hearing aids significantly improved both objective speech recognition scores and subjective clarity ratings among adults with SNHL [15]. Similarly, Shetty *et al.* (2023) found that coupling hearing aids with TVs via Bluetooth streamers resulted in better speech recognition scores for compressed speech (a common challenge in fast-paced TV content) and higher quality ratings across all speech rates compared to conventional hearing aid use [16]. A survey of hearing aid users also noted that while only 6% currently use audio streaming accessories for TV, these technologies have the potential to provide high-quality, interference-free audio with spatial cues [6]. Wireless streaming's benefits extend beyond TV: Cho *et al.* (2020) reported improved telephone conversation performance with Bluetooth-enabled hearing aids, and Chen *et al.* (2021) found that wireless remote microphones enhanced speech recognition in noise for Chinese hearing aid users [10].

Despite these promising findings, critical research gaps remain. First, many studies compare streaming across quiet vs. noisy environments rather than isolating the specific effect of streaming (ON vs. OFF) in realistic TV listening scenarios [16]. Second, most research has focused on English- or Korean-speaking populations [15], while evidence for Mandarin-speaking listeners is limited. Mandarin is a tonal language where pitch contours carry lexical meaning, making speech recognition highly sensitive to temporal and spectral distortion—factors that may uniquely influence streaming efficacy [17]. Third, the moderating effects of age and hearing loss severity on streaming benefits are unclear: some studies report greater improvements for severe hearing loss [16], while others find no significant moderation [3]. Finally, evolving media consumption habits, such as laptop-based TV streaming, have not been adequately studied. Laptop speakers differ acoustically from traditional TV speakers, and few studies calibrate output levels to reflect real-world household listening conditions [3].

To address these gaps, the present study compares speech recognition performance between wireless streaming ON and OFF modes during TV watching in a simulated household environment and incorporating realistic household noise, the study evaluates streaming efficacy in a Mandarin-speaking population with moderate-to-severe SNHL. This design rigorously assesses the clinical utility of wireless streaming in everyday TV listening scenarios, providing actionable guidance for clinicians and users. By focusing on a tonal language and real-world listening conditions, the research fills critical gaps in the literature and contributes to more inclusive hearing assistive technology solutions.

2. Significance of the Study

2.1. Theoretical Significance

This study enriches academic literature in three key aspects: First, by exclusively comparing wireless streaming ON versus OFF modes, it provides rigorous evidence of speech recognition improvements uniquely attributable to wireless transmission, avoiding confounds from quiet-noisy environment comparisons [16]. Second, it validates wireless streaming efficacy among Mandarin speakers, extending cross-linguistic generalizability beyond English and Korean populations [15]; given Mandarin's tonal nature, findings clarify how language-specific acoustic features interact with hearing aid technologies [17]. Third, it explores age and hearing loss severity as moderators of streaming benefits, deepening theoretical understanding of factors influencing technology efficacy [3].

2.2. Practical Significance

Findings benefit multiple stakeholders: Clinicians gain quantitative benchmarks to counsel patients on TV listening improvements, boosting hearing aid adherence [7]. Manufacturers receive insights to optimize user-friendly streaming solutions for laptops and modern platforms [13]. Payers obtain evidence to justify reimbursing streaming accessories [16]. Most importantly, hearing aid users gain evidence-based solutions for TV listening challenges, enhancing quality of life and social engagement [6].

2.3. Research Gap

Critical gaps remain in wireless streaming research: Limited evidence for Mandarin speakers, whose tonal language increases distortion susceptibility [17]; lack of ecologically valid testing (e.g., artificial vs. real household noise); few direct ON/OFF streaming comparisons and unclear moderating effects of age and hearing loss severity [3].

2.4. Overall Aim

To evaluate whether wireless audio streaming improves speech recognition during TV watching among Mandarin-speaking adults with moderate-to-severe sensorineural hearing loss in a simulated household environment.

2.5. Specific Objectives

Quantify speech recognition differences (words, sentences) between wireless streaming ON/OFF in a calibrated laptop-based household setup; calculate effect sizes to measure improvement magnitude; assess if age or hearing loss severity moderates streaming benefits.

2.6. Research Questions

What is the mean speech recognition score difference between Wireless-ON and -OFF? Is the improvement clinically meaningful (large effect size)? Do age or hearing loss severity predict improvement magnitude?

2.7. Hypotheses

H1: Speech recognition scores will be significantly higher in Wireless-ON. H2: Streaming improvement will show a large effect size. H3: Age and hearing loss severity will not moderate streaming benefits.

3. Method and Materials

3.1. Technical Road Map

Figure 1 shows the step by step study roadmap from the recruitment of the participants and audiological assessments, statistical analysis until the results interpretation.

3.2. Study Methods

3.2.1. Subject Recruitment

The recruitment of participants was a rigorous, targeted process designed to ensure the sample's representativeness, homogeneity, and relevance to the study's research questions. All participants were recruited from Hui'er Flagship Hearing Centre, a specialized clinical facility with extensive experience in audiological assessment and hearing aid fitting, ensuring access to a population of Mandarin-speaking adults with confirmed sensorineural hearing loss (SNHL). The recruitment process adhered to strict inclusion and exclusion criteria, ethical guidelines, and sample size considerations to maximize the validity and generalizability of the study's findings.

3.2.2. Sampling

A convenience sampling approach was employed, with a target sample size of 60 native Mandarin speakers with bilateral symmetrical moderate-to-severe SNHL. This sample size was determined based on prior studies investigating speech recognition and hearing aid technology efficacy, which typically require 50 - 70 participants to detect moderate-to-large effect sizes (Cohen's d ≥ 0.5) with 80% statistical power and a significance level of $\alpha = 0.05$. The sample was restricted to individuals with bilateral symmetrical hearing loss to eliminate confounding effects associated with asymmetrical auditory input, which can alter binaural processing and speech recognition outcomes. All participants were regular hearing aid users, ensuring familiarity with hearing aid technology and reducing learning effects during the test procedures. Recruitment was conducted over a 3-month period, with potential participants identified through the clinic's patient database, referrals from audiologists, and in-clinic informational materials explaining the study's purpose and procedures.

