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# THE EFFECT OF DIFFERENT SIMULATED REVERBERANT ENVIRONMENTS ON COCHLEAR IMPLANT USERS' BINAURAL FUSION

**Justin Aronoff*** **Prajna BK** **Natalie Gustafson**
Department of Speech and Hearing Science, University of Illinois at Urbana-Champaign, United States of America

## ABSTRACT

Interaural coherence (the statistical similarity of signals at both ears, excluding interaural time differences) strongly affects whether a listener perceives a single binaurally fused sound or two separate sounds from each ear. Reverberant environments can decrease the interaural coherence of a signal, decreasing the likelihood of hearing a single, punctate sound. While cochlear implant users are sensitive to changes in interaural coherence, the narrow dynamic range of electric stimulation together with current spread can reduce the difference in the interaural coherence across different reverberant environments. Therefore, cochlear implant users may experience limited differences in binaural fusion across different reverberant environments.

The goal of this study was to investigate whether cochlear implant users' binaural fusion of speech sounds was affected by changes in simulated reverberation. Participants were asked to indicate the size and number of auditory images that they heard in the various simulated environments as an indication of binaural fusion. Preliminary results indicated that, despite the reduced effects of reverberation on interaural coherence after cochlear implant processing, more reverberant simulated rooms resulted in a less binaurally fused image, suggesting that binaural fusion of speech sounds by cochlear implant users is affected by changes in simulated reverberation.

***Corresponding author**: jaronoff@illinois.edu.
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**Keywords:** binaural fusion, interaural coherence, reverberation

## 1. INTRODUCTION

Reverberation, or the reflections of sound in an environment that arrive more than ~50 milliseconds after the direct sound, contributes to various forms of distortion when it interacts with the direct acoustic signal. One such effect of reverberation is the reduction of interaural coherence (IC) in the binaural signal received by a listener. Interaural coherence measures the statistical similarity of the signals between the two ears, accounting for interaural time differences. It serves as a crucial binaural cue, influencing how sound is perceived in an environment. Several studies have shown that higher IC values facilitate binaural fusion for typical hearing (TH) listeners [1-4]. In reverberant environments, late reflections introduce spectrotemporal smearing of the acoustic signal, which can increase the variability of IC, or reduce it when the reflections are asymmetric [5]. Consequently, in real-world reverberant settings, the perception of a sound source is significantly influenced by the impact of room reflections on IC.

In bilateral cochlear implant (CI) users, the interaural coherence (IC) of the source signal is further altered by the signal processing strategies employed by the CI processor. The logarithmic compression used to convert the acoustic signal into electrical stimulation reduces the amplitude fluctuations inherent to the signal which may increase and compress the IC into a narrower range. Moreover, CI users exhibit lower sensitivity to IC than do individuals with acoustic hearing [6], suggesting they may be less affected by the dynamic changes in IC caused by the frequency-dependent effects of reverberation. The combined influence of reverberation and CI processing on sound source perception in realistic spaces for bilateral CI users is unknown.

The goal of this study is to investigate how sound perception in bilateral CI users is influenced by the degree of reverberation, measured by RT60 (ISO, 2009), in a simulated listening environment.

## 2. METHODS

### 2.1 Participants

Three adult bilateral CI users participated in this experiment using their clinical programs.

### 2.2 Stimuli

Stimuli consisted of AzBio multispeaker babble processed by the RAZR room acoustics simulator [7]. This room simulator models reverberation using the hybrid image-source and ray-tracing methods [7]. A small (5 meter x 4 meter x 3 meter) conference room was simulated, with the listener in the center of the room and the speaker directly in front of them at a distance of approximately 1 meter. The RT60 of the simulated room was systematically manipulated, ranging from 0.1 to 16 seconds.

### 2.3 Procedures

Participants were asked to indicate the number and size of perceived auditory images resulting from the stimuli, as well as the lateralization of the stimuli. They indicated this using a dial (Powermate, Griffin Technology). Participants saw an image of a head on the screen with an oval on it. By turning the dial clockwise, they could make the oval get larger. Continuing to turn the dial made the oval split into two ovals, one near each ear, indicating that the percept was no longer binaurally fused. Continuing to turn the dial clockwise made the two images get smaller. By pushing down and turning the dial, participants could move the oval to the left or right if there was a single auditory image, or they could change the color of the ovals to indicate if the left or right image was more dominant when they perceived two auditory images.

## 3. RESULTS

One of the three participants demonstrated a systematic increase in fusion dispersion scores with increasing RT60 score, although it appeared to asymptote for RT60s above 4 seconds. For the other two participants, they consistently perceived a diffuse percept regardless of the simulated RT60.

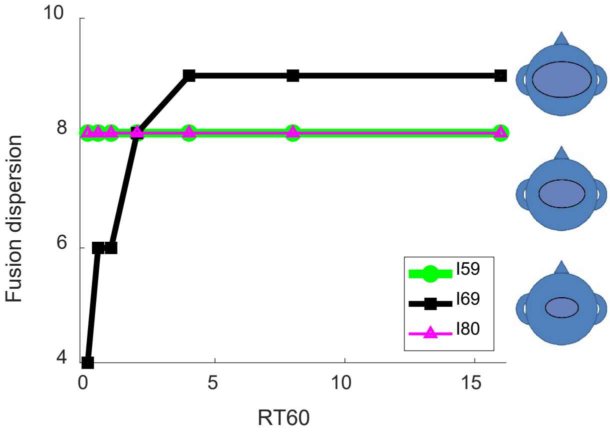


**Figure 1**. The effects of different RT60 values on binaural fusion for each participant.

## 4. DISCUSSION

Preliminary results show strong individual differences between the three subjects. Two subjects' data (I80 and I59) did not indicate a significant effect of RT60 on their perception of binaural fusion. This may signal that even a small amount of reverberant energy can distort the delivered electrical signal sufficiently to lead to a diffuse percept for some CI users. On the other hand, one subject (I69) perceived a gradual decrease in perceived binaural fusion which saturated at RT60 = 4 seconds, indicating that reverberation can affect binaural fusion for CI users.

## 5. CONCLUSION

The preliminary results from the study indicated that, despite the reduced effects of reverberation on interaural coherence after CI processing, more reverberant rooms can result in a less binaurally fused image for cochlear implant users, although this effect may not be consistent across listeners.

## 6. ACKNOWLEDGMENTS

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