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Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Paredes Gallardo, A., Epp, B., & Dau, T. (2015). *Can auditory stady-state responses reflect place-specific cochlear dispersion?*. Poster session presented at 5th International Symposium on Auditory and Audiological Research, Nyborg, Denmark.

Can auditory steady-state responses reflect place-specific cochlear dispersion?

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Introduction

The cochlear travelling wave propagates from the base to the apex, resulting in an increasing phase with distance from the cochlear base. Together with the tonotopic organization of the cochlea, this results in a frequency dependent delay of the resonance, a phenomenon known as cochlear dispersion.

Previous studies showed the applicability of auditory evoked potentials (AEP) to investigate cochlear dispersion along the basilar membrane (BM) (e.g. Dau et al., 2000). In contrast to those studies, the present study maximizes the response in a given frequency region, aiming to objectively estimate local cochlear dispersion in humans.

Hypothesis

For the same bandwidth and intensity, stimuli compensating for the phase response at a particular cochlear location will elicit the most "peaky" response at this position, giving rise to the highest-amplitude of the evoked potential.

Method

1. Auditory steady-state responses (ASSR) with **Schroeder tone complexes** (Schroeder, 1970) as stimulus.

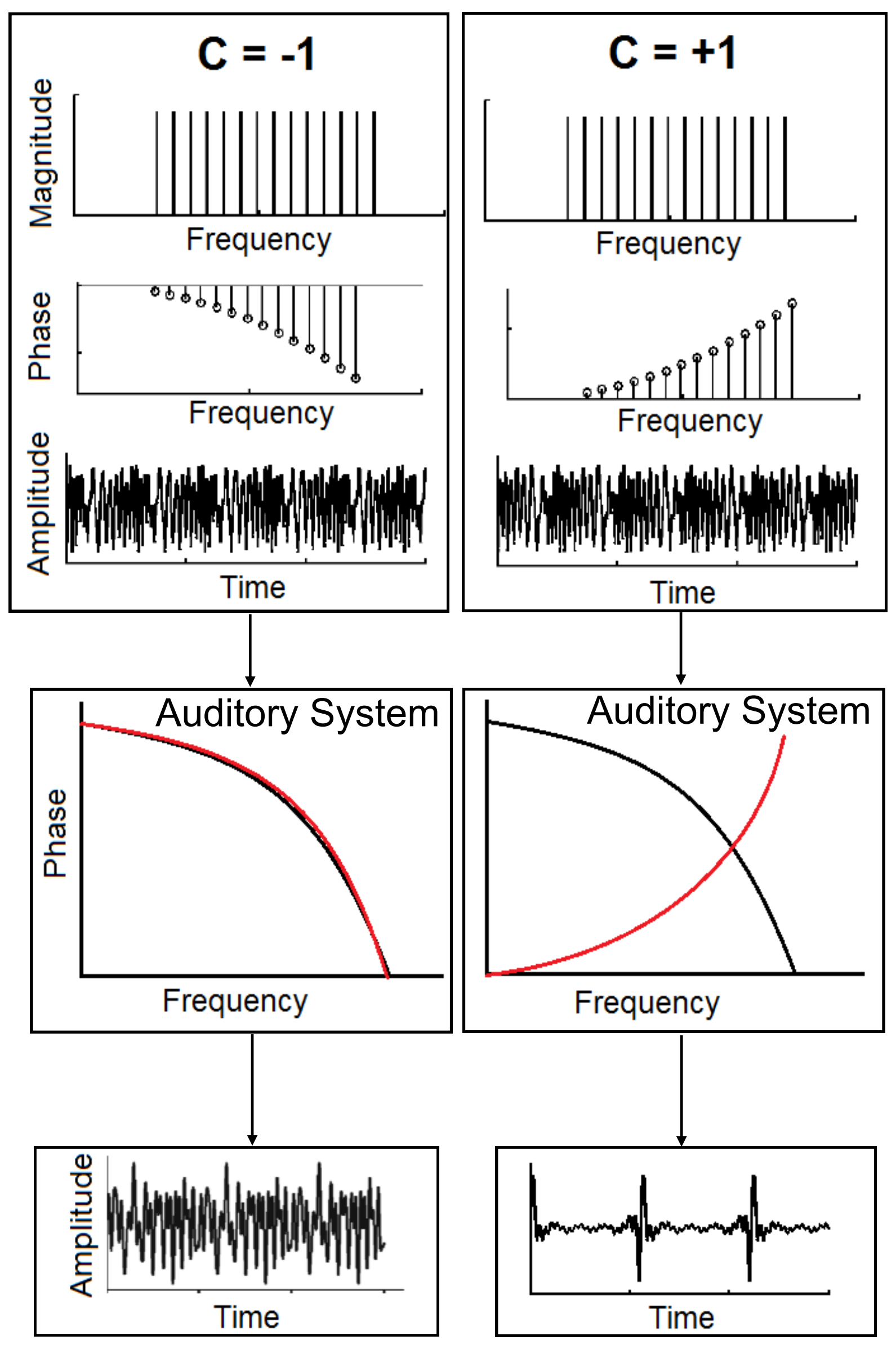

Fig. 1: Schematic of the hypothetical interaction between two Schroeder tone complexes and the human auditory system. A "peakier" output is obtained for the tone complex that compensates for the phase of the auditory system (C=+1). The phase (θ_n) of each harmonic (n) was calculated according to:

$$\theta_n = C\pi n(n-1)/N$$

where N is the total number of harmonics and C a coefficient introduced by Lentz and Leek, (2001) to allow sweep rate modifications.

2. ASSRs with a train of **compressive gammachirp impulse responses** (gcIR; Irino and Patterson, 2001) or a time-reversed version of them as stimulus.

