Auditory brain stem responses evoked by lateralized click stimuli

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Introduction

From psychoacoustical studies it is known that the most important cues for directional hearing are the interaural time difference (ITD) and the interaural level difference (ILD). Presenting a stimulus with an ITD and an ILD that point towards the same direction ('synergistic presentation') leads to a further lateralized perception than presenting the same respective ITD or ILD alone. In contrast, the 'antagonistic presentation', when ILD and ITD point to opposite lateral positions, results in more central percepts.

In evoked response studies binaural processing or binaural interaction (BI) is assessed in terms of the binaural difference potential (BD). It is defined as the difference between the potential obtained with binaural stimulation and the sum of the potentials obtained with monaural stimulation, symbolically BD = B − (L + R).

Furst et al. [2] suggested that the first major peak in the BD, DN1 or β in their nomenclature, is a physiological correlate of the categorial percept of binaural fusion. DN1 was present up to ITDs of 1 ms with a relatively constant amplitude, but undetectable for ITDs longer than 1.2 ms. With increasing ILD, DN1 amplitude decreased gradually and became undetectable for ILDs greater than 30 dB. Brantberg et al. [1] found an approximately constant DN1 amplitude for ITDs up to 1 ms. In contrast, McPherson and Starr [3] reported that the DN1 component gradually decreased with increasing ILD and ITD, and became undetectable for ILD > 16 dB and ITD > 1.6 ms. They stated an inverse correlation between DN1 amplitude and the psychophysical lateralization (introduced by either ILD or ITD).

The aim of the present study is to analyze the dependence of auditory brain stem responses (ABR) and BD on psychophysical lateralization if not only a single cue, ILD or ITD, is presented, but also for synergistic and trading stimulus configurations.

Methods

- Click evoked auditory brain stem responses from 12 normal hearing subjects were measured for 6 monaural and 9 binaural stimulus conditions from four channels. The binaural stimuli were the nine possible combinations of 3 ITDs (−0.4, 0 and 0.4 ms) and 3 ILDs (−12, 0 and 12 dB), see Fig. 1.
- Monaural and binaural stimuli were presented in random order on a sweep-by-sweep basis. 10000 sweeps for every stimulus condition were recorded, linear phase filtered, and averaged using a weighted iterative scheme, see Fig. 3.
- Residual noise was determined on a single-sweep-basis as the standard deviation over the sweeps σ.
- BD was computed by subtracting the sum of the monaural responses from the binaural responses, see Fig. 2.
- Residual noise of the BD was determined by adding the variances of left, right and binaural response. Only BD peaks with peak-to-peak voltages $V_{pp} > \sqrt{2} \cdot 2\sigma$ were considered as significant. In 11 out of 12 subjects significant BD components DP1 and DN1 were found, see Fig. 4.

