Investigating the effect of interaural asymmetries on binaural unmasking of vocoded speech and binaural integration using EEG

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INTRODUCTION

- Many individuals with bilateral cochlear implants (CIs) demonstrate performance asymmetries across ears resulting in limited binaural benefits, especially, binaural unmasking.[1]
  - It is not known whether binaural performance is limited more by the poorer ear, or by the degree of asymmetry across ears (Fig 1).
- Performance asymmetries likely stem from differences in temporal resolution across ears.[2] It is difficult to control for factors affecting temporal encoding in CI patients.
  - Therefore, we manipulated temporal resolution in normal hearing (NH) listeners by compressing the **dynamic range (DR)** of vocoded stimuli symmetrically and asymmetrically across ears.
- Previous work investigating asymmetries and binaural processing has focused mainly on behavioral measures,[1] but it is also important to investigate this question objectively to understand mechanisms underlying behavioral differences and include populations that are difficult to test behaviorally, like children.

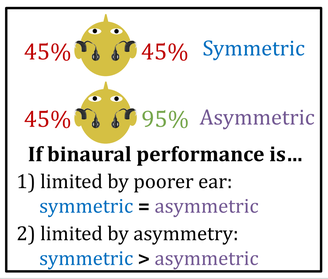


Fig 1. Example of listeners with symmetric and asymmetric speech performance.

PURPOSE

Experiment 1: Investigate the influence of symmetric and asymmetric DR on binaural unmasking in normal hearing individuals listening to vocoded speech.

Experiment 2: Investigate cortical neural sensitivity to changes in binaural fusion (a prerequisite for binaural unmasking) caused by symmetric and asymmetric DR.

Experiment 1 Methods

Participants

- 7 young NH adults (20-31 years old).

Stimuli and Task

- Target (T): Harvard IEEE sentences spoken by a female.
- Masker (M): AzBio sentences spoken by a female.
- Stimuli were processed with a 16-channel vocoder using a low-noise noise carrier.
- The temporal envelope of the signal was compressed in one or both ears to reduce DR (Fig 2).[3]
- Stimuli were presented at 65 dB-A over headphones at a signal-to-noise ratio of 0 dB.
- Listeners repeated target sentences and responses were scored by experimenter out of five key words.

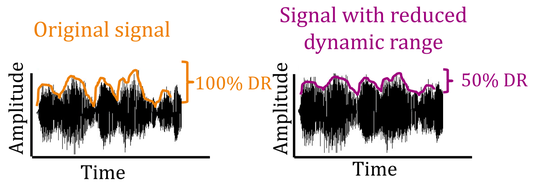


Fig 2. Stimulus with 100% DR (left) and 50% DR (right). DR compressed logarithmically so that for 50% DR a 10 dB dip became 5 dB and an 8 dB dip became 4 dB.[3] RMS level remained 65 dB-A.

Table 1. Conditions

	DR target ear	DR contra ear	
Quiet (T)	100%	X	
	71%		
	50%		
	35%		
	25%		
Monaural (T, M)	100%	X	
	71%		
	50%		
	35%		
	100% T, 50% M		
Binaural (T, M)	100%	100%	Symmetric DR
	71%	71%,	
	50%	50%,	
	35%	35%	
	71%	100%	Asymmetric DR
	50%		
	35%		
	100% T, 50% M	100%	Control

Table 1. Listening conditions. 30 trials were blocked into two runs/condition and order was randomized.

Because interaural similarities in signal representation are important for binaural fusion, we hypothesized that symmetric conditions would elicit greater binaural unmasking than asymmetric conditions.

Experiment 2 Proposed Methods

Background

- The **acoustic change complex (ACC)** is a cortical auditory evoked potential (AEP) elicited by changing an aspect of an ongoing stimulus.[4]
- The ACC is characterized by the N1-P2 waveform that reflects neural processing underlying behavioral sound discrimination.[5,6]
- The ACC can be elicited by increasing the correlation (and fusion) of binaural noise stimuli and by imposing amplitude modulations (AM) on monaural noise stimuli.[7,8]

Stimuli

- Uncorrelated speech shaped noise (SSN) perceived as large and diffuse in the head will change to 40 Hz AM SSN resulting in fusion of the sounds into one auditory image.
- SSN carriers will remain uncorrelated for AM portion.
- Change from diffuse to fused sound will elicit ACC (Fig 3).
- Temporal envelope will be compressed in one or both ears to reduce DR (Fig 2).
- Stimuli will be presented at 65 dB SPL via ER10X inserts.