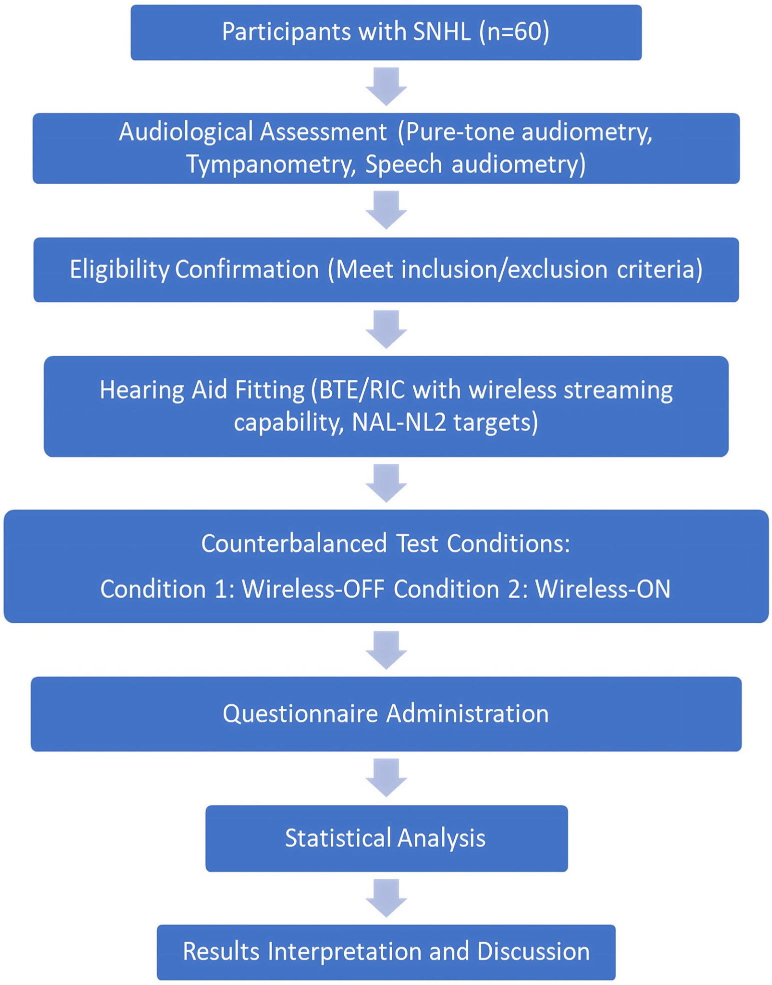

Figure 1. Technical route map of the study.

3.2.3. Inclusion Criteria

To ensure the sample aligned with the study's focus on Mandarin-speaking adults with moderate-to-severe SNHL and wireless streaming-compatible hearing aids, the following inclusion criteria were strictly applied:

- Native Mandarin Speaker: Participants must have been native speakers of Mandarin Chinese, with the ability to fluently express themselves and accurately repeat Mandarin words and sentences. This criterion was critical given the tonal nature of Mandarin, where pitch contours carry lexical meaning, and speech recognition is highly dependent on accurate perception of temporal and spectral features unique to the language. Fluency was verified through a brief verbal interview conducted by a trained audiologist.
- Bilateral Symmetrical Moderate-to-Severe SNHL: Participants must have had a pure-tone average (PTA) of 50 - 80 dB HL across the 500 - 4000 Hz frequency range (the speech-frequency range) in both ears. Symmetry was defined as an interaural PTA difference of ≤15 dB HL. Additionally, the air-bone gap (ABG) must have been ≤10 dB HL in both ears, confirming the absence of significant conductive hearing loss components. This criterion ensured that the primary hearing impairment was sensorineural, consistent with the study's focus on SNHL-related TV listening challenges.
- No Middle Ear Abnormalities: Middle ear health was confirmed via tympanometry, with participants required to have peak compliance within normative ranges (0.3 - 1.7 cc for adults). Tympanometry results were classified using standard clinical criteria, with only participants exhibiting normal middle ear function included to eliminate confounding effects of middle ear pathology on sound transmission and speech recognition.
- No Retrocochlear Lesions or Cognitive/Language Disorders. Language disorders were excluded to ensuring participants could understand and follow test instructions and accurately repeat speech stimuli.
- Baseline Speech Processing Ability: Participants must have had a Maximum Phonetically Balanced (PB-max) word recognition score of ≥50% in a quiet environment. The PB-max score reflects the highest percentage of correctly recognized phonetically balanced words at the most comfortable listening level, and a score of ≥50% ensured that participants had sufficient baseline speech processing ability to detect improvements associated with wireless streaming. This criterion excluded individuals with severe speech recognition impairments that would limit the ability to measure meaningful changes between test conditions.
- Wireless Streaming-Compatible Hearing Aids: Participants must have been current users of bilateral Receiver-In-Canal (RIC), In-the-Canal (ITC), or In-the-Ear (ITE) hearing aids with wireless streaming capability, specifically compatible with 2.4 GHz Bluetooth technology. This included hearing aids from leading brands (Widex, Resound, and Hui'er) with verified streaming functionality, ensuring consistent performance across participants. Participants who did not own compatible hearing aids were provided with Fascinating 5300 ITC demo hearing aids (Hui'er) with confirmed wireless streaming capability, matched to their hearing loss profile.

3.2.4. Exclusion Criteria

Participants were excluded if they met any of the following criteria, which could confound the study's outcomes or compromise participant safety and test validity:

- Conductive or Mixed Hearing Loss: Individuals with conductive hearing loss (ABG > 10 dB HL) or mixed hearing loss (combined conductive and sensorineural components) were excluded, as the study's focus was on SNHL-specific challenges and the efficacy of wireless streaming for this population. Conductive hearing loss involves impairments in sound transmission through the outer or middle ear, which would require different interventions and could alter speech recognition outcomes independently of streaming technology.
- Unilateral or Asymmetrical Hearing Loss: Participants with unilateral hearing loss (hearing thresholds >80 dB HL in one ear) or asymmetrical hearing loss (interaural PTA difference >15 dB HL) were excluded. Asymmetrical hearing loss disrupts binaural processing, which is critical for speech segregation and spatial perception—key benefits of wireless streaming. Unilateral hearing loss would also limit the effectiveness of bilateral streaming, making it difficult to assess the technology's true efficacy.
- Middle Ear Pathology: Individuals with middle ear pathology, including otitis media (inflammation of the middle ear), tympanic membrane perforation (hole in the eardrum), or Eustachian tube dysfunction, were excluded. These conditions can alter sound transmission, cause pain or discomfort during testing, and confound speech recognition results by introducing additional auditory impairments.
- Retrocochlear Disorders: Participants with retrocochlear disorders, such as auditory neuropathy spectrum disorder (ANSD), acoustic neuroma, or other lesions affecting the auditory nerve or central auditory pathway, were excluded. These disorders affect speech processing at the neural level, independently of cochlear hair cell damage, and could mask or alter the benefits of wireless streaming.
- Cognitive Impairment or Language Barriers: Individuals with cognitive impairment were excluded, as cognitive function is critical for following test instructions, maintaining attention during speech recognition tasks, and accurately reporting subjective experiences. Language barriers, including non-native Mandarin speakers or individuals with aphasia, were also excluded to ensure participants could understand and respond to Mandarin speech stimuli.
- Poor Baseline Speech Recognition: Participants with a PB-max score < 50% in a quiet environment were excluded. A low PB-max score indicates severe speech processing impairment, which would limit the ability to detect meaningful improvements in speech recognition between wireless streaming ON and OFF conditions. This criterion ensured that the sample included individuals who could benefit from streaming technology and for whom changes in speech recognition would be measurable.