Stimuli

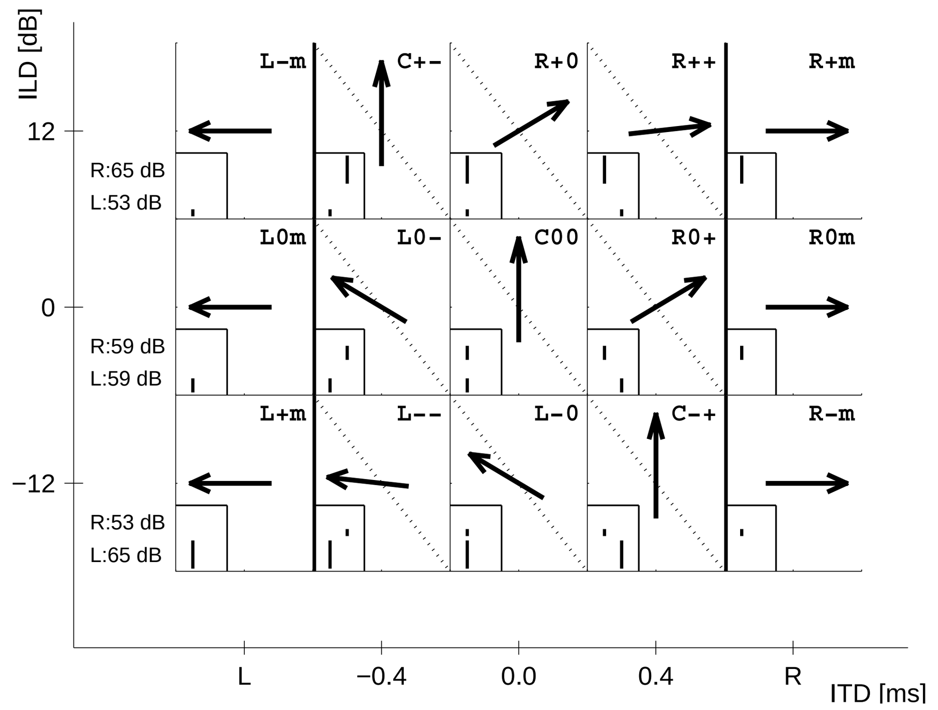

Fig. 1: Naming convention and lateralization of the stimuli: Centrally perceived stimuli are marked with a 'C'. Stimuli lateralized to the left and right side are marked with 'L' and 'R', respectively. For the monaural stimuli the second character indicates the level: '−' for 53, '0' for 59 and '+' for 65 dB nHL, respectively. For the binaural stimuli the second and third character denote the sign of ILD and ITD, respectively. Arrows point into the direction of perceived lateralization. The dotted lines connect stimuli eliciting similar lateralization.