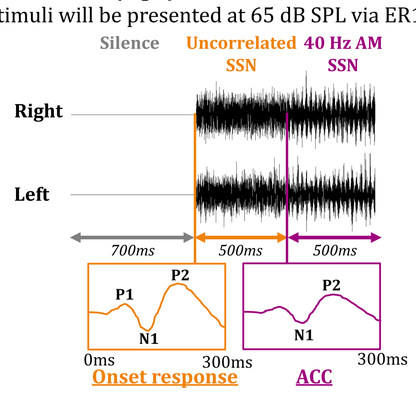


Fig 3. Example of binaural stimuli for one trial and corresponding onset and ACC AEPs. Monaural stimuli will have same structure.

Participants and Procedure

- Young NH adults will be tested in the near future.
- Condition order will be randomized, and 300 trials will be run per condition.
- Participants will watch a silent show during testing.
- Electrode montage: recording electrode on vertex (C_z) , linked reference electrodes on each mastoid, ground electrode on clavicle.

Table 2. Conditions

	Left Ear DR	Right Ear DR	
Binaural	50%	50%	Symmetric DR
	50%	100%	Asymmetric DR
	Unmodulated correlated SSN		Correlated SSN
Monaural	X	100%	Control
	X	50%	
	50%	X	

Table 2. Conditions. Percentages refer to DR of amplitude modulated portion of stimuli.

Given that the ACC is sensitive to changes in binaural fusion, we hypothesize that greater similarity in stimuli across ears will result in better fusion and a larger ACC.

Binaural Conditions

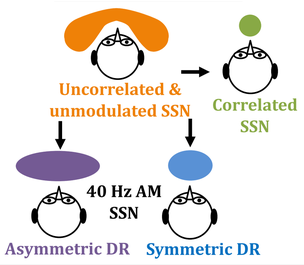


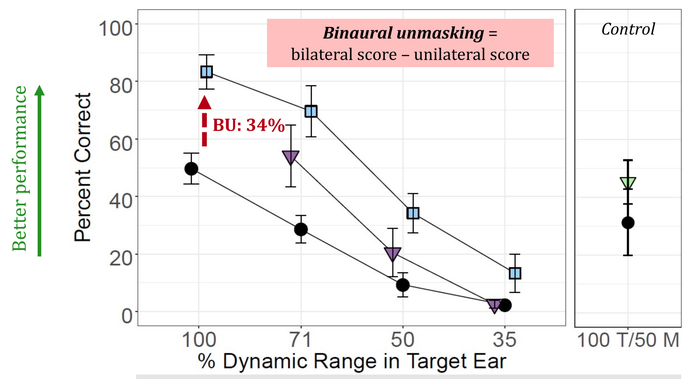
Fig 4. Predicted change in fusion and perceived intracranial location for binaural conditions.

Monaural Control Conditions

- Monaural conditions were included in order to differentiate effects of ACC elicited by AM vs. ACC elicited by binaural fusion.
- If ACC is larger in binaural than monaural conditions, we can attribute difference to change in fusion/auditory image size.

EXPERIMENT 1: RESULTS

How do across-ear asymmetries in DR affect binaural unmasking?



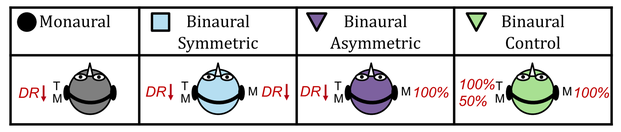


Fig 5: Mean speech intelligibility as a function of DR of the target ear. Error bars are ± one SD.

- Speech intelligibility in monaural and binaural conditions decreased as DR compression increased.
- Performance increased from monaural to binaural conditions (binaural unmasking) at every DR except 35%
  - shown by comparison between the black and purple or blue symbols.
- For binaural conditions, performance was better (greater binaural unmasking) when DR of both ears was symmetrically reduced (blue), compared to when it was asymmetrically reduced (purple).

Are differences between symmetric and asymmetric conditions due to masker intelligibility?

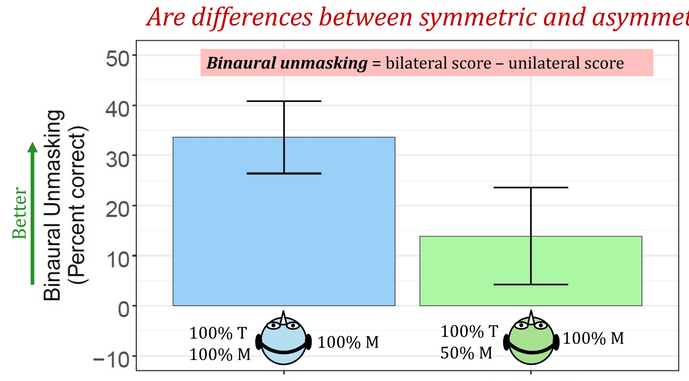


Fig 6: BU for 100% DR symmetric condition (blue) and control condition (green). Error bars are ± one SD.

