DOI: 10.61782/fa.2025.0716

FORUM ACUSTICUM
EURONOISE 2025

PSYCHOACOUSTICS OF REMIXING MUSIC: CATERING TO HARD-OF-HEARING AND NORMAL-HEARING AUDIENCES FOR ENHANCED EXPERIENCES

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ABSTRACT

Music mixing practices are typically designed for normal-hearing (NH) listeners, often overlooking the preferences of hard-of-hearing (HoH) individuals. This study investigates differences in preferred Lead-to-Accompaniment Ratio (LAR) between NH and HoH listeners. Experiment 1 compared LAR preferences between NH (mean 7.61 dB) and HoH participants (mean 10.41 dB), while Experiment 2 examined variations across different degrees of hearing loss. Results indicate that HoH listeners consistently prefer a higher LAR than NH listeners, with stronger preferences observed as hearing loss severity increases. Specifically, mild HoH listeners preferred a mean LAR of 6.32 dB, whereas profound HoH listeners preferred a mean LAR of 13.10 dB. These findings suggest that conventional music mixing approaches may not optimally serve HoH individuals.

To enhance accessibility, customizable audio mixing strategies, such as user-adjustable LAR settings, should be considered. Future research should validate findings using audiometric verification and explore additional auditory factors influencing music perception. By integrating adaptive mixing practices, the music industry can create a more inclusive listening experience for individuals with hearing impairments.

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Keywords: *hearing loss, lead-to-accompaniment ratio, music perception, audio mixing, accessibility*

1. INTRODUCTION

Music plays a pivotal role in social bonding, emotional expression, and overall well-being. Attending live music performances with friends enhances social interactions, fosters a sense of community, and creates shared experiences that contribute to emotional fulfillment and psychological health [1]. The collective enjoyment of music allows individuals to feel included in a larger social group, strengthening relationships and enhancing social cohesion. However, for individuals with hearing loss, these experiences can be less enjoyable, as they often struggle to perceive and appreciate the music in the same way as their normal-hearing (NH) peers. This disparity can lead to feelings of exclusion and frustration, diminishing their engagement with live performances and other shared auditory experiences.

One of the primary reasons for this exclusion lies in the fact that different individuals have varying hearing needs, making a single audio mix unsuitable for everyone. Additionally, in both live and recorded settings, sound technicians balance various audio elements, such as vocals, instruments, and effects, to create a mix optimized for the majority—listeners with normal hearing. However, these standardized mixing practices do not accommodate the unique auditory needs of hard-of-hearing (HoH) individuals, who may require different balances between musical elements, particularly in the Lead-to-Accompaniment Ratio (LAR). This issue is not limited to live music

performances; it extends to recorded music, soundtracks in films and television, radio broadcasts, and commercial audio productions. Consequently, HoH individuals frequently encounter audio mixes that do not align with their auditory preferences, leading to disengagement from music and other media.

This literature review explores the differences in music perception and preferences between HoH and NH listeners, with a specific focus on LAR. By synthesizing recent research on psychoacoustics, music perception, and audio mixing practices, this review aims to identify key challenges and gaps in the field, ultimately supporting the need for more inclusive audio mixing strategies that accommodate diverse hearing profiles.

1.1 Music Listening Preferences Among Hard-of-Hearing vs. Normal-Hearing Listeners

Hearing loss significantly alters how individuals perceive and experience music. While NH listeners can discern a wide range of frequencies and dynamic contrasts, HoH listeners often experience difficulties in differentiating between musical elements, particularly when multiple sound sources are present. Reduced frequency selectivity and impaired level perception result in a diminished ability to perceive vocals and instrumental separation, leading to a less immersive listening experience [2].

Research involving cochlear implant (CI) users provides insights into these challenges. Pons et al. [3] investigated the use of source separation algorithms to remix music for CI users. Their study revealed that CI users often have different mixing preferences than NH listeners, with a tendency to favor individualized mixes that emphasize vocal elements. This preference is attributed to the deficient pitch perception in CI users, which makes it challenging to enjoy complex musical structures. By enhancing vocal clarity and simplifying the accompaniment, music becomes more accessible and enjoyable for CI users.