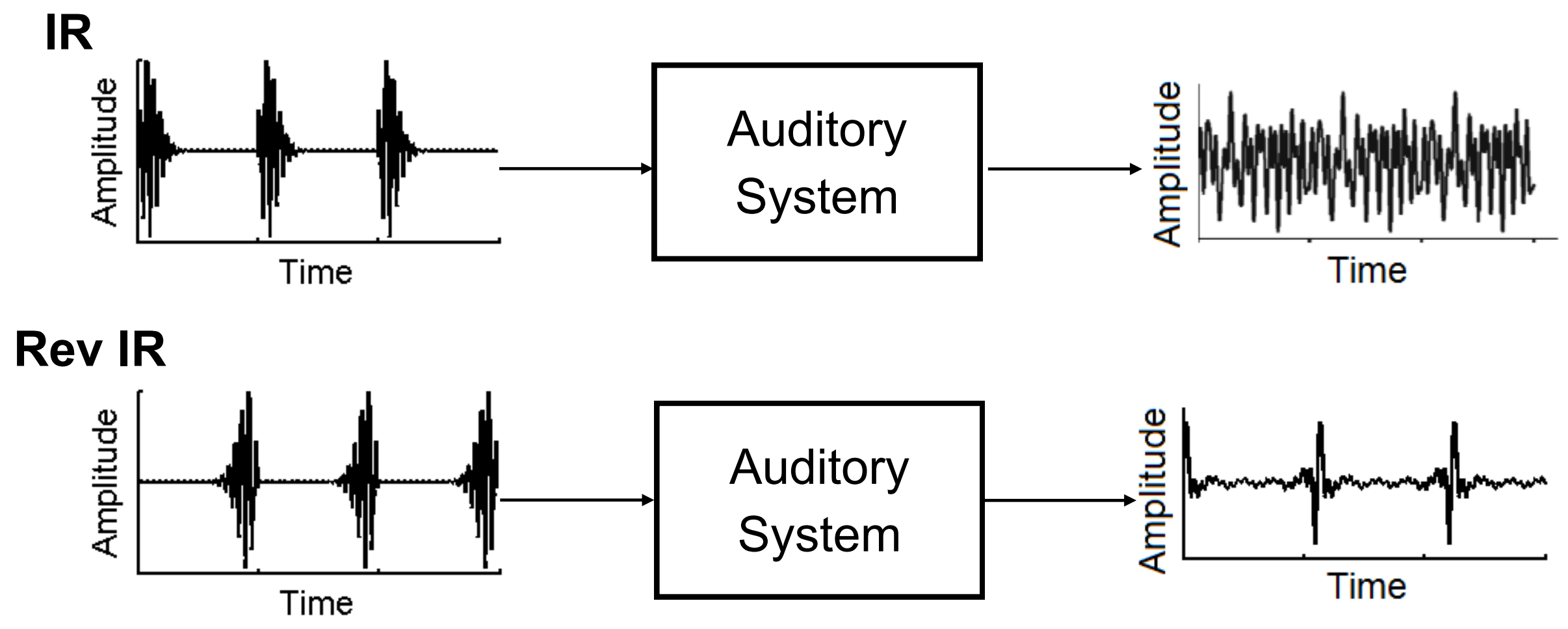

Fig. 2: Schematic of the hypothetical interaction between gcIRs and the human auditory system. The stimulus built with time-reversed gcIRs ideally compensates for the auditory filter phase response, generating a "peaky" internal representation. In contrast, the stimulus built with gcIRs ideally doubles the delays applied by the auditory system, generating a flat internal representation.

3. **Simulations** of frequency selectivity and dispersion using a linear transmission line model (TLM; Epp et al, 2010) were generated with the same stimuli.

