DOI: 10.61782/fa.2025.0323

EFFECT OF REDUCING THE STATIC INTERAURAL TIME DIFFERENCE IN BIMODAL LISTENERS

Zirn, S.[1], Roth, S. [1,2], Mueller, F.-U. [1,2], Hemmert, W.[2], Angermeier, J. [1,3]
[1]University of Applied Sciences Offenburg, Peter Osypka Institute of Medical Engineering, Offenburg, Germany
[2] Technical University of Munich, Munich, Germany
[3]Osypka AG, Rheinfelden, Germany

ABSTRACT

Previous work has shown that the ability to localize sound signals in the horizontal plane can be improved in listeners provided with a cochlear implant (CI) in one ear and a hearing aid (HA) in the contralateral ear (bimodal listeners) when the static interaural time delay between the modalities is technically reduced. The timing mismatch is caused by differences in the processing latencies of CI and HA and by different stimulation sites (CI: auditory nerve; HA: external auditory canal). In 2020 the CI manufacturer MED-EL has made the technical reduction of the timing mismatch available by a programmable across-frequency CI stimulation delay.
To reduce the timing mismatch even further, we now use frequency-dependent delays to minimize the timing mismatch in every frequency band. Results show that the rms and the signed bias of sound localization can be further reduced in most bimodal study participants when using frequency-specific delays compared to an across-frequency delay. However, it is methodically complex to determine appropriate delays for different frequency bands. It is therefore questionable whether frequency-specific delays are useful in clinical practice.

Keywords: *bimodal hearing, sound localization, timing*

1. INTRODUCTION

Bimodal hearing refers to the use of two different types of hearing devices in opposite ears: a cochlear implant in one ear and a hearing aid in the other. This approach leverages the distinct advantages of each device to enhance overall auditory perception, particularly for individuals with asymmetric hearing loss or those who receive limited benefit from hearing aids alone.

A cochlear implant bypasses damaged parts of the inner ear by directly stimulating the auditory nerve with electrical signals, providing access to sound for individuals with severe to profound sensorineural hearing loss [7]. On the other hand, a hearing aid amplifies sound acoustically and is suited for individuals who have some residual hearing capability [3]. When used together in a bimodal configuration, these devices can complement each other, with the cochlear implant providing clear access to speech and the hearing aid enriching sound quality and providing additional auditory cues, such as pitch and timbre, that enhance music perception and spatial awareness [4].

Research and clinical experience show that bimodal hearing can significantly improve speech understanding in noise, localization of sound, and overall quality of life for individuals with hearing loss. This synergistic effect capitalizes on the brain's ability to integrate complex signals from both devices, fostering a more natural and comprehensive listening experience [5, 6]. Despite the synergistic effect and its potential benefits, sound localization is usually significantly worse in bimodal listeners compared to bilateral HA users or even bilateral CI

[*]**Corresponding author**: stefan.zirn@hs-offenburg.de.

users [8]. One reason for this are interaural mismatches in bimodal stimulation.

2. INTERAURAL MISMATCHES IN BIMODAL HEARING

Bimodal hearing presents unique challenges, primarily due to potential interaural mismatches in loudness, frequency, and timing. These mismatches can affect the integration of auditory information and the overall hearing experience.

Loudness Mismatches: Loudness perception can differ significantly between the electrically-stimulated ear with a cochlear implant and the acoustically-amplified ear with a hearing aid. The dynamic range of a cochlear implant is typically smaller than that of normal acoustic hearing, requiring careful adjustment to match loudness levels across ears [3]. This discrepancy can lead to difficulty in balancing sound perception, affecting binaural cues necessary for localization and speech understanding in noise [7].

Frequency Mismatches: Frequency mismatches occur because cochlear implants often provide less precise frequency resolution compared to acoustic hearing aids. Cochlear implants convey sound via a limited number of electrodes, each stimulating a broad frequency band, which might not align perfectly with the natural cochlear tonotopy that hearing aids aim to preserve [4]. This can impact the quality of sound perception, especially for complex sounds like music, which rely heavily on fine frequency discrimination [6].