Binaural difference potential

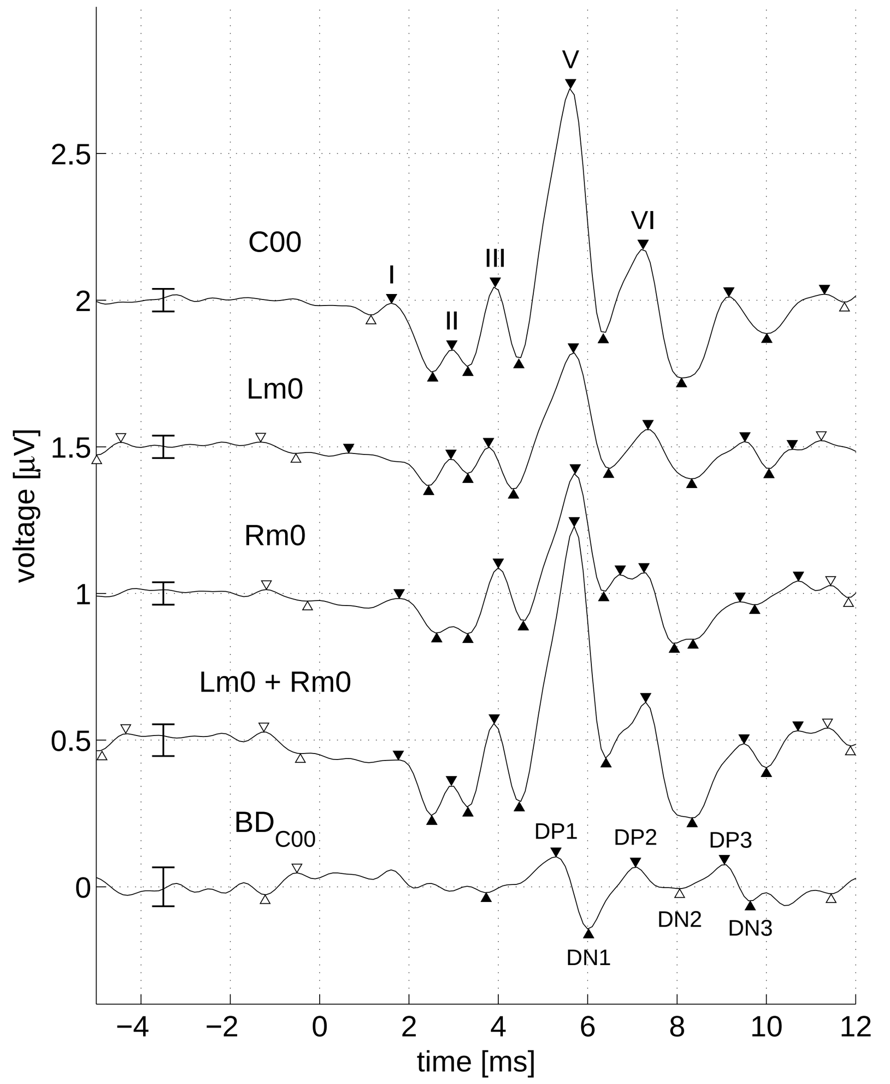

Fig. 2: Derivation of the binaural difference potential for subject dj to diotic stimulation, channel A2. **Top row:** response to the binaural stimulus with Jewett peaks, **second row:** response to the monaural left stimulus, **third row:** response to the monaural right stimulus, **fourth row:** sum of the monaural responses, **Bottom row:** binaural difference potential with nomenclature of peaks. Errorbars indicate ±3 standard deviations. Open triangles: $V_{pp} \geq \sqrt{2}\cdot 2\sigma$, filled triangles: $V_{pp} \geq \sqrt{2}\cdot 3\sigma$.

Recordings

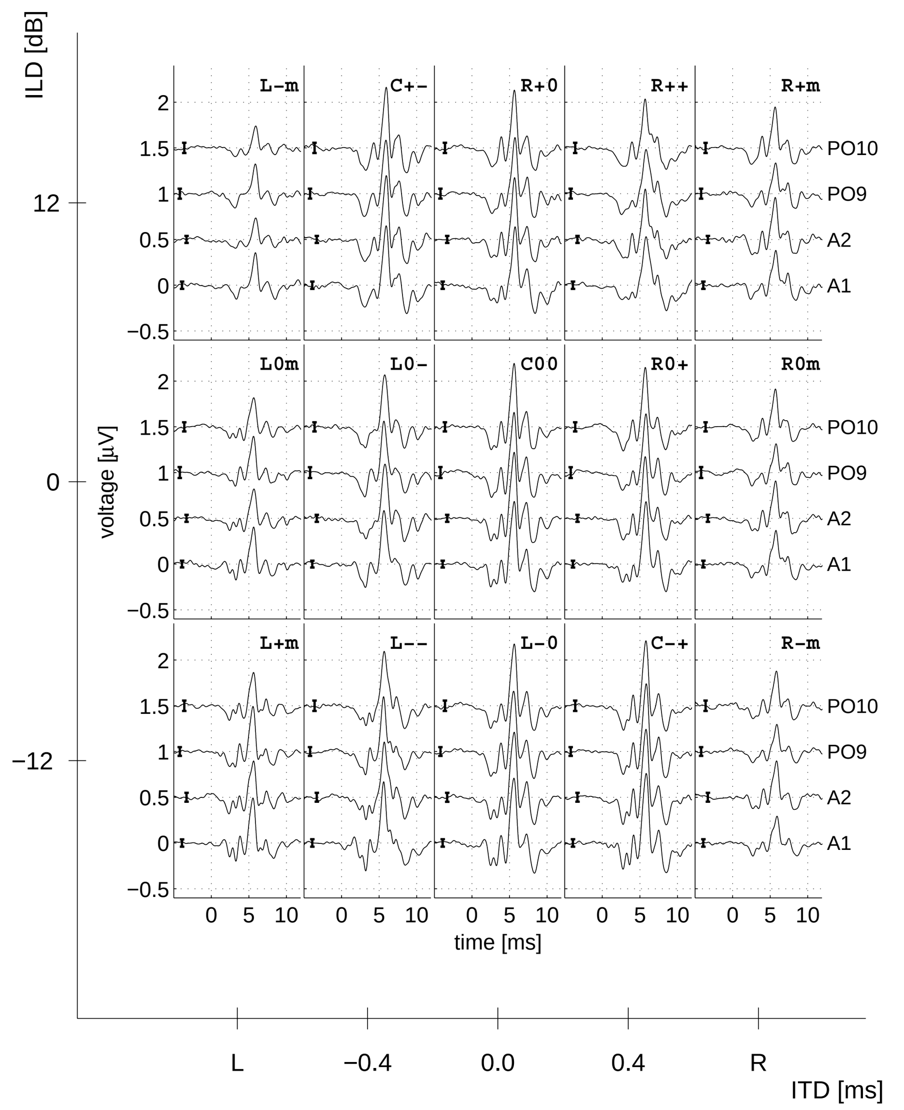

Fig. 3: ABR for the 15 stimulus conditions, 9 binaural and 6 monaural, for one subject (dj). Stimuli are arranged as in Fig. 1. Plot offset between the channels is 0.5 μV. Errorbars indicate ±3 standard deviations.

