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Session D10

BINAURAL AUDITORY EVOKED POTENTIALS WITH VIRTUAL ACOUSTICS

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Abstract

The binaural difference potential (BD) is commonly regarded as neural correlate for binaural processing. It is calculated as the difference between binaural (B) and summed monaural (L+R) auditory brain stem responses (ABRs). Previous studies used click stimuli with "artificial" binaural differences, i.e., fixed interaural time and level differences (ITD, ILD) [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). Eight virtual directions in the horizontal plane with 45∞ angular spacing were chosen for this study. In addition, the unconvolved "pure" chirp was presented diotically as a reference condition. ABRs were recorded from 32 scalp electrodes. In contrast to stimuli with artificial binaural differences, the "natural" spatial stimuli result in an object perceived outside the subject's head (externalization). The BD shows a systematic dependence on the laterality of the virtual sound source. The latency of BD wave DN1 increases monotonically with laterality. The BD is largest for central (front, back, diotic) and smaller for lateral directions. This is in accordance with results from click stimuli with "artificial" binaural differences [7]. Differences between frontal and backward directions are mostly not significant. The results indicate that at the level of the brain stem mainly lateralization is extracted. Spectral cues are presumably processed on cortical levels of the auditory pathway.

Motivation

ï ITD and ILD alone merely produce an acoustic object lateralized ìinside the headî.

ï Additional spectral cues introduced by virtual acoustics result in an externalized object to distinguish between front/back, top/bottom

ï Underlying questions:
- How do spectral cues (in addition to ITD/ILD) affect the potentials?
- Does the more ìnaturalî 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?

Methods

ï **Stimulus:** broadband chirp with flat spectrum in the frequency range from 100-18000 Hz
- In order to provide synchronous discharges of auditory nerve fibers along the length of 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)

ï **Presentation**
- via insert earphones (Etymotic Research ER-2)
- 8 virtual directions by convolution with individual HRIRs (left/right/binaural each)
- reference condition: unconvolved chirp (left/right/binaural)
- 27 conditions presented in randomized order, 40 dB SL

ï **Recording of ABR**
- 7 subjects
- 32 channel setup (channels A1, A2, PO9 and PO10 for evaluation of amplitudes/latencies)
- average over 10000 presentations per condition

Stimuli

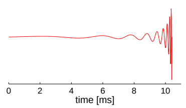


Fig. 1a: Broadband chirp stimulus with flat spectrum in the frequency range 100-18000 Hz. The chirp compensates for the basilar membrane dispersion providing synchronous discharges of auditory nerve fibers along the length of the entire cochlear partition [2].

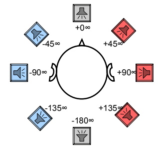


Fig. 1b: The chirp was convolved with individual HRIRs corresponding to eight virtual directions on the horizontal plane with an angular spacing of 45∞. In addition the unconvolved (diotic) chirp was presented as a reference condition (blue: stimuli from the left, gray: stimuli on the median plane, red: stimuli from the right).

Binaural potentials (4 channels, subject RH)

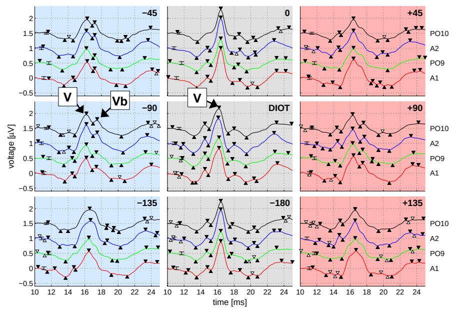


Fig. 2a: Binaural potentials for all virtual directions and the diotic reference condition (DIOT). Depicted are channels A1, A2, PO9 and PO10. Subject: RH. Errorbars indicate ±3 S.E.M. Triangles denote peak pairs whose peak-to-peak values exceed $\sqrt{2}\cdot 3$ S.E.M. All stimulus conditions evoke a prominent ABR wave V. For some lateral directions, wave V is followed by a second peak Vb (not for all subjects).