Results

Schroeder Tone Complexes

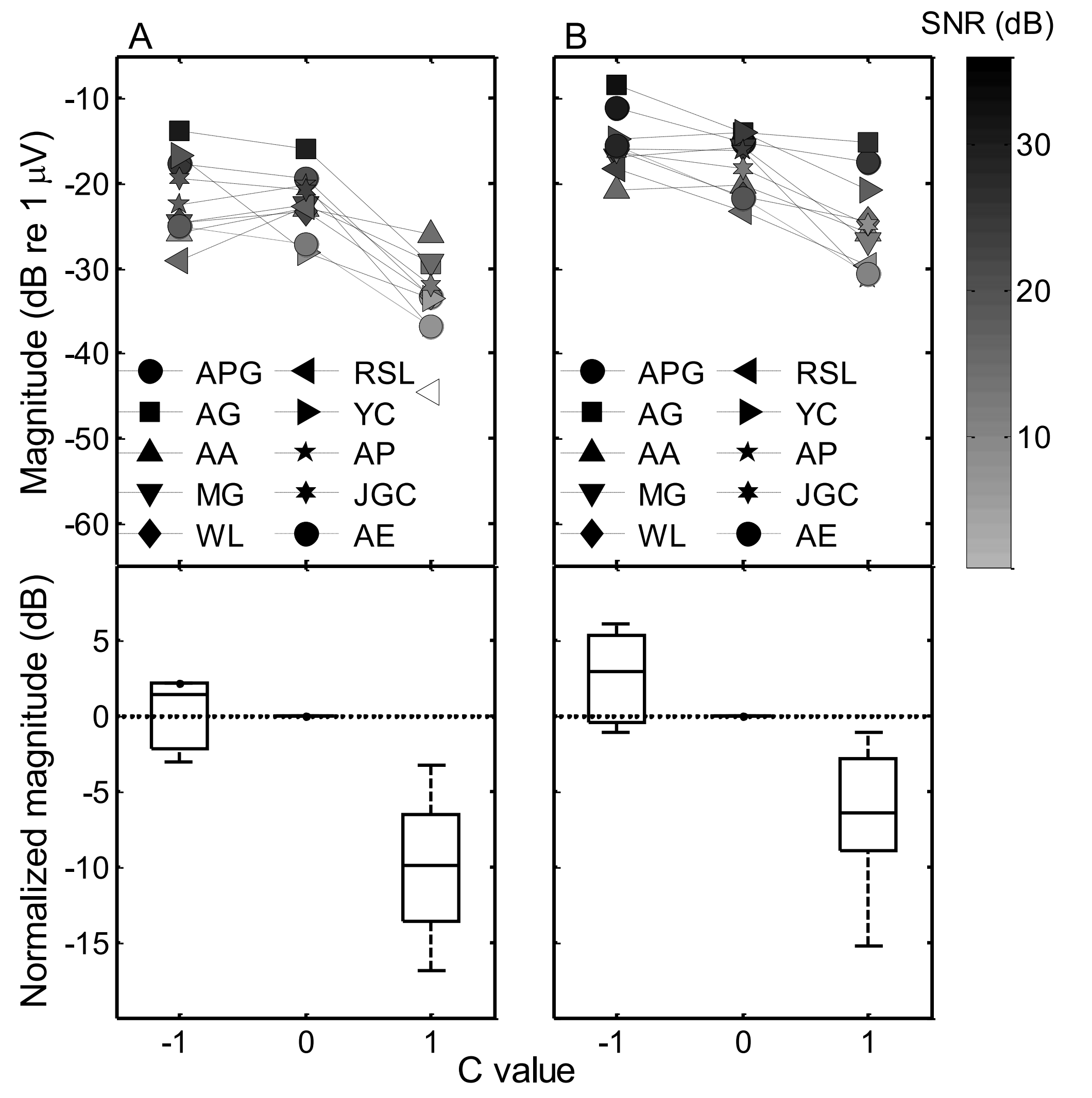

Fig. 3: ASSR magnitude in response to **Schroeder tone complexes** with *fc* = 1 kHz. Individual data is shown for 45 dB SPL (A) and 70 dB SPL (B). The respective normalized data is shown in the lower panels, where the magnitude of each response is normalized respect to the response at *C* = 0 for each subject. The color of each marker indicates the signal-to-noise ratio.