BD for 12 subjects

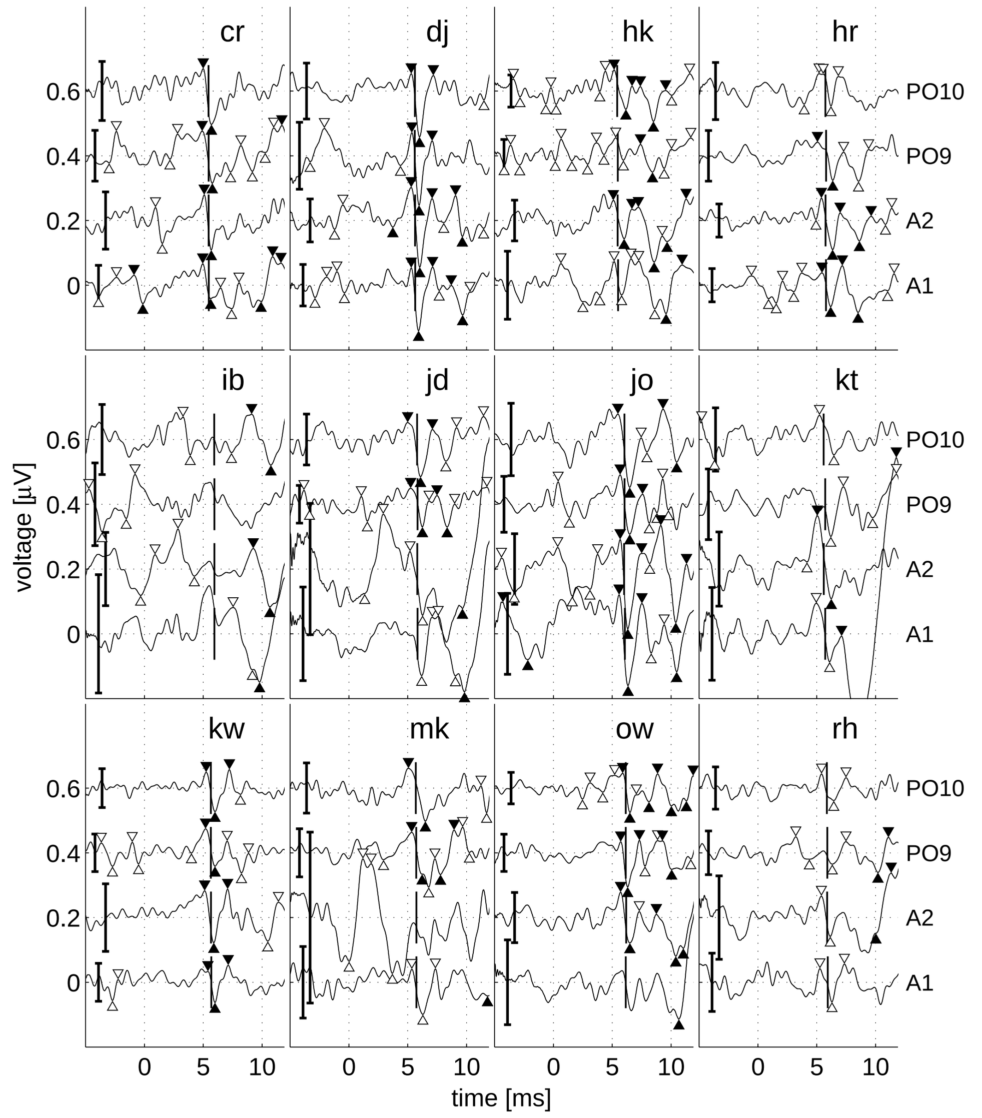

Fig. 4: BDs for 12 subjects and 4 channels. Errorbars indicate ±3 standard deviations. Vertical lines show the latency of wave V in the corresponding binaural potential. A pair of consecutive BD components is considered as significant if its peak-to-peak-value $V_{pp} \geq \sqrt{2} \cdot 2\sigma_{\mathrm{BD}}$ (open triangles), i.e., if its SNR is ≥ 6 dB, filled triangles: $V_{pp} \geq \sqrt{2}\cdot 3\sigma$. Subjects with low noise level, e.g. cr, dj, hr and kw, show a systematic BD with components DP1 and DN1.