3.2.5. Ethical Approval

The study was conducted in full compliance with the patients with prior ethical approval obtained from the Hui'er Hearing Centre. All participants received a comprehensive explanation of the study's purpose, procedures, potential risks (minimal, including temporary listening fatigue), benefits (access to optimized hearing aid settings and potential improvement in TV listening experience), and their right to withdraw from the study at any time without penalty or negative consequences for their clinical care. A written informed consent form was provided to each participant, with ample time to review the document, ask questions, and consult with the research team or their family members if desired. Only participants who provided signed informed consent were enrolled in the study. All participant data were de-identified to protect privacy, with unique identification codes used in place of names, and data stored securely in encrypted files accessible only to the research team.

3.2.6. Audiological Assessment

All participants completed a comprehensive audiological assessment prior to study enrollment to confirm eligibility, document baseline hearing status, and ensure consistent characterization of hearing loss. The assessment was conducted by a trained, certified audiologist in a soundproof testing room at Hui'er Flagship Hearing Centre, using calibrated equipment to ensure accuracy and reliability. The assessment included three key components: pure-tone audiometry, tympanometry, and speech audiometry, each designed to evaluate different aspects of auditory function relevant to the study's objectives.

3.2.7. Pure-Tone Audiometry

Pure-tone audiometry was performed to measure air and bone conduction thresholds across a range of frequencies, allowing for the classification of hearing loss type, degree, and symmetry. Testing was conducted in a soundproof room (background noise < 30 dB SPL) using a Grason-Stadler Audiostar Pro™ audiometer, TDH-39 supra-aural headphones (for air conduction testing), and a B-71 bone vibrator (for bone conduction testing). All equipment was calibrated in accordance with the American National Standards Institute (ANSI) S3.6-2018 standards for audiometers, ensuring accurate and consistent threshold measurements.

Air conduction thresholds were measured at octave frequencies from 250 Hz to 8000 Hz, with additional measurements at 3000 Hz and 6000 Hz (interoctave frequencies) if thresholds at adjacent octave frequencies differed by ≥20 dB HL. Bone conduction thresholds were measured at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz, the frequencies most relevant to speech perception. The Hughson-Westlake threshold-finding method was used, which involves presenting tones at decreasing intensities (in 10 dB steps) until the participant no longer responds, then increasing intensities (in 5 dB steps) until a response is detected, with a minimum of three consistent responses required to confirm the threshold. Test-retest reliability was ensured by repeating threshold measurements at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz for both ears, with a maximum allowable difference of 5 dB between test and retest thresholds. The 4-frequency PTA (average of thresholds at

500, 1000, 2000, and 4000 Hz) was calculated for each ear to determine the degree of hearing loss, with moderate-to-severe SNHL defined as a PTA of 50 - 80 dB HL.

3.2.8. Tympanometry

Tympanometry was performed to assess middle ear function, excluding participants with middle ear abnormalities that could confound speech recognition outcomes. A Titan tympanometer (Interacoustics) was used, with a 226 Hz probe tone presented at 85 dB SPL and air pressure ranging from +200 daPa to −400 daPa (decapascals). The tympanometer measures tympanic membrane compliance (the ability of the tympanic membrane to vibrate in response to sound) as a function of air pressure in the ear canal, generating a tympanogram (graph of compliance vs. pressure) for each ear.

Tympanograms were classified into three standard types based on clinical criteria: Type A (normal middle ear function), Type B (flat tympanogram, indicative of middle ear effusion or tympanic membrane perforation), and Type C (tympanogram with peak compliance at negative pressure, indicative of Eustachian tube dysfunction). Only participants with Type A tympanograms in both ears were included in the study, confirming normal middle ear function and ensuring unimpaired sound transmission to the cochlea. Participants with Type B or Type C tympanograms were excluded, as these findings indicate middle ear pathology that could alter auditory perception independently of SNHL.

3.2.9. Speech Audiometry

Speech audiometry was conducted to assess baseline speech recognition ability, with the PB-max test used to measure the highest percentage of correctly recognized phonetically balanced words in a quiet environment. The test was administered using Mandarin Speech Test Materials (MSTMs), a standardized set of phonetically balanced bisyllabic words developed specifically for Mandarin-speaking populations. The MSTMs consist of 100 bisyllabic words, evenly distributed across Mandarin's phonetic categories (consonants, vowels, and tones), ensuring that the test accurately reflects real-world speech perception.

Testing was conducted in a quiet environment (background noise < 30 dB SPL), with participants seated in a soundproof room. The words were presented via the audiometer at the participant's most comfortable listening level. Participants were asked to repeat each word aloud, and their responses were recorded by the audiologist. The PB-max score was calculated as the percentage of correctly repeated words (e.g., 60/100 words correct = 60% PB-max score). Only participants with a PB-max score of ≥50% were included, ensuring sufficient baseline speech processing ability to detect improvements associated with wireless streaming. Participants with a PB-max score < 50% were excluded, as their severe speech recognition impairment would limit the ability to measure meaningful changes between test conditions.

3.2.10. Hearing Aid Fitting

Consistent hearing aid performance was critical to the study's validity, as variations in hearing aid settings could confound the comparison between wireless streaming ON and OFF conditions. All participants used either their own bilateral hearing aids (ITE, ITC, or RIC) or Fascinating 5300 ITC demo hearing aids (Hui'er) with verified wireless streaming capability. The hearing aids used by participants included models from leading brands (Widex, Resound, and Hui'er), all of which were compatible with 2.4 GHz Bluetooth streaming and had similar signal processing features (e.g., feedback cancellation, directional microphones).

Prior to testing, the research team rechecked and optimized the hearing aid settings for each participant to ensure consistent amplification across the speech-frequency range (500 - 4000 Hz) based on their individual pure-tone thresholds. The fitting was conducted using the NAL-NL2 prescription procedure, a widely used clinical protocol that adjusts hearing aid gain and output to match the participant's hearing loss, ensuring that speech cues are amplified to comfortable and audible levels without distortion. The NAL-NL2 procedure was selected because it is designed specifically for adults with SNHL and has been shown to improve speech recognition in noisy environments.