BD (4 channels, subject RH)

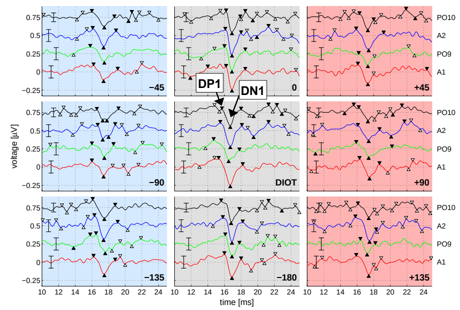


Fig. 2b: Binaural differences for 8 virtual directions and the diotic reference condition (DIOT). Depicted are channels A1, A2, PO9 and PO10. Subject: RH. Errorbars indicate ±3 S.E.M. Triangles denote peak pairs whose peak-to-peak values exceed $\sqrt{2}\cdot 3$ S.E.M. All stimulus conditions evoke a prominent BD wave DN1 (first negative deflection).

Binaural potentials: Amplitudes and latencies

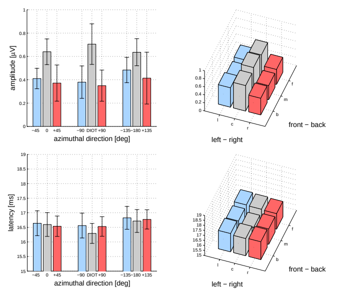


Fig. 3a: Amplitudes (**top**) and latencies (**bottom**) of wave V for all virtual directions and the diotic reference condition, mean over subjects and channels. Left panel: 2-D representation, right panel: 3-D representation. The reference condition (DIOT) produces the largest amplitude. All directions along the median plane (0∞, 180∞, DIOT) show higher amplitudes than lateral directions. There are no significant differences between front and back.

BD: Amplitudes and latencies

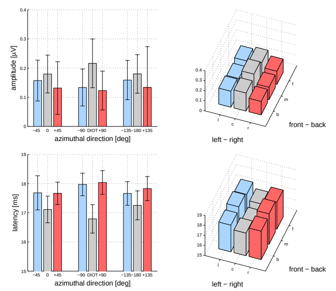


Fig. 3b: Amplitudes (DP1-DN1, **top**) and latencies (DN1, **bottom**) for all virtual directions and the diotic reference condition, mean over subjects and channels. Left panel: 2-D representation, right panel: 3-D representation. All directions along the median plane (0∞, 180∞, DIOT) show larger amplitudes and smaller latencies than lateral directions. The latency increases monotonically with laterality.

Comparison of the latencies

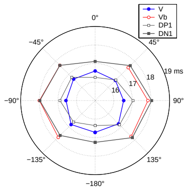
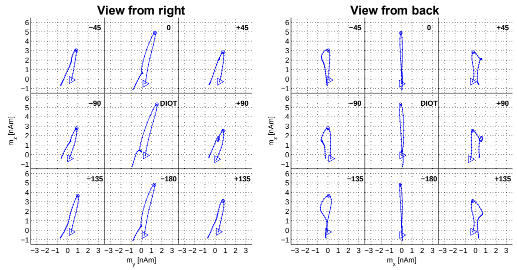


Fig. 5: Latencies of binaural potentials (V, Vb) and BDs (DP1, DN1). Mean over subjects and 4 channels. For wave V, latencies are almost constant for all directions. In contrast, latencies for BDs increase with laterality. The latency of DN1 is slightly higher than that of wave Vb for lateral directions.

Dipole moment trajectories of a fitted rotating dipole



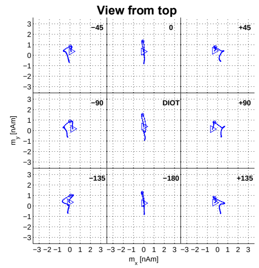


Fig. 6: Dipole source analysis of binaural potentials, mean over all subjects. The moment trajectories of a rotating dipole in the three planes for all 9 stimulus conditions are shown. x points to the right, y to the front and z to the top. The fit interval started 1 ms before (triangles) to wave V and ended 2.5 ms after wave V. 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 with laterality of the virtual sound source. The locations of the dipoles are nearly the same for all stimulus conditions (not shown).

Results

ï The diotic reference conditions produces the largest amplitudes and shortest latencies for both the binaural potentials and BDs.

ï The BDs show a systematic dependence on the laterality of the virtual sound source. The latency of BD wave DN1 increases monotonically with laterality. The BD is largest for central (front, back, diotic) and smaller for lateral directions.

ï No differences between front and back directions can be found for binaural potentials and BDs.

Conclusion

ï At the level of the brainstem only ITD and ILD are evaluated.

ï Spectral cues are presumably processed on cortical levels of the auditory pathway.

References

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