Similarly, Buyens et al. [4] conducted a pilot study examining music mixing preferences among CI recipients. The results indicated that CI users preferred lead vocal levels to be enhanced relative to the rest of the instruments in the mix. This finding suggests that standard mixes available to the public may not be suitable for CI listeners, highlighting the need for alternative mixing strategies that cater to their specific auditory requirements.

Extending this research to hearing aid (HA) users, Benjamin and Siedenburg [2] demonstrated that individuals with hearing loss prefer an elevated LAR compared to NH listeners. Their findings suggest that HoH listeners require enhanced vocal prominence to compensate for difficulties in speech perception within complex auditory environments. Specifically, the study found that HoH participants favored a higher LAR, indicating a preference for louder lead vocals relative to the accompaniment. This preference underscores the necessity for tailored audio mixing strategies to meet the distinct preferences of HoH listeners.

Beyond perceptual challenges, hearing loss also influences emotional engagement with music. HoH listeners often report lower levels of emotional arousal and pleasure when listening to conventional music mixes. This disparity is attributed to an insufficient balance of spectral energy, where key auditory cues are either masked or attenuated, preventing full immersion in the musical experience [5]. These findings underscore the need for adaptive audio mixing strategies that consider the unique auditory profiles of HoH individuals.

1.2 Significance of This Study

The present study is particularly relevant given its strong alignment with recent findings by Benjamin and Siedenburg [2]. Both studies, conducted independently but around the same time, arrived at similar conclusions regarding the preference for elevated LAR levels among HoH listeners. This convergence strengthens the reliability of these findings and highlights the urgent need for research-driven changes in music mixing practices. However, while Benjamin and Siedenburg [2] focused on HA users, our study provides complementary insights that may differ in participant demographics, music selection, and methodology. By comparing and contrasting these perspectives, our study contributes to a broader understanding of how hearing loss affects music perception and offers practical recommendations for inclusive audio mixing.

1.3 Research Question

In summary, existing research indicates that HoH listeners, including HA and CI users, prefer a higher LAR to facilitate better vocal intelligibility and overall music enjoyment. However, conventional mixing practices often overlook these preferences, and we do not yet know the exact LAR value associated with HoH listeners. This gap underscores the necessity for further research to establish concrete quantitative preferences. Therefore, this study aims to investigate: Do NH and HoH listeners differ in their preferred LAR levels? Specifically, what are the preferred LAR values for each group, and how do they compare? Furthermore, do

preferred LAR values vary with the degree of hearing loss?

2. METHODS

2.1 Participants

In Experiment 1, a total of 256 participants took part in the study, including NH listeners (n = 199) and Bilateral HoH listeners (n = 57). Participants were recruited through social media platforms. The study was conducted online, allowing participants to complete the experiment remotely without the need for in-person meetings.

In Experiment 2, the study focused exclusively on Bilateral HoH listeners (n = 84), who were further categorized into hearing impairment subgroups: mild HL (hearing levels thresholds in the range 26-40 dB, n = 26), moderate HL (hearing levels thresholds in the range 41-70 dB, n = 21), severe HL (hearing levels thresholds in the range 71-90 dB, n = 14), and profound HL (hearing levels thresholds above 91 dB, n = 23). Hearing status was determined via self-report, where participants categorized their hearing loss severity using predefined functional descriptors and according to the above dB hearing level thresholds (if were known to the participants).

Participants provided informed consent before taking part in the study. The study was open to individuals aged 15 and above, and all participants were required to complete an extensive online questionnaire regarding their auditory profile, including hearing loss characteristics, onset, stability, and type of hearing impairment. All experimental tasks were carried out on the participant's smartphone or personal computer.

2.2 Stimuli and Equipment

Participants listened to three commercially available songs performed by Kate Bush (Wuthering Heights), Leonard Cohen (Dance Me to the End of Love), and Bruce Springsteen (Streets of Philadelphia). These songs were chosen to ensure familiarity across participants and to represent both male and female vocalists, thereby facilitating the selection of preferred LAR.