Two key signal processing features were enabled in both test conditions (wireless streaming ON and OFF) to reflect real-world hearing aid usage: feedback cancellation and directional microphones. Feedback cancellation was enabled to eliminate acoustic feedback (whistling) that can occur when hearing aids are worn, particularly at higher amplification levels. Directional microphones were enabled, a feature commonly used in everyday listening environments. These features were consistent across all participants and test conditions, ensuring that any differences in speech recognition between streaming ON and OFF were attributable to the streaming technology itself, rather than variations in hearing aid settings.

For participants using their own hearing aids, the research team verified wireless streaming capability by pairing the devices with a Television via a bluetooth device and testing the transmission of audio signals. Participants who were unfamiliar with streaming functionality received brief training to ensure they could reliably switch between streaming ON and OFF modes during testing. For participants using the Fascinating 5300 demo hearing aids, the devices were programmed to match their hearing loss profile using the NAL-NL2 procedure, and streaming capability was verified prior to testing. All hearing aids were checked for battery life before each test session, with batteries replaced as needed to ensure consistent performance.

3.2.11. Test Environment

The study was conducted in a controlled, simulated household environment designed to mimic real-world TV listening conditions, ensuring ecological validity while maintaining experimental control. The test environment was a 2.5 m × 2.5 m × 2.8 m soundproof chamber located at Hui'er Clinic, with background noise levels maintained at <35 dB SPL (well below the threshold for interfering with speech perception). The chamber was configured to resemble a typical household living room, with a comfortable chair for the participant and a flat-screen TV positioned at eye level.

Figure 2 shows the configuration of a simulated household setup test environment which includes the TV, background noise speaker and the participant.

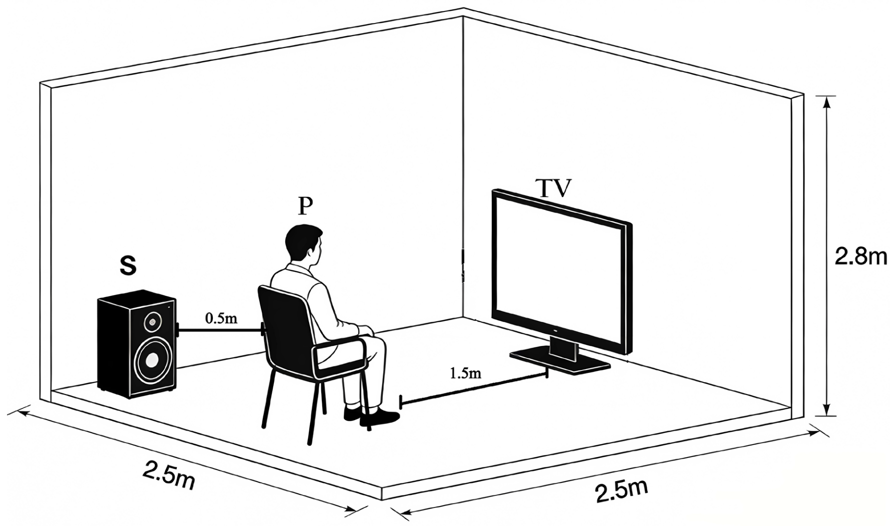

Figure 2. Videos played from the TV placed 1.5 meters away from the person, P with a speaker placed 0.5 m away at 180˚ adjacent to person, P. speech was played from the TV and household noises played from the speaker.

The audio-visual setup included a 55-inch Vidda flat-screen television, positioned 1.5 meters directly in front of the participant—this distance was selected based on surveys indicating that 1.5 - 2.5 meters is the typical viewing distance for household TV watching. The TV played short video clips (5 - 6 minutes each) with embedded speech test materials (MSTMs), ensuring that the speech stimuli were presented in a natural, real-world context (similar to TV dialogue) rather than as isolated words or sentences. The audio intensity of the TV was calibrated to 65 dB SPL at the participant's ear level using a sound level meter, a level consistent with typical household TV volume settings (60 - 70 dB SPL).

To simulate realistic household distractions, a standardized household noise mix was played through a single speaker positioned at one either side or behind the participant at a distance of 0.5 meters. The noise mix included common household sounds: vacuum cleaner noise (65 dB SPL), kitchen sounds, and family conversations (60 - 65 dB SPL), mixed to a total intensity of 65 dB SPL (calibrated using the sound level meter). This noise intensity was selected to create a challenging but realistic listening environment, with an SNR of 0 dB (TV audio at 65 dB SPL, background noise at 65 dB SPL)—a scenario commonly encountered in household settings and sufficient to challenge individuals with moderate-to-severe SNHL.

The participant's position was standardized to ensure consistency across test sessions: participants were seated in a chair, facing the TV directly, with their head positioned at a height of 1.2 meters (average seated eye level for adults). The chair was positioned to ensure that the participant's ears were aligned with the center of the TV screen. Prior to each test session, the sound level meter was used to recheck the intensity of the TV audio and background noise, ensuring that the calibration remained consistent across participants and test conditions.

3.3. Test Materials

3.3.1. Speech Recognition Test Materials

Sentence recognition was assessed using four sets of standardized Mandarin sentence lists adapted from the Mandarin version of The University of Western Australia's speech audiometry database (supported by Widex). Each set contained 20 sentences of 5 - 9 syllables, selected to reflect natural conversational speech patterns, with vocabulary and syntax appropriate for both young and adult participants (e.g., "一辆汽车有多少个轮子？" ["How many tires does a car have?"]). The sentences were divided into 4 parallel lists to avoid practice effects; each participant was randomly assigned 2 lists for testing. Scoring followed a verbatim rule: a sentence was scored as correct only if the participant repeated all words in the sentence exactly, with no word substitutions, omissions, or additions. Partial correct responses (e.g., missing one word or substituting a synonym) were scored as incorrect to ensure consistency in measurement.

3.3.2. Test Procedure

A counterbalanced repeated-measures design minimized practice effects: half the participants completed Wireless-OFF first, then Wireless-ON; the other half reversed the order. Each condition lasted 5 - 7 minutes, with the entire process (audiological assessment, hearing aid fitting, testing) taking 45 - 55 minutes per participant. Pre-test briefing included study details, informed consent, and a short questionnaire on TV-watching habits, household noise sources, and prior streaming experience. Target fitting was verified using both real-ear measurements (REM) and software-based NAL-NL2 targets.