- Greater unmasking in symmetric compared to asymmetric conditions could be due to the intelligibility of the contralateral masker.[1,9]
- However, when target and contralateral masker DRs were held at 100%, and just DR of the masker in the target ear was reduced, participants exhibited less unmasking (green vs. blue).

This suggests that the disparity between symmetric and asymmetric conditions was not just due to difficulty ignoring a salient masker, **but that differences in DR across ears affected participant's ability to fuse maskers and perceptually separate the masker from the target.**

EXPERIMENT 2: ANALYSIS AND PROJECTED RESULTS

Data Analysis

- Data will be amplified, low-pass filtered at 30 Hz, baseline corrected, and artifacts will be removed.
- N1=max negative peak from 100-200ms and P2= max positive peak from 150-300ms after stimulus onset (Onset response) or stimulus change (ACC).
- Measures of interest:
  - N1 and P2 peak latencies
  - N1-P2 peak-to-peak amplitude
  - ACC to Onset amplitude ratio

Predicted ACC Waveforms for Binaural Conditions

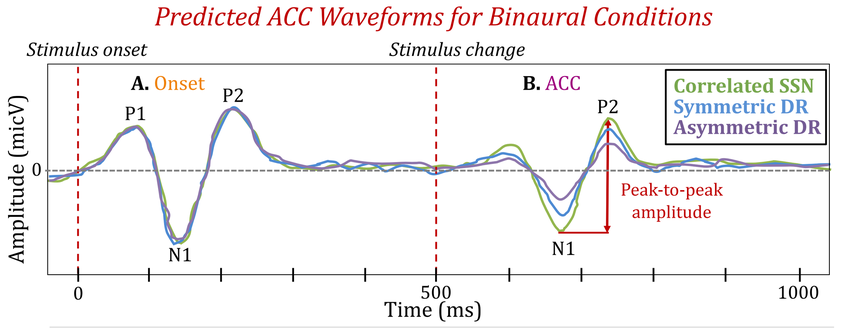


Fig 7. Predicted sample waveforms for binaural conditions with peaks labeled for Onset response (A) and ACC (B).

Predicted ACC Amplitude Results for Binaural Conditions:

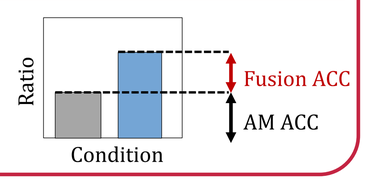
- All conditions will elicit the same onset response to uncorrelated SSN (Fig 7A).
- **Correlated SSN condition:** change from uncorrelated SSN to correlated SSN = largest ACC (Fig 7B-green).
  - Replicates previous findings that ACC can be elicited by change in fusion.[8]
- **Asymmetric DR condition:** smallest ACC (Fig 7B-purple).
- **Symmetric DR condition:** medium ACC (smaller than Correlated SSN but larger than Asymmetric DR; Fig 7B-blue).
- **Alternatively:** ACC for Asymmetric DR condition may be larger than Symmetric DR due to 100% DR in right ear, which is a larger acoustic change from unmodulated SSN than 50% DR in the symmetric condition.

Contributions of Amplitude Modulation and Fusion to ACCs

- In order to examine differences in ACCs due to fusion, we may need to parse out effects of AM.
- Monaural ACCs for each DR will be measured.
- Because these are monaural, there is no fusion, so any resulting ACC can be attributed entirely to AM.
- To control for amplitude differences due to binaural vs. monaural stimulation, ACC to Onset ratios will be compared for binaural and monaural conditions.

ACC to Onset ratio = ACC peak-to-peak amp/ Onset peak-to-peak amp

Fig 8. Predicted pattern of ACC to onset ratio results for **50% monaural** and **symmetric DR** conditions.



SUMMARY

Experiment 1: This study explored the effect of symmetric and asymmetric DR on binaural unmasking in NH listeners.

- Binaural unmasking was greater when DR was compressed symmetrically versus asymmetrically. This indicates that similarities in temporal information across ears are more important for binaural processing than having one "good" ear with a larger DR.
- Across-ear asymmetries in DR may be one factor contributing to asymmetric speech intelligibility in bilateral CI users. These asymmetries are likely to be involved in the limited binaural benefits demonstrated by these listeners.

Experiment 2: This study aims to objectively quantify changes to binaural fusion caused by symmetric and asymmetric DR using the ACC.

- If reduced binaural unmasking in asymmetric conditions is due to poor fusion of asymmetric maskers, then this will be reflected by a smaller ACC in the asymmetric condition compared to symmetric condition.

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