74

Binaural Auditory Evoked Potentials With Virtual Acoustics

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Introduction

The binaural difference potential (BD) is commonly regarded as neural correlate for binaural processing. It is calculated as the difference between binaural and summed monaural auditory brainstem responses (ABRs). Previous studies used click stimuli with "artificial" binaural differences, i.e., fixed interaural time and level differences [1, 3-7]. In this work, instead of the click an optimized chirp was used, designed to compensate for basilar membrane dispersion resulting in a significantly larger ABR wave-V amplitude [2]. The chirp was presented with "natural" binaural differences, i.e., convolved with individual head-related impulse responses (HRIRs). Stimulus conditions were a) eight directions on the horizontal plane (ITD, ILD, and spectral cues) and b) eight directions on the sagittal plane (only spectral cues). In addition, the unconvolved "pure" chirp was presented diotically as a reference condition. Auditory evoked potentials (AEPs) were recorded from 32 scalp electrodes and both ABRs and middle latency responses (MLRs) were derived. In contrast to stimuli with artificial binaural differences, the "natural" spatial stimuli result in a perceived object outside the subject's head (externalization).

Motivation

- ITD and ILD alone merely produce an acoustic object lateralized "inside the head".
- Additional spectral cues introduced by virtual acoustics result in an externalized object allowing the subjects to distinguish between front/back, top/bottom
- Underlying questions:
  - How do spectral cues (in addition to ITD/ILD) affect the potentials?
  - Does the more "natural" auditory object produce a larger binaural difference potential (BD)?
  - Is there a systematic relationship between the direction of the sound source and the auditory evoked potentials?
  - Does spectral processing take place in the brain stem or primary auditory cortex?

Methods

- **Stimulus:** broadband chirp with flat spectrum in the frequency range 100-14000 Hz
  - In order to provide synchronous discharges of auditory nerve fibers along the entire cochlear partition, the equations defining the chirp were calculated to be the inverse of the delay-line characteristics of the basilar membrane [2] (see Fig. 1a)
- **Presentation**
  - via insert earphones (Etymotic Research ER-2)
  - 14 virtual directions by convolution with individual HRIRs (left/right/binaural each)
  - reference condition: unconvolved chirp (left/right/binaural)
  - All 45 conditions presented in an interleaved manner at a level of 40 dB SL
- **Recording of AEP**
  - 7 subjects
  - 32 channel setup (channels A1, A2, PO9 and PO10 for evaluation of amplitudes/latencies)
  - average over 10000 presentations per condition
  - Offline filtering of raw AEP data:
    - Bandpass 100-1500 Hz for ABR evaluation
    - Bandpass 20-300 Hz for MLR evaluation

Results

- ABR and MLR data show a systematic dependence only on variation of azimuth (laterality of the virtual sound source). Variation of elevation does not affect the ABR/MLR.
- The dependence on azimuth is evident in both amplitude/latency evaluation of the data and the moment trajectories of a fitted rotating dipole.

Conclusion

- At the level of the brain stem (ABR) and primary auditory cortex (MLR) only ITD and ILD are evaluated.
- Spectral cues are presumably processed at higher levels of the auditory pathway.

References

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[3] Furst, M., Levine, R. A., and McGaffigan, P. M. (1985). "Click lateralization is related to the beta component of the dichotic brain stem auditory evoked potentials of human subjects", J Acoust Soc Am 78 (5), 1644-1651.

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Stimuli

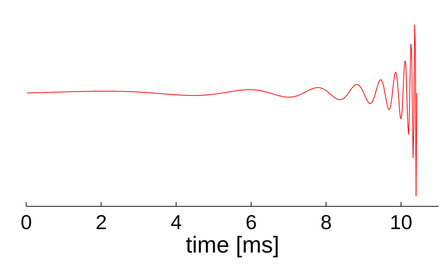


Fig. 1a: Broadband chirp stimulus with flat spectrum in the frequency range 100-14000 Hz. The chirp compensates for the basilar membrane dispersion providing synchronous discharges of auditory nerve fibers along the length of the entire cochlear partition [2].