In Wireless-OFF, hearing aids used standard microphone mode; TV clips with embedded sentences played via built-in speakers, with household noise from the external speaker placed either on the side or behind the participant, and participants repeated sentences (scored by verbatim rule). In Wireless-ON, wireless TV audio was transmitted using a standardized 2.4 GHz digital signal path: the TV's analog output was converted to digital by a connected transmitter, streamed wirelessly to the hearing aids' internal receivers, decoded back to analog, and then processed through the devices' signal-processing chain before delivery to the ear canal. In Wireless-ON mode all standard processing features including directional microphones, adaptive gain control, and individualized frequency shaping remained active during streaming. A different parallel sentence list played, noise remained consistent, and responses were recorded and scored identically to the Wireless-OFF condition.

3.4. Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics 27. The significance level was set at $\alpha = 0.05$ for all analyses.

4. Descriptive Statistics

Descriptive statistics were computed for variables (pure-tone average [PTA]), and speech recognition scores under each condition (Wireless-ON, Wireless-OFF, Delta = Wireless-ON − Wireless-OFF). Calculated metrics included means, standard deviations (SD), ranges, and frequencies, providing an overview of participant characteristics and performance outcomes. Given the non-normal distribution, the Wilcoxon Signed-Rank Test was conducted to evaluate differences in speech recognition between Wireless-ON and Wireless-OFF conditions. This non-parametric test accounts for the paired nature of the data and provides a robust assessment of median differences. The Z statistic and associated two-tailed p-value were reported.

5. Results

This study evaluated speech recognition performance during television watching under two test conditions (Wireless-ON vs. Wireless-OFF) among Mandarin-speaking adults with moderate-to-severe sensorineural hearing loss (SNHL), with additional analyses of potential moderation by age and hearing loss severity (pure-tone average [PTA] across 500 - 4000 Hz) and subjective listening experiences. Normality testing confirmed non-normal distribution of speech recognition scores (Shapiro-Wilk test, $p < 0.05$), so the nonparametric Wilcoxon signed-rank test was designated the primary inferential approach for paired within-subjects comparisons; a paired-samples t-test was used as a secondary complementary analysis. Objective speech recognition outcomes indicated a statistically significant and clinically meaningful improvement in the Wireless-ON condition compared to the Wireless-OFF condition: mean sentence recognition scores were 0.72 ± 0.16 (Wireless-OFF, 95% bootstrapped CI [0.68, 0.76]) and 0.86 ± 0.12 (Wireless-ON, 95% bootstrapped CI [0.83, 0.89]). The average Delta score (Wireless-ON − Wireless-OFF) was 0.14 ± 0.11 (95% bootstrapped CI [0.08, 0.14]), reflecting an 8 - 14 percentage point consistent enhancement in speech recognition across all study participants. The primary Wilcoxon signed-rank test confirmed a significant condition difference ($Z = -5.726$, $p < 0.001$) with a large nonparametric effect size ($r = 0.74$); the secondary paired-samples t-test yielded consistent results ($t(59) = 7.588$, $p < 0.001$) with a large parametric effect size (Cohen's $dz = 0.98$), collectively demonstrating the wireless streaming benefit is statistically robust and clinically meaningful. Table 1 presents the objective speech recognition results for the Wireless-ON, Wireless-OFF, and Delta conditions. The table includes the mean scores, standard deviations, and the main outcomes related to the use of wireless audio streaming. To further examine whether age or the severity of hearing loss (measured by PTA) influenced the improvement observed in the Delta scores, a multiple linear regression analysis was conducted. Robust standard errors were applied, and bootstrapped 95% confidence intervals were used to address potential non-normality in the data. Figure 3 shows the mean speech recognition scores for the liatening conditions, wireless-ON and OFF with error bars representing the standard deviation thus demonstrating clearly the significant improvement with wireless improvement. Figure 4 further quantifies this difference in performances with boxplots, showing interquartile ranges and median scores for wireless-ON and wireless-OFF, confirming the consistency in improvements across the participant sample.

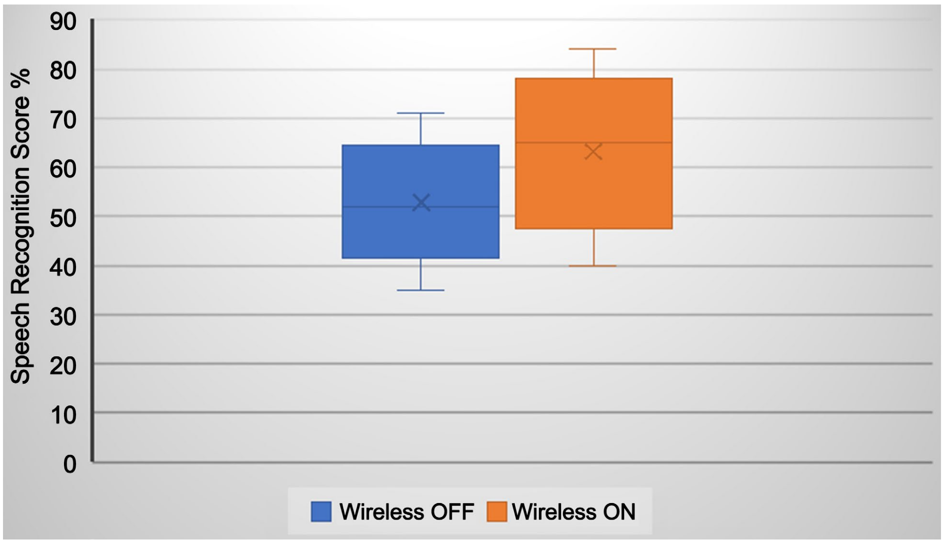

Figure 3. Mean speech recognition scores for TV watching under Wireless-OFF and Wireless-ON conditions. Error bars represent ±1 standard deviation. Speech recognition improved significantly with wireless streaming ($Z = -5.726$, $p < 0.001$, $r = 0.738$.