Timing Mismatches: Temporal processing differences between the ears can also pose challenges. Cochlear implants process sound with manufacturer dependent delays due to differences in signal processing and stimulate the auditory nerve directly. However, acoustic hearing aids process sounds in front of the ear and input the amplified sound into the outer ear canal. From there on the natural middle and cochlear delays apply [2]. The resulting timing differences can impair sound localization [1].

Addressing these interaural mismatches involves personalized device programming and fitting strategies to better align the loudness [10], frequency [9], and timing [1] cues offered by each device, thereby enhancing the benefits of bimodal hearing.

3. METHODS

Bimodal hearing test subjects were seated in an audiometric booth equipped with a sound localization setup designed to assess auditory spatial awareness, 11 loudspeakers were positioned in a horizontal arc at ear level in front of the subject, each spaced 15° apart, covering a total span from -75° to +75° relative to the forward-facing position. A central loudspeaker is positioned at 0°, with others extending symmetrically in both directions. Correspondingly, an LED array with 180 LEDs mirrored this setup, each LED representing a loudspeaker position for response indication. The test began with the subject seated, facing the 0° speaker. During the test, pulsed noise with level an spectral roving was randomly played from the loudspeakers. Subjects then indicated perceived sound locations by activating the corresponding LED. These responses are recorded for analysis.
Before the test started loudness between ears/devices was balanced. Subjects were then tested in three different conditions in a randomized order. Condition 1: No compensation of timing nor frequency mismatch. Condition 2: Compensation of timing mismatch by an across-frequency delay applied to CI stimulation. Condition 3: Compensation of the interaural timing mismatch together with the frequency mismatch. In this condition frequency-specific delays were applied to CI stimulation.

4. RESULTS

Figure 1 illustrates the rms error of sound localization of 8 bimodal hearing test subjects.

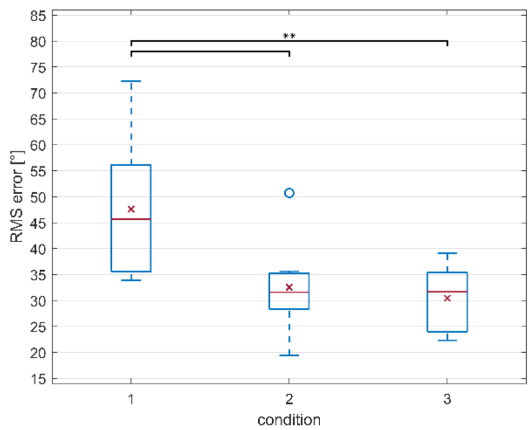

Figure 1. RMS error of sound localization of 8 bimodal listeners in three different listening conditions. Condition 1: Without compensation; condition 2: with timing

compensation; condition 3: with timing & frequency compensation.

Activating the across-frequency delay had no significant effect on the rms error (difference between condition 1 and 2). But we think that including more test subjects will lead to a significant reduction comparable to the results in [1]. Frequency-specific delays (condition 3) further reduced the rms error in some subjects, but in others there was no difference, resulting in a non-significant difference between condition 2 and 3.

5. CONCLUSION

This paper presents results of an ongoing study aiming at reducing the interaural stimulation mismatches in bimodal listening. Results show that the rms of sound localization can be further reduced in some bimodal study participants when using frequency-specific delays compared to an across-frequency delay. However, only a slight further improvement has been achieved in the 8 test subjects tested so far. The approach for combined time and frequency adjustment is methodologically complex, especially the determination of suitable delays for different CI frequency bands. Up to this point, it is questionable whether frequency-specific delays are useful in clinical practice.

6. ACKNOWLEDGMENTS

We thank the test subjects who participated in our study. We would also like to thank MED-EL for their continued support of our research.

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