a) Variation of azimuth

b) Variation of elevation

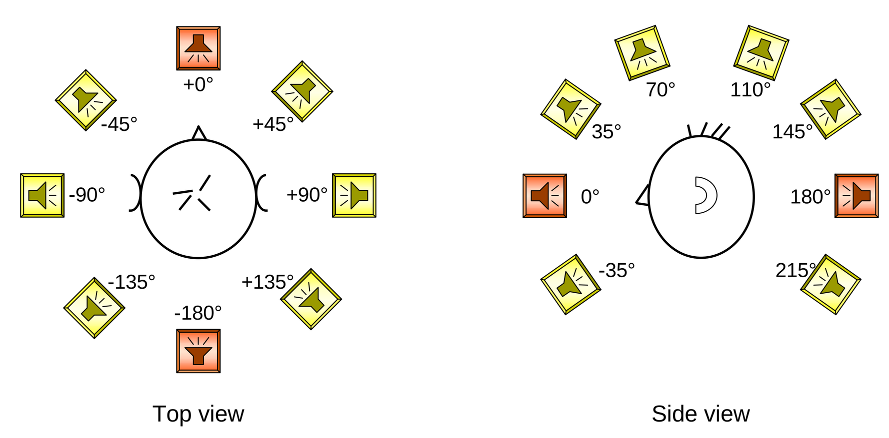
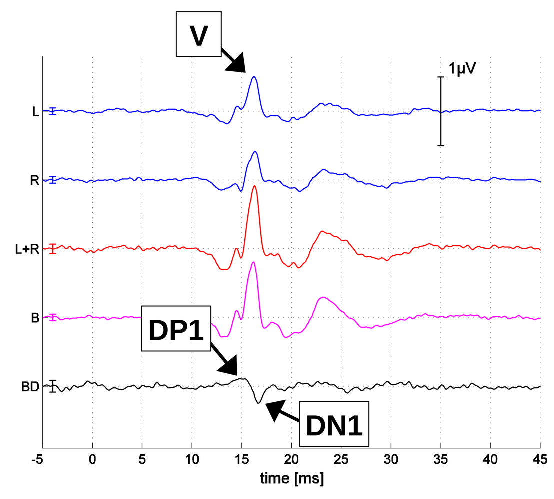


Fig. 1b: The chirp was convolved with individual HRIRs corresponding to a) eight virtual directions on the horizontal plane and b) eight virtual directions on the sagittal plane. In addition the unconvolved (diotic) chirp was presented as a reference condition. The directions indicated by the red speakers lie on both horizontal and sagittal plane and were only measured once.

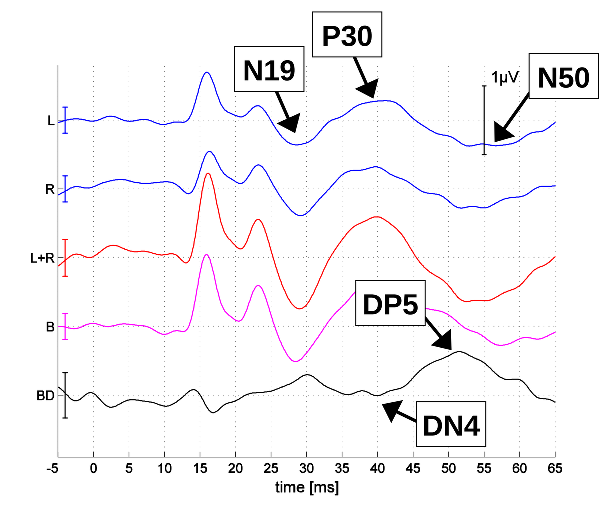
ABR: waveform morphology

Fig. 2: The binaural difference potential is calculated as the difference between binaural (B) and summed monaural (L+R) responses. Responses to the diotic (unconvolved) chirp, electrode position A1. ABR filter settings (100-1500 Hz, 200 taps FIR). Labels denote prominent ABR peaks. Errorbars indicate ±3 S.E.M. Note that due to the properties of the chirp, all latencies are about 10.5 ms higher than for click stimulation. Subject: rh



MLR: waveform morphology

Fig. 3: Same as Fig. 2, but with MLR filter settings (20-300 Hz, 200 taps FIR). Labels denote prominent MLR peaks. Errorbars indicate ±3 S.E.M. Note that due to the properties of the chirp, latencies are about 10.5 ms higher than for click stimulation. Subject: rh



ABR: Amplitudes

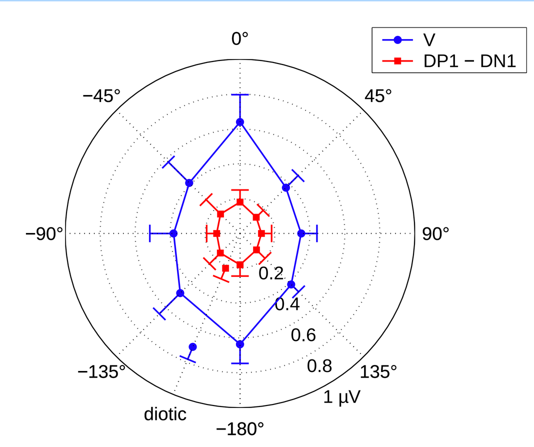


Fig. 4a, Variation of azimuth: Mean amplitudes over subjects and channels A1, A2, PO9, PO10.