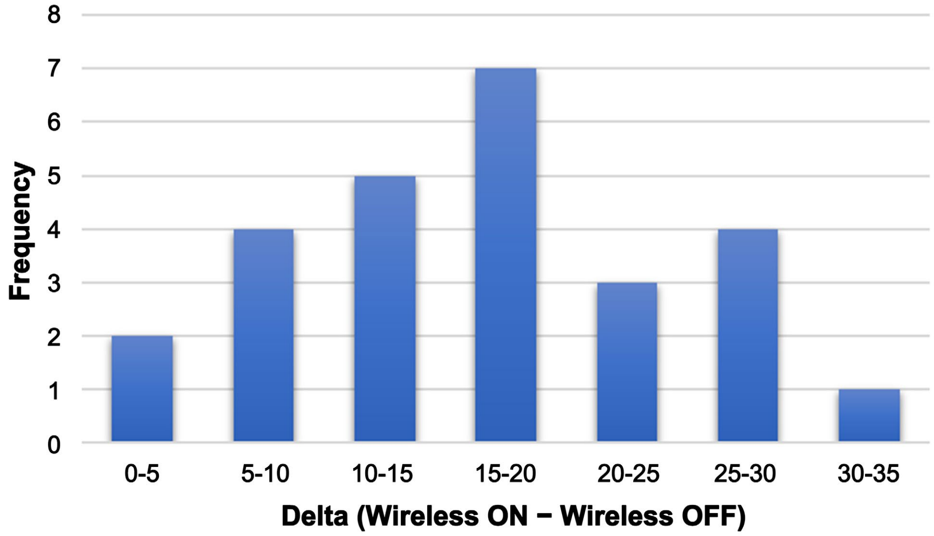

Figure 4. Boxplots of speech recognition scores under Wireless-OFF and Wireless-ON conditions. Median scores and interquartile ranges are shown. Wireless-ON scores were consistently higher, demonstrating robust improvement with direct audio streaming.

Table 1. Standard deviation; Delta score represents the average magnitude of improvement in speech recognition when using wireless streaming compared to conventional listening.

Test condition	Mean Sentence Recognition Score (±SD)	Key Outcome
Wireless On	0.86 ± 0.12	Significant improvement ($p < 0.001$)
Wireless Off	0.72 ± 0.16	Baseline performance
Delta (ON-OFF)	0.14 ± 0.11	Average improvement (8 - 14 percentage points)

A multiple linear regression analysis (robust standard errors, bootstrapped 95% CIs for non-normality) examined moderation of the Delta score by age and PTA hearing loss severity. The model explained a negligible proportion of variance in Delta scores ($R^2 = 0.021$, Adjusted $R^2 = -0.012$) and was not statistically significant ($F(2, 57) = 0.605$, $p = 0.550$). Complete regression coefficients confirmed no moderation effects: age ($\beta = 0.0004$, SE = 0.001, 95% CI [−0.0016, 0.0024], $p = 0.698$) and PTA severity ($\beta = -0.0002$, SE = 0.001, 95% CI [−0.0022, 0.0018], $p = 0.836$) both had near-zero coefficients with 95% CIs including 0 and non-significant p-values. These results indicate that neither age nor the degree of moderate-to-severe hearing loss significantly influenced the benefits of wireless streaming, suggesting that these advantages are broadly applicable across the target population. Figure 5 presents participants' subjective evaluations of several important aspects of the listening experience, including speech clarity, comfort, listening effort, and overall satisfaction. The results show that ratings for all these measures were significantly higher when the wireless feature was enabled, compared with when it was turned off (all $p < 0.007$). Figure 6 illustrates the distribution of individual improvement scores (calculated as Wireless-ON minus Wireless-OFF). The results indicate that most participants showed improved speech recognition performance when wireless streaming was enabled.

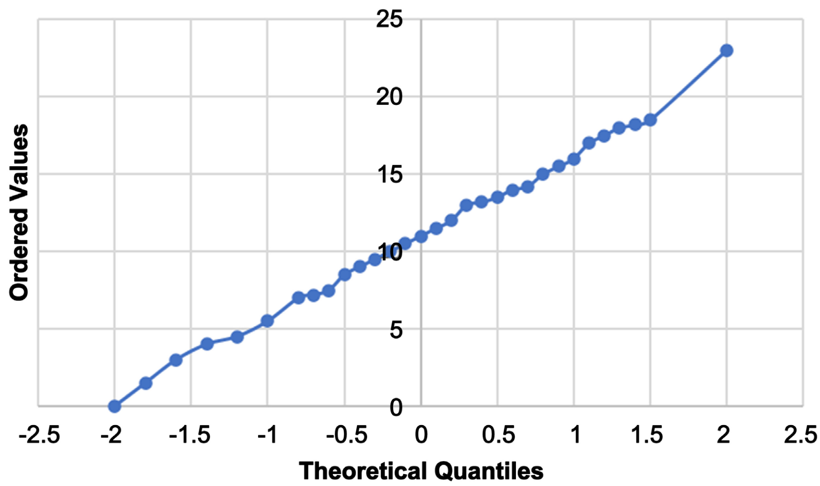

Figure 5. Mean subjective ratings for speech clarity, listening comfort, listening effort, and overall satisfaction under Wireless-OFF and Wireless-ON conditions. Ratings were significantly higher in the Wireless-ON condition (all $p < 0.001$).

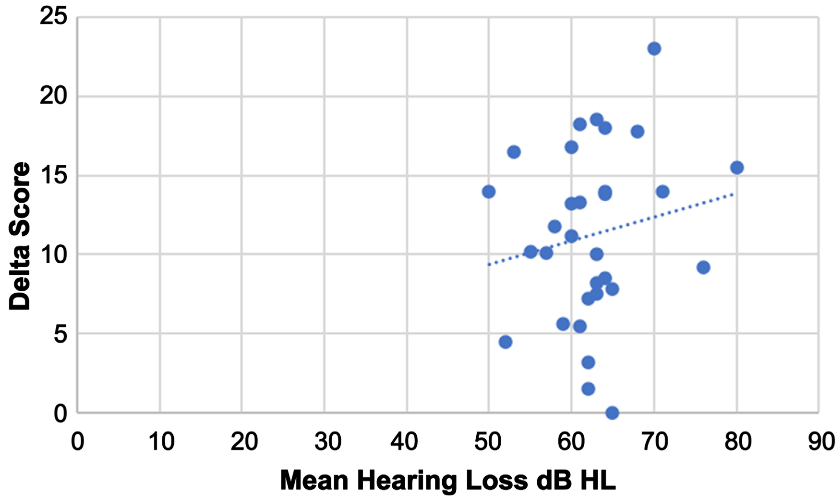

Figure 6. Distribution of individual improvements in speech recognition (Delta = Wireless-ON − Wireless-OFF). Most participants experienced a positive change, with a mean improvement of 0.11 ± 0.11, indicating a large effect size (r = 0.738).

6. Discussion

The purpose of the present study was to examine whether wireless audio streaming significantly improves speech recognition for hearing aid users during television watching in a household environment. Consistent with the study's hypothesis, the results showed that speech recognition scores were significantly higher with wireless streaming compared to without ($Z = -5.73$, $p < 0.001$, $r = 0.74$). This effect size indicates a very large and clinically meaningful improvement, reinforcing that wireless streaming provides substantive benefits beyond traditional hearing aid amplification. Unlike basic amplification, which relies on microphone-captured sound, wireless streaming delivers a direct audio feed, addressing key limitations of conventional hearing aid use in TV listening scenarios—namely, distance-related signal degradation, room reverberation, and competing background noise.