Audio files were presented in MP3 format (44,100 Hz, 32-bit sampling rate). For each song, two predefined versions were created: a vocal-only version and an instrument-only version. Participants used a sliding control, presented on their smartphone or personal computer screen, to adjust the LAR by modifying the balance between these two tracks.

Participants were instructed to use headphones or their regular hearing aids/cochlear implants (if applicable) to complete the experiment. They were asked to listen in a quiet home environment and to avoid adjusting any device settings during the experiment. Hearing-impaired participants were advised to use their hearing aids or cochlear implants in the same mode they would typically use while watching a movie.

2.3 Procedure

2.3.1 Experiment 1: NH vs. HoH LAR Preferences

Participants in both the NH and HoH groups listened to the three music tracks and adjusted the singer's level using the sliding control. Before starting, participants set their comfortable listening level using recorded speech of a male and a female speaker. Once the preferred listening level was established, participants proceeded to adjust the LAR for each of the three songs. The final preferred LAR values were recorded and averaged for each participant. The goal was to determine whether there were significant differences in LAR preferences between NH and HoH listeners.

2.3.2 Experiment 2: Effect of Hearing Loss Severity on LAR Preferences

The second experiment focused solely on the HoH group. Participants were categorized into four hearing loss subgroups (mild, moderate, severe, and profound HL) based on their self-reported functional hearing level and dB hearing level thresholds. The same LAR adjustment task was performed, and LAR preferences were analyzed to assess whether greater hearing loss severity was associated with increased LAR preferences.

2.4 Data Collection and Analysis

Data collection was conducted remotely via an online interface. Only participants who fully completed the experimental tasks were included in the analysis. The software SPSS was used for statistical analysis.

Preferred LAR values (mean ± standard deviation) were calculated for each participant and group. A one-way analysis of variance (ANOVA) was conducted to assess whether LAR preferences significantly differed between groups. Post hoc tests (Tukey's HSD) were performed to evaluate pairwise differences. Effect sizes (η^2) were calculated to quantify the magnitude of observed differences.

3. RESULTS

3.1 Experiment 1: NH vs. HoH LAR Preferences

The independent variables (IVs) in this experiment were hearing status (NH vs. HoH, between-subjects) and song (Bruce Springsteen, Kate Bush, Leonard Cohen, within-subjects), and the dependent variable (DV) was the preferred LAR.

A repeated-measures ANOVA revealed a significant main effect of song on LAR preferences ($F(2, 253) = 22.36$, $p < 0.001$, $\eta^2 = 0.081$). Post hoc comparisons indicated that the Kate Bush song (Wuthering Heights) had significantly higher LAR values compared to both the Bruce Springsteen song (Streets of Philadelphia; mean difference = 2.77 dB, $p < 0.001$) and the Leonard Cohen song (Dance Me to the End of Love; mean difference = 3.78 dB, $p < 0.001$). Additionally, the Bruce Springsteen song had significantly higher LAR values compared to the Leonard Cohen song (mean difference = 1.01 dB, $p = 0.034$). This suggests that the musical content influenced LAR preferences across participants.

A one-way ANOVA confirmed a significant main effect of hearing status on LAR preference ($F(1, 254) = 6.75$, $p = 0.010$, $\eta^2 = 0.026$; Figure 1). On average, HoH listeners preferred a higher LAR (10.41 dB) than NH listeners (7.61 dB), with a mean difference of 2.80 dB. This result aligns with prior research indicating that individuals with hearing impairments struggle with auditory scene segregation, leading to a preference for clearer and more prominent vocal elements.