Results

- The amplitude of wave V, A_{V}, is largest for centrally perceived stimuli, see Fig. 5. With increasing lateralization, A_{V} decreases, seen as a 'ridge' in the 3d-plot.
- A_{V} for lateralized stimuli is significantly smaller than A_{V} for central stimuli (Wilcoxin rank test, $\alpha = 0.01$).
- The latency of wave V, t_V, is minimal for the synergistic stimuli and stimuli with ITD = 0 ms. For binaural stimuli with ITD an inverted amplitude-latency-dependence is observed: With increasing amplitude the latency *increases*, see Fig. 6.
- t_V for the antagonistic stimuli is significantly larger than for all other binaural stimuli ($\alpha = 0.01$).
- The amplitude of the BD, $A_{\mathrm{DP1-DN1}}$, depends similarly on stimulus conditions as A_{V}: Smallest amplitudes are found for the lateralized stimuli, largest amplitudes for the central stimuli, see Fig. 7.
- BD amplitudes between central and synergistic stimuli differ significantly (Wilcoxin rank test, $\alpha = 0.05$).
- The latency of DN1, t_{DN1}, is mainly determined by the ITD and is, on average, 0.21 ms ≈ ITD/2 larger for stimuli with ITD = ±0.4 ms than for stimuli with ITD = 0 ms ($\alpha = 0.05$).

Discussion

A systematic relation between binaural wave V amplitude as well as BD amplitude DP1-DN1, and stimulus lateralization was demonstrated for all subjects. The significant differences between antagonistic and synergistic responses show that ILD and ITD are not processed independently in the brain stem. Independent processing of ILD and ITD would lead to the same amplitudes for synergistic and antagonistic stimulation.

Physiological recordings in animals showed that the superior olive (SO) is the first stage of binaural interaction [6]. In evoked-potential studies, it was shown by means of a spatio–temporal dipole model [5] that the active structures at the latency of wave V are the SO and the lateral lemniscus (LL). This view is also supported by leason studies from Melcher and Kiang [4]. Therefore, it can be concluded that the analysis and coding of directional information first takes place in the SO and the LL as the neural generators of the peaks in the BD.