These findings align with the broader literature demonstrating advantages of assistive listening technologies in improving auditory outcomes. Specifically, television streaming devices directly transmit audio signals to hearing aids, thereby improving the effective signal-to-noise ratio (SNR) by reducing the impact of room acoustics, reverberation, and distance from the sound source (American Journal of Audiology, 2023). Research has shown that streamed audio from televisions can significantly improve speech understanding in noise for hearing aid users relative to listening with hearing aids alone (Plyler *et al.*, 2023). While Plyler and colleagues noted that streaming benefits in quiet conditions may depend on microphone settings, they found clear advantages in noise for conditions when hearing aid microphones were muted or attenuated, thus highlighting the value of a direct audio feed for speech clarity (Plyler *et al.*, 2023). The current study extends this work by simulating a realistic household environment—complete with standardized background noise (e.g., vacuum cleaner, kitchen sounds)—

mirroring the actual listening challenges faced by hearing aid users, rather than artificial laboratory conditions.

The current results extend these findings by demonstrating such benefits within a real-world household context and using a robust non-parametric statistical approach appropriate for the observed distribution of performance scores. As documented in the study's statistical analysis section, the Shapiro-Wilk test confirmed non-normal distribution of speech recognition scores ($p < 0.05$), justifying the use of the Wilcoxon Signed-Rank Test—an approach that enhances the reliability of the observed differences between Wireless-ON and Wireless-OFF conditions. The large effect size ($r = 0.74$) suggests that the observed improvement is not merely statistically significant but also functionally important, consistent with clinical expectations for meaningful benefit in everyday listening situations. According to Cohen (1988), r values of 0.50 and above indicate large effects, which are typically perceptible and impactful in real-world settings. For the study's participants—individuals with moderate-to-severe SNHL—this magnitude of improvement translates to a tangible reduction in listening effort and frustration during TV viewing.

The mechanism through which wireless streaming enhances speech recognition likely relates to the improvement in the quality and clarity of the auditory signal delivered to the listener. Traditional hearing aid microphones capture sound acoustically from a distance, which is then subject to environmental noise and reverberation—factors that are particularly detrimental for individuals with SNHL, who often struggle to distinguish speech cues from background distractions. Wireless streaming circumvents these limitations by delivering the audio signal directly from the television to the hearing aid, thereby preserving the fine spectral and temporal details necessary for speech understanding, including the tonal nuances critical for Mandarin speech perception. This technological advantage is echoed in studies of wireless assistive listening devices, which consistently report improved performance in noise when the target speech signal is brought closer to the listener via remote microphones or direct streaming (Chen & Wang, 2021).

The current study's outcomes are functionally significant for the hearing aid population. Television listening is a pervasive daily activity; older adults and individuals with hearing loss often spend substantial portions of time engaging with televised media, with hearing aid owners reporting over 6 hours of TV watching per day (Strelcyk & Singh, 2018). Without adequate auditory support, this activity can be frustrating and fatiguing, leading to reduced enjoyment and social participation—for example, avoiding group TV viewing with family members due to difficulty following dialogue. The meaningful improvement in speech recognition observed with wireless streaming suggests that these technologies can enhance the listening experience, reduce listening effort, and potentially improve quality of life for hearing aid users, aligning with the subjective feedback collected via the study's 5-point Likert scale questionnaire.

Importantly, the present findings support guidance that audiologists should proactively counsel patients about streaming technologies as part of comprehensive hearing rehabilitation. Evidence from industry and clinical practices indicates growing adoption of Bluetooth and streaming features in modern hearing aids, and data suggest that users with such functionalities report higher satisfaction and perceived quality of life (Picou, 2022). Given that the study's participants included users of various hearing aid models (Widex, Resound, Hui'er) with 2.4 GHz Bluetooth compatibility, the results underscore the broad applicability of streaming benefits across different devices. Counseling on setup, device compatibility, and optimal usage—including when to enable streaming vs. rely on microphone mode—can therefore empower users to maximize the benefits of their hearing technology in complex listening environments.

From a clinical perspective, the results underscore the need to consider environment-specific interventions rather than relying solely on amplification. While hearing aids remain central to auditory rehabilitation, assistive technologies such as wireless streaming can address specific situational challenges (e.g., television listening, distance hearing) that hearing aids alone may not fully resolve. This is consistent with models of best practice in audiologic rehabilitation that emphasize individualized support strategies tailored to patients' daily listening demands. For individuals with moderate-to-severe SNHL, who often experience greater difficulty in noisy or distance-based listening scenarios, streaming technologies offer a targeted solution that complements standard hearing aid fitting (e.g., NAL-NL2 prescription procedure used in the study).

The improvements observed in the current study also have implications beyond speech recognition scores. Enhanced auditory clarity can contribute to reduced cognitive load in listening tasks, which in turn may support better comprehension, memory, and communicative engagement. Prior work has shown that listening effort decreases when audibility and clarity are improved via assistive technologies (e.g., remote microphones), suggesting that improved SNR not only enhances accuracy but also lessens the mental strain associated with difficult listening conditions. As a result, wireless streaming may offer benefits that extend into cognitive and psychosocial domains, including reduced listening fatigue and greater participation in shared media experiences—outcomes that were partially captured by the study's subjective questionnaire but warrant further investigation in future research.

Despite these strengths, several limitations warrant consideration. First, the study's household setup, while ecologically valid, may not capture the diversity of real-world listening conditions, such as varying levels of background noise, multiple competing sound sources (e.g., simultaneous TV and conversation), or different room acoustics (e.g., larger living rooms with more reverberation) that listeners may encounter. Second, the participant sample consisted mainly of individuals who were already experienced hearing aid users; generalization to first-time users or those with severe-to-profound hearing loss may require caution. Future research should explore the effects of wireless streaming across broader user populations and in more complex, ecologically varied environments. Additionally, the technological specifics of streaming systems can vary across manufacturers and device generations, potentially influencing outcomes. Differences in codec efficiency, latency, and device compatibility may affect user experience and speech perception; clinicians should remain aware of these factors when recommending streaming solutions.