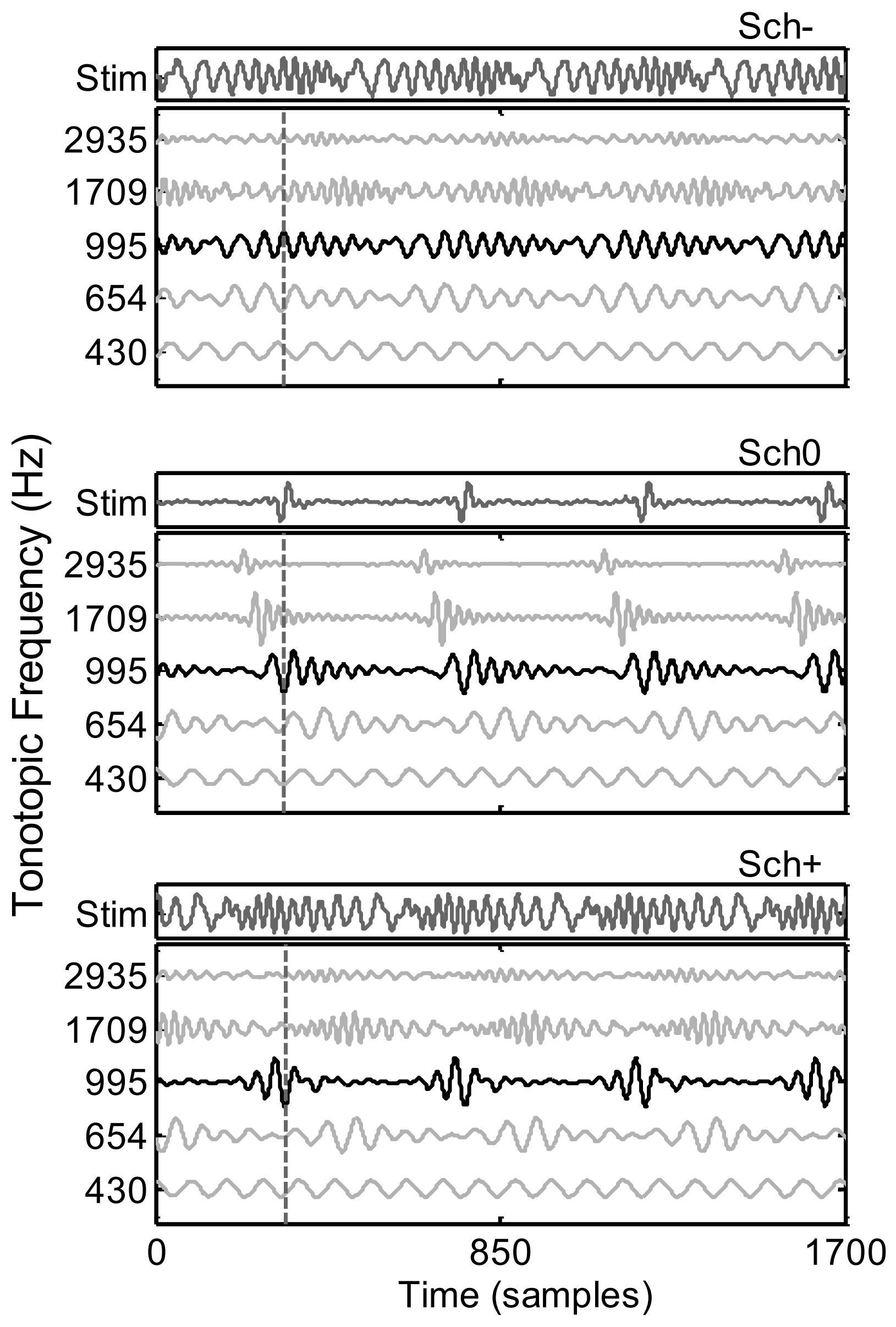

Fig. 4: TLM simulations of BM velocity in response to **Schroeder tone complexes** with *fc* = 1 kHz at five tonotopic frequencies. Each panel contains the response to the negative, zero phase or positive Schroeder tone complex (top to bottom). On the top of each panel, the corresponding stimulus is shown for qualitative reference.