References

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Wave V amplitudes

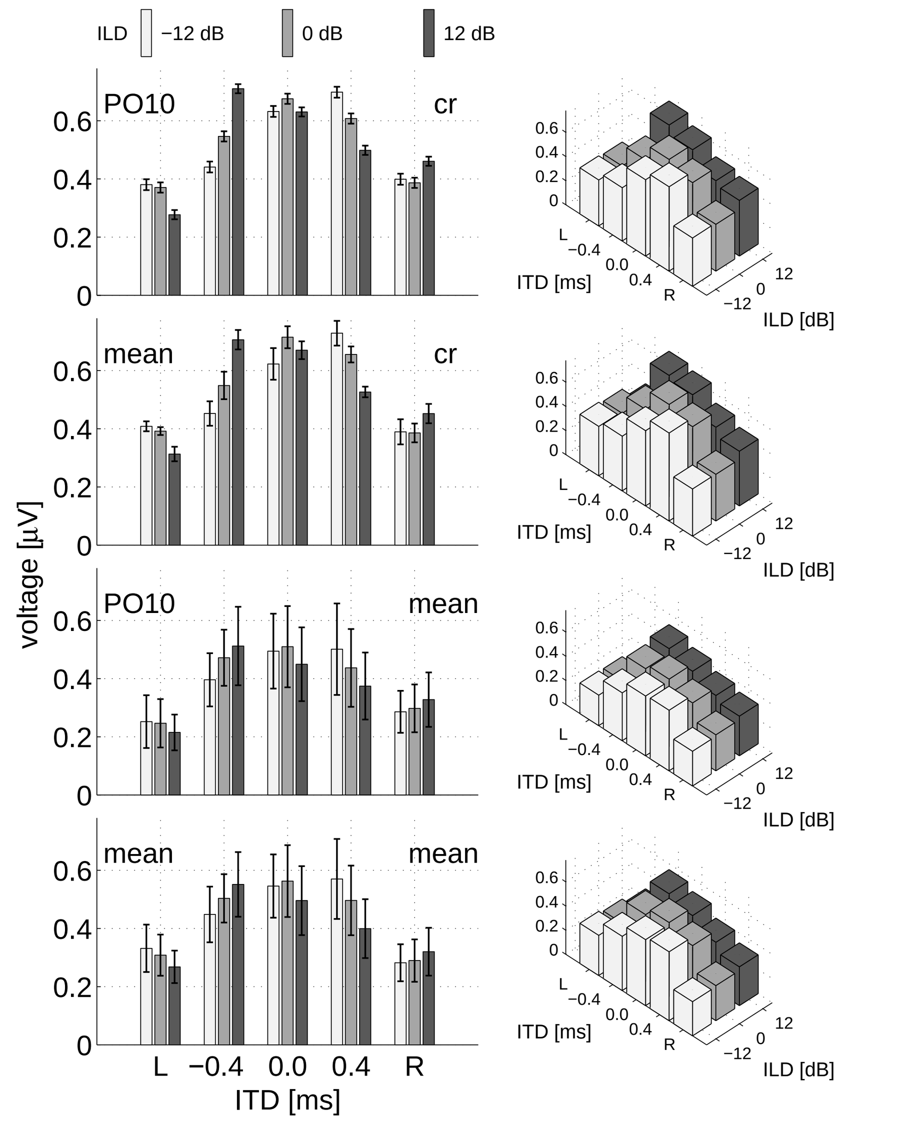

Fig. 5: Amplitudes of wave V as function of ILD and ITD. **Left column:** two-dimensional representation. **Right column:** corresponding three-dimensional representation. **Top row:** Data for channel PO10 and subject cr, errorbars indicate the intraindividual standard deviation σ. **Second row:** Data for mean over channels and subject cr. **Third row:** Data for channel PO10 and mean over subjects, errorbars show interindividual standard deviations. **Bottom row:** Data for mean over channels and subjects.