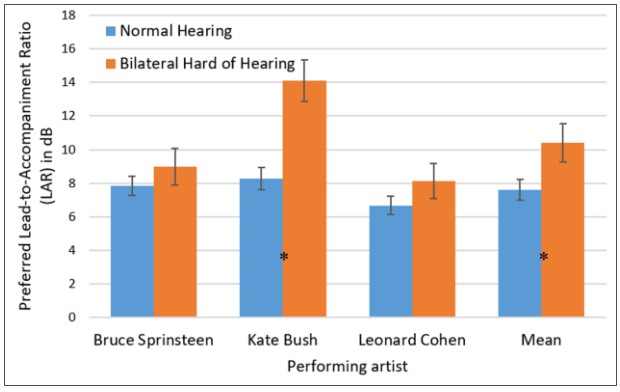

Figure 1. Preferred Lead-to-Accompaniment Ratio in dB for Normal Hearing and Bilateral Hard of Hearing listeners across three performing artists. Error bars represent standard error of the mean. ∗ indicates a statistically significant difference between groups of listeners ($p < 0.05$).

A repeated-measures ANOVA revealed a significant interaction effect between song and hearing status ($F(2, 253) = 10.03$, $p < 0.001$, $\eta^2 = 0.038$; Figure 1), indicating that the influence of song on LAR preferences differed between NH and HoH listeners. Post hoc comparisons revealed that while NH listeners showed relatively stable LAR preferences across the three songs, HoH listeners exhibited greater variability. Specifically, HoH participants demonstrated a significantly stronger preference for higher LAR values in the Kate Bush song compared to the other two songs ($p < 0.05$). This suggests that hearing-impaired listeners may be more influenced by specific acoustic characteristics of songs when adjusting their LAR preferences.

3.2 Experiment 2: Effect of Hearing Loss Severity on LAR Preferences

Further analysis examined the relationship between hearing loss severity and LAR preferences within the HoH group. A one-way ANOVA revealed a significant effect of hearing loss severity on preferred LAR ($F(3, 80) = 2.749$, $p = 0.048$, $\eta^2 = 0.093$). The mean LAR values for each group were as follows: mild hearing loss (6.32 dB), moderate hearing loss (8.97 dB), severe hearing loss (10.64 dB), and profound hearing loss (13.10 dB). The overall mean LAR across all HoH participants was 9.56 dB. Pairwise comparisons (Tukey's HSD) showed that participants with profound hearing loss selected significantly higher LAR values than those with mild hearing loss (mean difference = 6.78 dB, 95% CI [0.45, 13.10], $p = 0.031$). However, no significant differences were observed between other hearing loss groups. These results are illustrated in Figure 2.

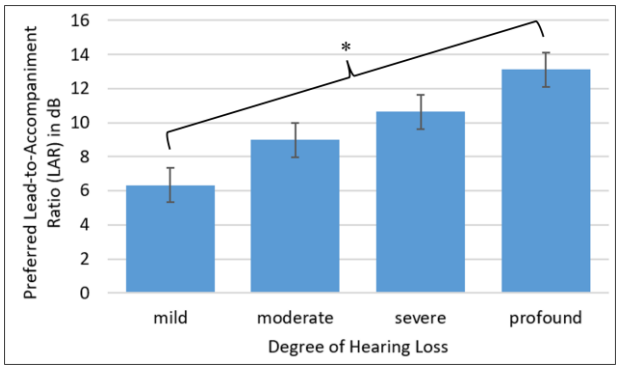

Figure 2. Preferred Lead-to-Accompaniment Ratio in dB across different degrees of hearing loss. Error bars represent standard error of the mean. ∗ indicates a statistically significant difference between the mild and profound hearing loss groups ($p < 0.05$).

4. DISCUSSION

The findings of this study align with previous research highlighting the unique music perception challenges faced by HoH individuals. Consistent with prior literature [2,4], our results demonstrate that HoH listeners prefer an elevated LAR compared to their NH peers. This preference was evident both in the general HoH group (Experiment 1) and across different degrees of hearing loss (Experiment 2), with participants exhibiting a progressively stronger preference for higher LAR values as hearing loss severity increased. These findings reinforce the notion that standard audio mixing practices may not be optimal for HoH listeners and suggest a need for adaptive mixing strategies to enhance their music experience.