Gammachirp Impulse Responses

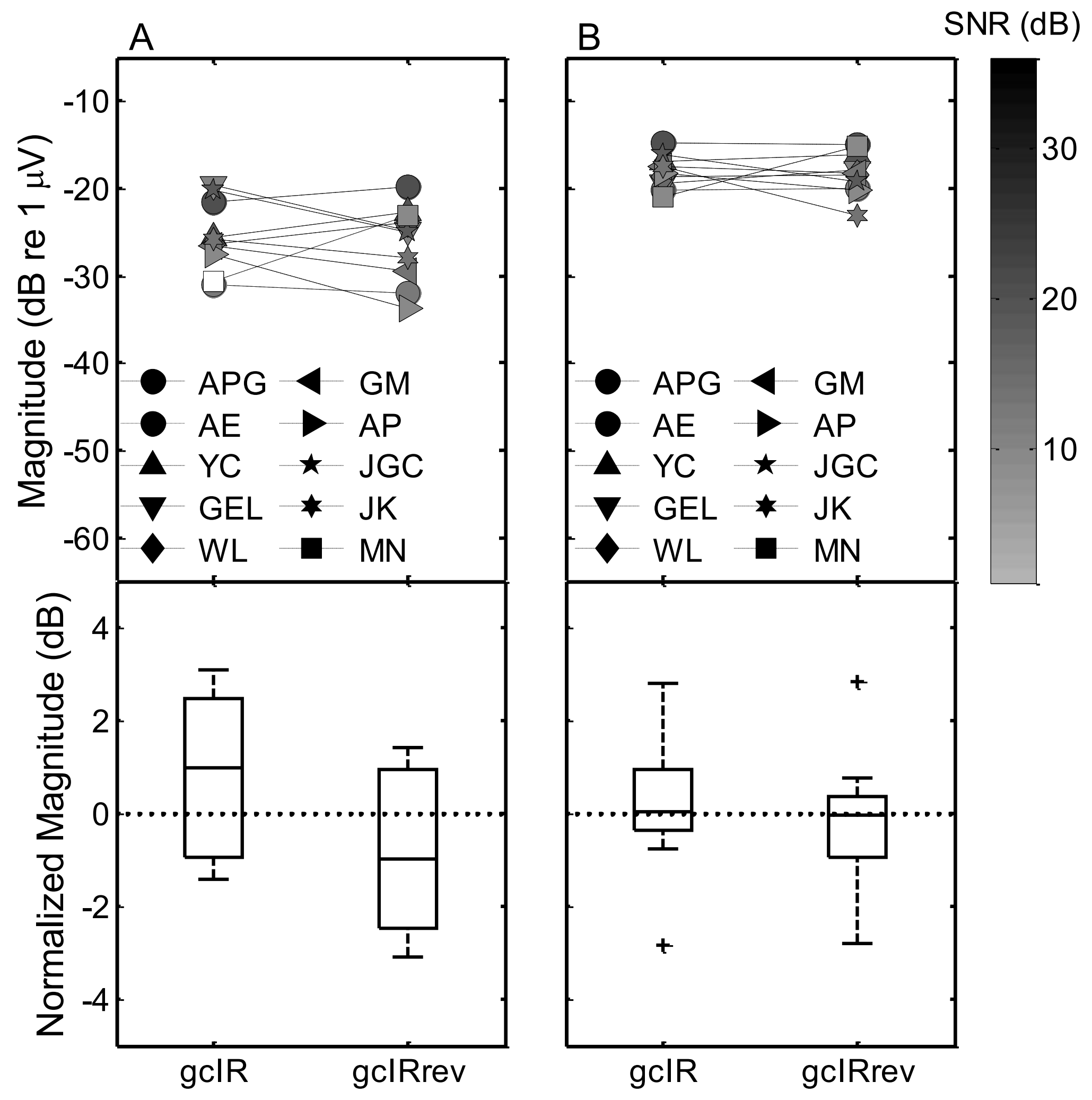

Fig. 5: ASSR magnitude in response to **cGC IRs** with *fc* = 2 kHz. Individual data is shown for 50 dB SPL (A) and 70 dB SPL (B). The respective normalized data is shown in the lower panels, where the magnitude of each response is normalized respect to the mean of the response for each subject. The color of each marker indicates the signal-to-noise ratio.