Wave V latencies

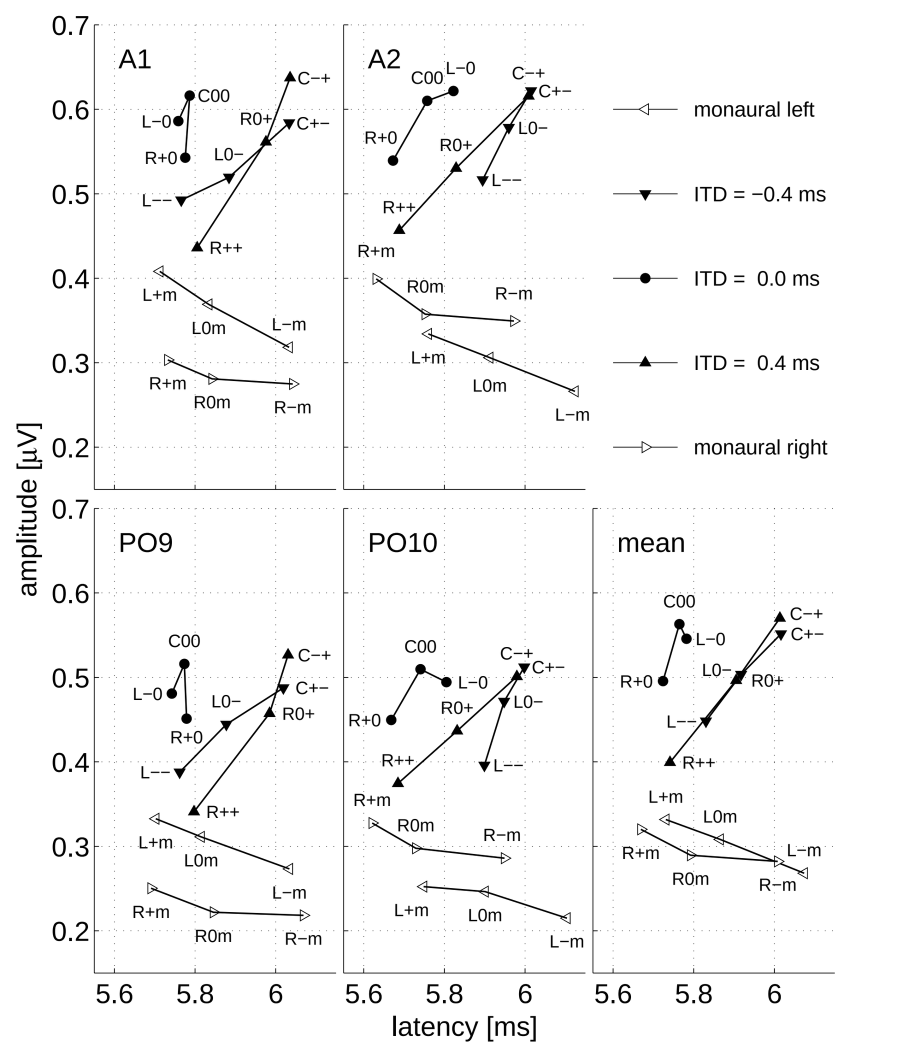

Fig. 6: Amplitude of wave V as function of wave V latency, mean over subjects. The subplots are for different channels and mean over channels. Data belonging to the same ITD are connected with lines, stimulus names are according to Fig. 1.