In Experiment 1, NH listeners demonstrated relatively stable LAR preferences across different songs, while HoH listeners exhibited greater variability. This suggests that HoH individuals are more sensitive to specific acoustic characteristics of songs, likely due to their impaired ability to segregate auditory elements. The significantly higher LAR preferences observed in the Kate Bush song (Wuthering Heights) compared to the other songs further support this notion, as certain musical features may disproportionately affect perception among HoH listeners. These results align with previous studies indicating that CI users and HA users tend to favor enhanced vocal prominence due to difficulties with pitch perception and auditory scene segregation [3].

Experiment 2 revealed a clear trend: as hearing loss severity increased, so did the preferred LAR. This finding is consistent with previous research suggesting that individuals with greater hearing impairment require a more pronounced vocal presence to achieve optimal music perception [2]. Importantly, our results showed that the difference in LAR preference was statistically significant between mild and profound hearing loss groups but not between adjacent severity levels. This suggests that while hearing loss generally influences LAR preference, the effect is most pronounced at the more extreme ends of the spectrum.

Beyond the perceptual findings, our study underscores the broader implications of these preferences for music production and live performance settings. Traditional audio mixing approaches optimize the listening experience for NH individuals, inadvertently excluding those with hearing impairments. Our findings suggest that alternative mixing strategies—such as customizable LAR settings or individualized audio profiles—could significantly improve accessibility for HoH listeners. These adaptations could be particularly beneficial in live concerts, streaming services, and personal listening environments, ensuring that music remains an inclusive experience.

4.1 Limitations and Future Research

While our study provides valuable insights into the music perception preferences of HoH listeners, some limitations should be noted. First, hearing loss severity was self-reported rather than audiometrically verified, which may introduce variability in group classification. Future studies should incorporate objective hearing assessments to strengthen classification accuracy. Second, the study was conducted in an online setting, limiting control over participants' listening environments. Future research could employ laboratory conditions with standardized playback equipment to minimize variability in audio presentation.

Additionally, our study focused on LAR preferences but did not assess other critical factors, such as spectral balance, dynamic range compression, or spatialization, which may also influence music perception in HoH listeners. Future research should explore these additional variables to develop a more comprehensive understanding of audio preferences among individuals with hearing impairment.

In conclusion, our findings provide empirical support for the need to reconsider current music mixing practices to better accommodate HoH listeners. By implementing adaptive audio mixing strategies, the music industry can foster greater inclusivity, ensuring that individuals with

hearing loss can fully engage with and enjoy musical experiences.

5. CONCLUSION

This study demonstrates that HoH listeners prefer a higher LAR than NH individuals, with preferences increasing as hearing loss severity worsens. These findings suggest that traditional music mixing practices may not fully accommodate HoH listeners.

Customizable audio mixing strategies, such as user-adjustable LAR settings, could enhance music accessibility across various listening contexts. Implementing such adaptations may help bridge the gap between NH and HoH listeners, improving inclusivity in music enjoyment.

Some limitations should be noted, including the reliance on self-reported hearing status and the lack of controlled listening environments. Future research should incorporate audiometric verification and controlled settings to improve data reliability. Exploring additional auditory factors, such as spectral balance and dynamic range compression, could further refine inclusive mixing practices.

Overall, our findings emphasize the need for reconsidering music mixing conventions to better support HoH individuals. Integrating research-driven modifications in audio production and assistive technologies can foster a more inclusive musical experience.

6. ACKNOWLEDGMENTS

The authors would like to express their gratitude to the participants who took part in this study and provided valuable insights and to Shaked Bigi for her assistance. We extend our gratitude to Dr. Devora Brand and the undergraduate students from the Department of Communication Disorders at Jerusalem Multidisciplinary College for their dedication and effort in data collection.

This research was supported by a grant from The Israel Innovation Authority (Grant #83364) as part of the research and development project titled: "Development of Technology for the Accessibility of Auditory Content for Populations with Hearing Difficulties or Attention Deficit Disorders."

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