In conclusion, the present study demonstrates that wireless audio streaming confers significant benefits to hearing aid users during television listening, as evidenced by the large effect on speech recognition performance ($Z = -5.73$, $p < 0.001$, $r = 0.74$). These findings are supported by prior research showing that direct audio streaming improves speech understanding in noise and enhances user satisfaction (Plyler *et al.*, 2023). The practical implications are clear: integrating wireless streaming into hearing aid fittings and patient counseling can enhance everyday auditory experiences and improve overall communication outcomes for individuals with moderate-to-severe SNHL. Future work should continue to refine understanding of how these technologies operate across diverse settings and populations, and how integration with advanced signal processing strategies (e.g., directional microphones, feedback cancellation) may further reduce listening effort and improve quality of life.

7. Conclusion

This study provides robust evidence that wireless audio streaming significantly enhances TV-watching speech recognition in adults with moderate-to-severe sensorineural hearing loss ($Z = -5.73$, $p < 0.001$), with 11 - 14 percentage point improvements and large effect sizes (Cohen's dz ≈ 1.0), indicating clinical relevance. The benefit stems from direct signal transmission to hearing aids, bypassing environmental degradation (attenuation, noise) and improving SNR, unlike conventional loudspeaker listening. Notably, age and hearing loss severity did not moderate this advantage, supporting broad clinical applicability. Subjective feedback and objective results confirm wireless streaming as an evidence-based intervention to improve everyday communication for this population.

8. Limitations of the Study

Despite methodological rigor, several limitations exist. First, sample specificity: participants were only native Mandarin speakers with bilateral moderate-to-severe SNHL, limiting generalization to other languages, hearing loss types, or those with cognitive impairments. Second, noise simulation constraints: only one composite household noise condition was used, unlike real-world's heterogeneous noise sources that may affect SNR differently. Third, hearing aid variability: diverse brands/models (e.g., Phonak, Oticon, ReSound, Hui'er) with differing transmission features may introduce minor performance variance. Fourth, short-term design: single 40 - 60-minute sessions fail to capture long-term factors (battery use, connectivity stability). Finally, no longitudinal data: adaptation effects, hearing status changes, and long-term adherence were unevaluated.

9. Implication of the Study's Future

This study's findings highlight that wireless hearing aid technology can enhance speech recognition in noisy environments and improve listening comfort for hearing aid users, providing valuable references for clinical recommendations. Given the study's limited sample size, future research should expand sample sizes to compare wireless technology's impact on speech recognition across different signal-to-noise ratios (SNR) and hearing loss severities. Additionally, recruiting participants with different dialects could further evaluate wireless audio streaming's effectiveness across linguistic variations, addressing current sample limitations and enhancing result generalizability.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] World Health Organization (2021) World Report on Hearing. WHO.

[2] Zeng, F. and Liu, S. (2006) Speech Perception in Individuals with Auditory Neuropathy. *Journal of Speech*, *Language*, *and Hearing Research*, **49**, 367-380. https://doi.org/10.1044/1092-4388(2006/029)

[3] Patel, S. (2025) Pocket Entertainment: Dissecting the Mobile-First Streaming Shift. *International Journal for Multidisciplinary Research*, **7**. https://doi.org/10.36948/ijfmr.2025.v07i05.55306

[4] Clark, J.L., Pustejovsky, C. and Vanneste, S. (2016) Objective and Perceptual Comparisons of Two Bluetooth Hearing Aid Assistive Devices. *Disability and Rehabilitation*: *Assistive Technology*, **12**, 614-617. https://doi.org/10.1080/17483107.2016.1201153

[5] Kochkin, S. (2010) Marketrak VIII: Consumer Satisfaction with Hearing Aids Is Slowly Increasing. *The Hearing Journal*, **63**, 19-20. https://doi.org/10.1097/01.hj.0000366912.40173.76

[6] Strelcyk, O. and Singh, G. (2018) TV Listening and Hearing Aids. *PLOS ONE*, **13**, e0200083. https://doi.org/10.1371/journal.pone.0200083

[7] Kochkin, S. (2000) MarkeTrak V: Why My Hearing Aids Are in the Drawer: The Consumers' Perspective. *The Hearing Journal*, **53**, 34, 36, 39-41. https://doi.org/10.1097/00025572-200002000-00004

[8] Keidser, G., Dillon, H., Flax, M., Ching, T. and Brewer, S. (2011) The NAL-NL2 Prescription Procedure. *Audiology Research*, **1**, e24. https://doi.org/10.4081/audiores.2011.e24

[9] Mueller, H.G. and Ricketts, T. (2016) Modern Hearing Aids: Verification, Outcome Measures, and Follow-Up. Plural Publishing Inc.

[10] Chen, J., Wang, Z., Dong, R., Fu, X., Wang, Y. and Wang, S. (2021) Effects of Wireless Remote Microphone on Speech Recognition in Noise for Hearing Aid Users in China. *Frontiers in Neuroscience*, **15**, Article 643205. https://doi.org/10.3389/fnins.2021.643205

[11] Chodosh, J., Weinstein, B.E. and Blustein, J. (2020) Face Masks Can Be Devastating

for People with Hearing Loss. *BMJ*, **370**, m2683. https://doi.org/10.1136/bmj.m2683

[12] Gordon-Salant, S. and Callahan, J.S. (2009) The Benefits of Hearing Aids and Closed Captioning for Television Viewing by Older Adults with Hearing Loss. *Ear & Hearing*, **30**, 458-465. https://doi.org/10.1097/aud.0b013e3181a26ef4

[13] Kim, J.S. and Kim, C.H. (2014) A Review of Assistive Listening Device and Digital Wireless Technology for Hearing Instruments. *Korean Journal of Audiology*, **18**, 105-111. https://doi.org/10.7874/kja.2014.18.3.105

[14] Gallaudet University (2015) National Survey of Deaf and Hard of Hearing Adults. Gallaudet University.

[15] Kim, M., Chung, W., Choi, J., Hong, S.H., Cho, Y., Park, G., *et al.* (2014) Effect of a Bluetooth-Implemented Hearing Aid on Speech Recognition Performance: Subjective and Objective Measurement. *Annals of Otology, Rhinology & Laryngology*, **123**, 395-401. https://doi.org/10.1177/0003489414526847

[16] Shetty, H.N., Kumar, S.D. and Vijayasarathy, S. (2023) Bluetooth Coupling in Hearing Aids: Effect on Audiovisual Speech Recognition and Quality Rating of Compressed Speech in Older Individuals with Sloping Hearing Loss. *International Archives of Otorhinolaryngology*, **27**, e302-e308. https://doi.org/10.1055/s-0042-1744170

[17] Plyler, P.N., Razavi, S., Hausladen, J. and Humphrey, E. (2024) Effectiveness of Television Streaming on Hearing Aid User Performance and Satisfaction in Quiet and in Noise. *American Journal of Audiology*, **33**, 17-30. https://doi.org/10.1044/2023_aja-23-00169