- Strong dependence of ABR amplitudes on laterality of the sound source
- Highest amplitude for the diotic reference condition

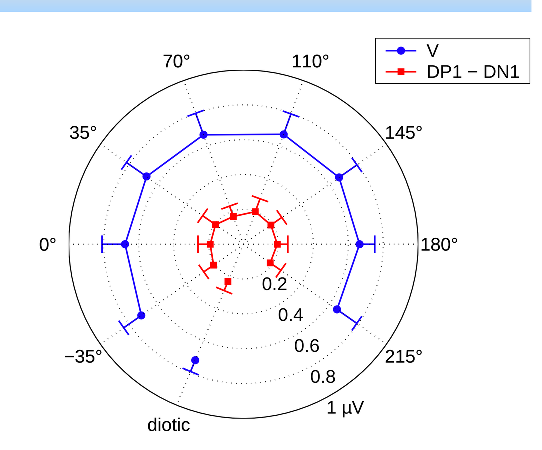


Fig. 4b, Variation of elevation: Mean amplitudes over subjects and channels A1, A2, PO9, PO10.

- No dependence of ABR amplitudes on elevation of the sound source

MLR: Amplitudes

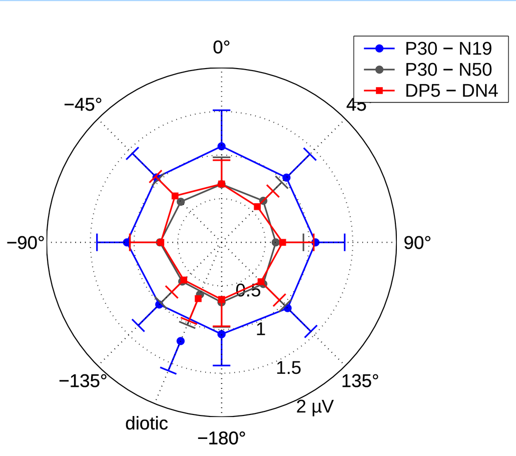


Fig. 5a, Variation of azimuth: Mean amplitudes over subjects and channels A1, A2, PO9, PO10.

- No dependence of MLR amplitudes on azimuth of the sound source

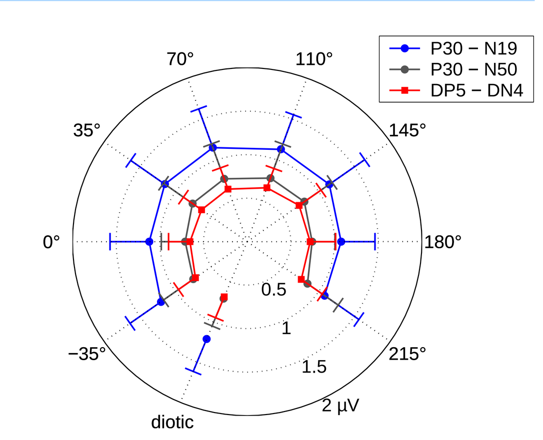


Fig. 5b, Variation of elevation: Mean amplitudes over subjects and channels A1, A2, PO9, PO10.

- No dependence of MLR amplitudes on elevation of the sound source

ABR: Latencies

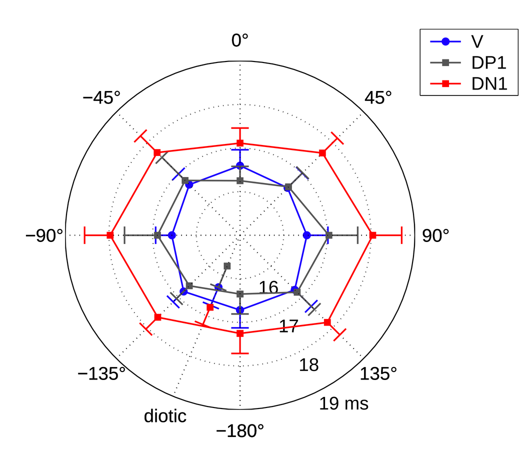


Fig. 6a, Variation of azimuth: Mean latencies over subjects and channels A1, A2, PO9, PO10.