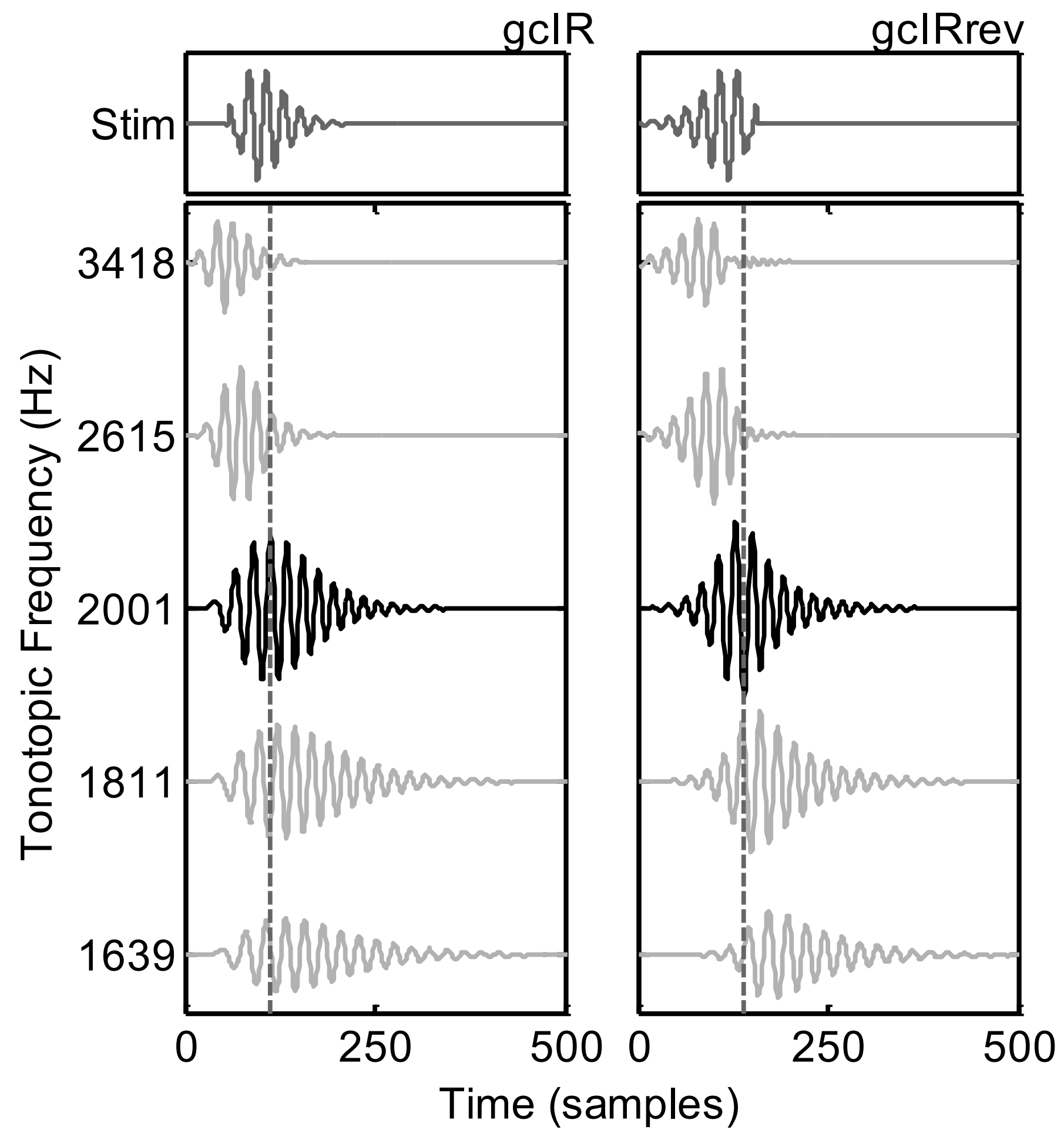

Fig. 6 TLM simulations of BM velocity in response to **cGC IRs** with *fc* = 2 kHz at five tonotopic frequencies. Left and right panels contains the response to the IR and to the time reversed IR respectively. On the top of each panel, the corresponding stimulus is shown for qualitative reference.

Main findings

- A greater ASSR magnitude was elicited in response to the negative Schroeder tone complex than to the positive Schroeder tone complex.
- TLM simulations with the negative Schroeder tone complex show flat envelopes in the individual frequency channels but only a small phase shift across frequency.
- Similar ASSR magnitudes were obtained in response to both gcIR and time-reversed gcIR.
- TLM simulations also show small differences between the BM response to the tested conditions.
- Despite the small size of the effect, the same pattern as with the Schroeder tone complexes were observed.

Conclusions

- Even though dispersive effects in the on-frequency channel may be represented at a peripheral level, the across-frequency asynchrony of the BM excitation may dominate the "summed" response.
- The ASSR response is therefore dominated by the synchronized activity across frequency.
- Brainstem responses, as reflected in the ASSR, are not sensitive enough to reflect frequency-specific cochlear dispersion.

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