BD amplitudes

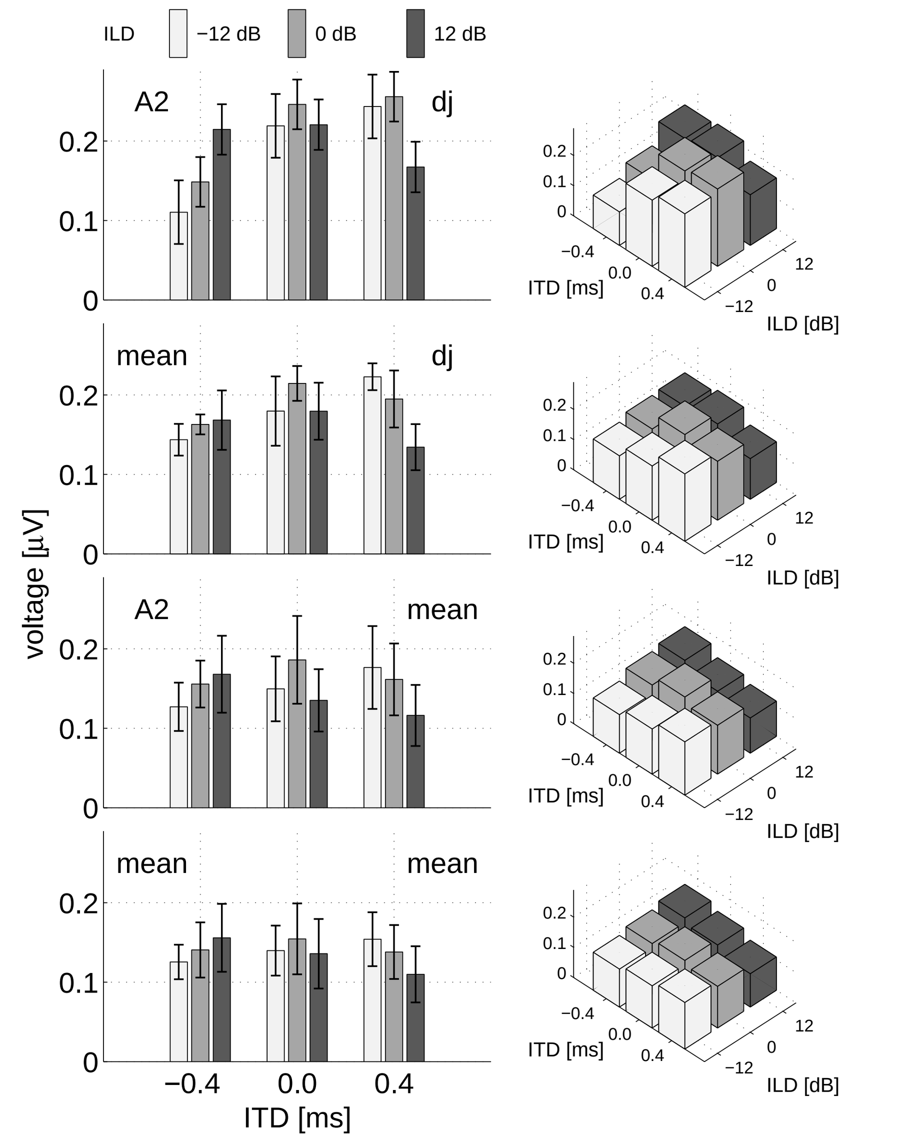

Fig. 7: Amplitudes of BD-wave DP1-DN1 as function of ILD and ITD. **Left column:** two-dimensional representation. **Right column:** corresponding three-dimensional representation. **Top row:** Data for channel A2 and subject dj, errorbars indicate the intraindividual standard deviation σ. **Second row:** Data for mean over channels and subject dj. **Third row:** Data for channel A2 and mean over subjects, errorbars show interindividual standard deviations. **Bottom row:** Data for mean over channels and subjects.

BD latencies

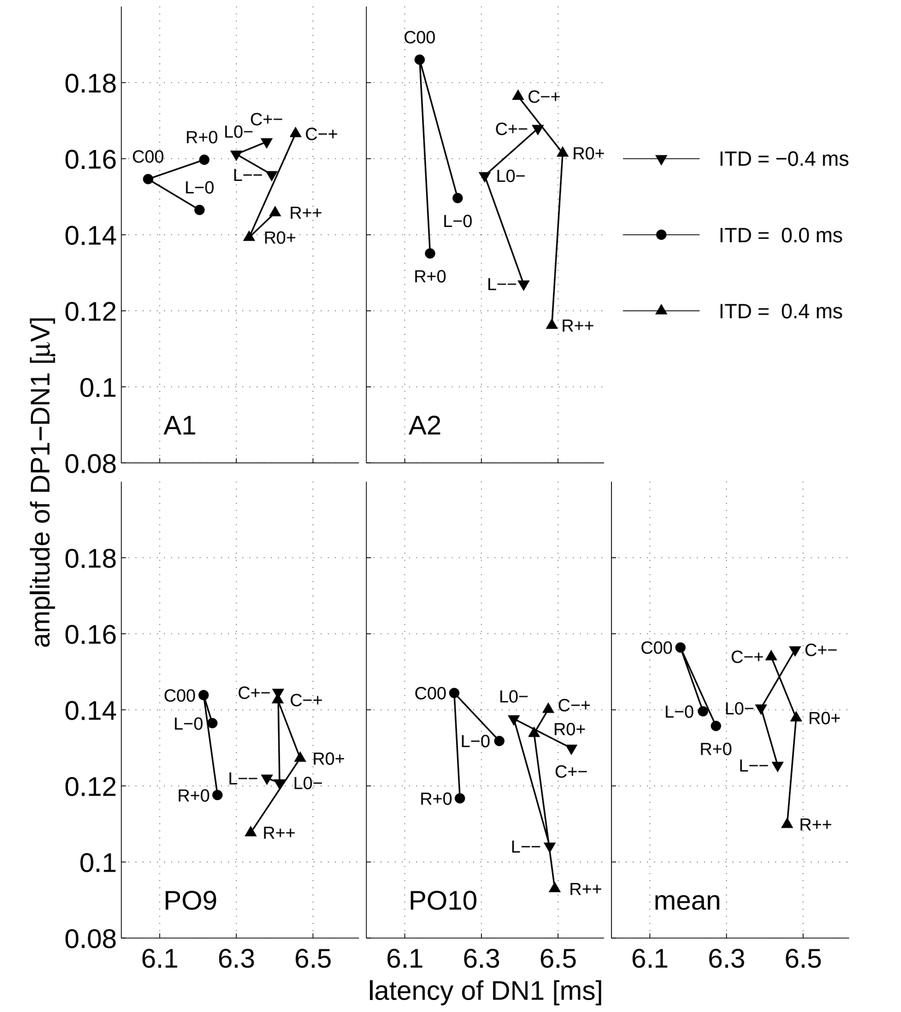

Fig. 8: BD amplitude DP1-DN1 as function of DN1 latency, mean over subjects. The subplots are for different channels and mean over channels. Data belonging to the same ITD are connected with lines, stimulus names are according to Fig. 1.