- ABR wave-V: almost constant latency for all directions
- Shortest latency for the diotic reference condition
- DP1 and DN1: Latency increases monotonically with degree of laterality

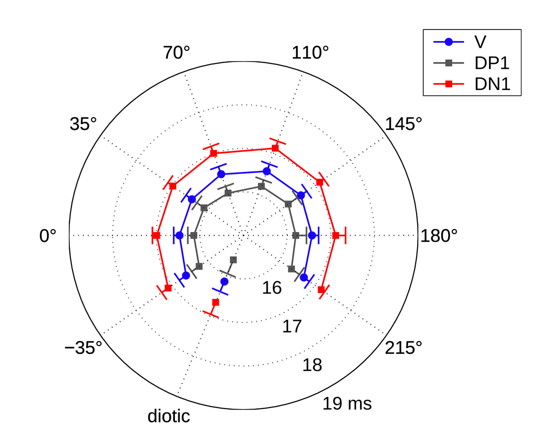


Fig. 6b, Variation of elevation: Mean latencies over subjects and channels A1, A2, PO9, PO10.

- No dependence of ABR latencies on elevation of the sound source

MLR: Latencies

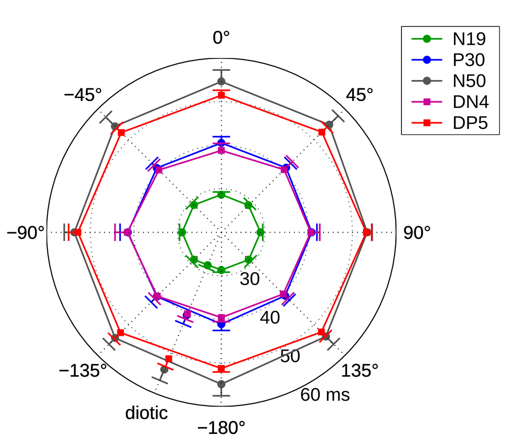


Fig. 7a, Variation of azimuth: Mean latencies over subjects and channels A1, A2, PO9, PO10.

- DN4 and DP5: Slight increase in MLR latencies with degree of laterality

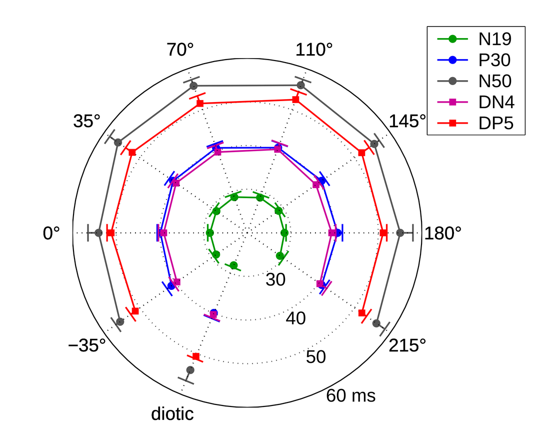


Fig. 7b, Variation of elevation: Mean latencies over subjects and channels A1, A2, PO9, PO10.

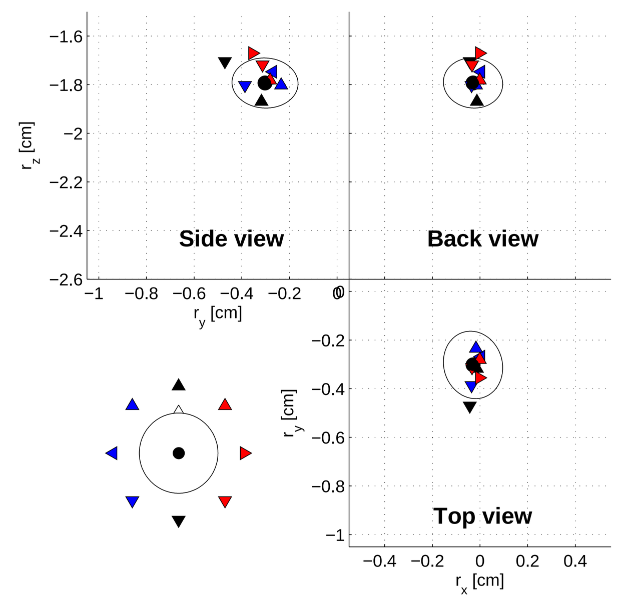
- No dependence of MLR latencies on elevation of the sound source

ABR: Fit of a rotating dipole

Fig. 8a+b, Dipole locations: Source analysis of binaural potentials, mean over subjects. For all stimulus conditions, the locations of a fitted rotating dipole in the three planes are shown. x points to the right, y to the front and z to the top. The fit interval started 1 ms before (triangles) to wave V and ended 2.5 ms after wave V. Error-ellipses indicate 95% confidence region of the frontal stimulus.

For all stimulus conditions the same brain stem region is activated. No systematic variation of location with stimulus direction can be observed.

a) Variation of azimuth



b) Variation of elevation

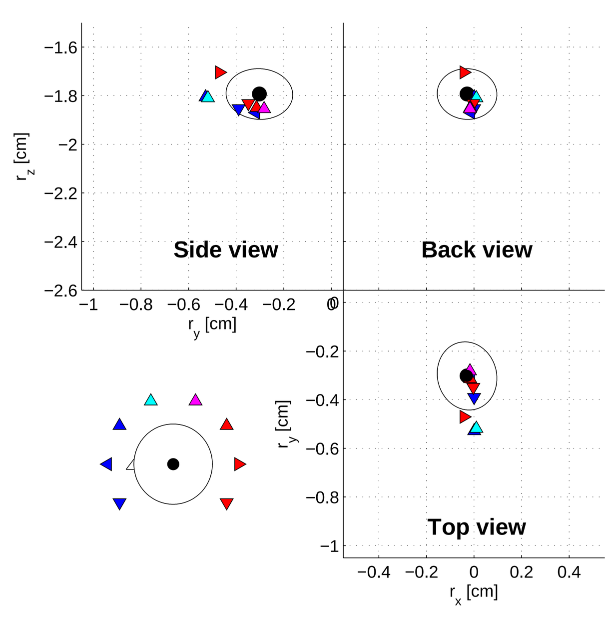
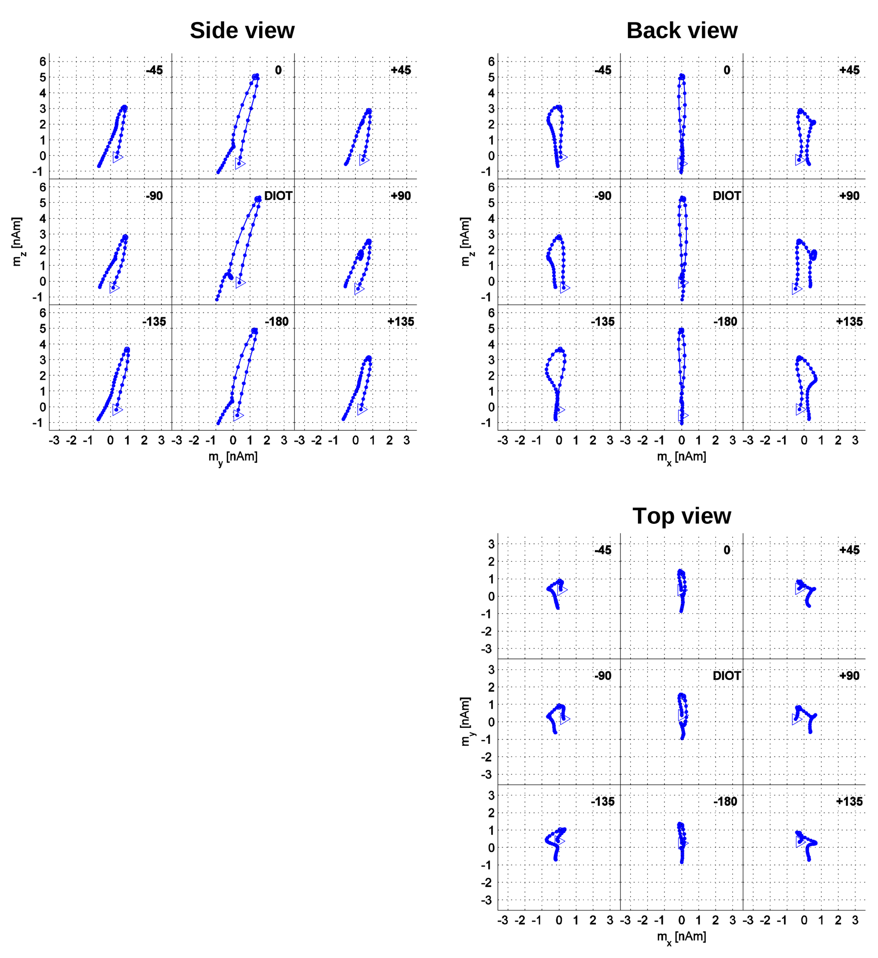


Fig. 9a+b, Dipole moments: Moment trajectories of a rotating dipole in the three planes for all stimulus conditions. x points to the right, y to the front and z to the top. The fit interval started 1 ms before (triangles) to wave V and ended 2.5 ms after wave V. At the latency of wave V, error-ellipses indicate 95% confidence regions.

The dipole moment is largest in z-direction. Moments in x- and z-direction vary only with laterality of the virtual sound source.

a) Variation of azimuth



b) Variation of elevation