4aPP4

Auditory evoked potentials to changes in interaural cross correlation

Helmut Riedel, Helge Lüddemann, Birger Kollmeier

Medizinische Physik, Carl von Ossietzky Universität Oldenburg
D-26111 Oldenburg, Germany

email: helmut.riedel@uni-oldenburg.de, helge.lueddemann@mail.uni-oldenburg.de, birger.kollmeier@uni-oldenburg.de

CARL VON OSSIETZKY universität OLDENBURG

SFB 517 Neurokognition

Introduction

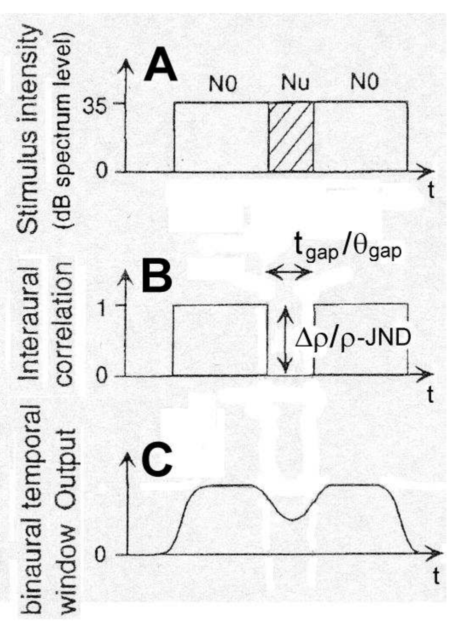
The objective of this study is to analyze the human binaural system using late auditory evoked potentials (LAEP) and to compare the results to psychoacoustic data. Psychoacoustical studies [1, 2, 3] have shown that the auditory system is sensitive to changes in the interaural correlation ρ. Thresholds for brief changes in ρ ('binaural gaps') depend on the reference correlation ρ_{ref}: for $\rho_{ref} = 0$ much larger gaps are needed for detection than for $\rho_{ref} = \pm 1$ [1]. The detection of a small deviation $\Delta\rho$ from a reference correlation also strongly depends on ρ_{ref}. ρ-JNDs are about ten times larger for $\rho_{ref} = 0$ compared to $\rho_{ref} = 1$ [2].

Jones et al. [4] measured LAEPs for changes from a diotic (ρ=1) to an uncorrelated (ρ=0) stimulus and vice versa. They found a N1 component with 130 ms latency and a P2 with 220 ms latency. Components for changes in interaural time difference were similar suggesting that these responses are not specific for the stimulus and can be elicited by any perceptible change of interaural parameters.

In contrast to the 'indirect' binaural difference potentials (BD = B - (L+R)) used in auditory brainstem responses [6, 7], employing changes in interaural parameters constitutes a more direct approach to objectively investigate the binaural system in humans using LAEP. A subtraction of monaural contributions is not necessary since these stimuli do not evoke any monaural response.

In the current study, the influence of the duration of 'binaural gaps' and changes in ρ on late auditory evoked potentials (LAEP) is parametrically studied. Objective JNDs and threshold gap durations can be estimated for the three reference correlations ($\rho_{ref} = -1, 0, +1$). Using a simple model, an estimate of the duration of a binaural temporal window is derived from the psychoacoustic data.

A concept of temporal binaural processing



A: A sequence of 3 noise segments with different ρ. **B:** Binaural gap in the middle segment. Gap duration is t_{gap}, magnitude of ρ change during the binaural gap is denoted by $\Delta\rho$. **C:** Perception of binaural gaps is assumed to be sluggish due to a temporal integration window underlying binaural processing (taken from [1], with modifications).

Methods

Stimuli:

- Gaussian bandpass noise (100-2000 Hz) at 65 dB SPL, running noise (EEG: continuous stimulation, no silence between events)
- Interaural correlation ρ in consecutive segments is achieved by mixing two independent noises n_1 and n_2 (i.e., $\rho(n_1, n_2) = 0$) [3]:

$$L = n_1, \qquad R = \rho \cdot n_1 + \sqrt{1-\rho^2} \cdot n_2$$

- Iterative algorithm to eliminate spectral splatter without degrading desired value of interaural correlation ρ

Psychoacoustic measurements:

- 7/9 normal hearing subjects in Experiment I/II
- 3-interval-3-AFC with adaptive stepsize, 1-up-2-down,

LAEP Recordings:

- 4/7 normal hearing subjects in Experiment I/II
- 1000 sweeps per subject and stimulus condition
- Bandpass filtering (1-20 Hz) and iterated weithed averaging ([5])

Experiment I

Transitions between different interaural correlations

Psychoacoustic thresholds for $\Delta\rho$

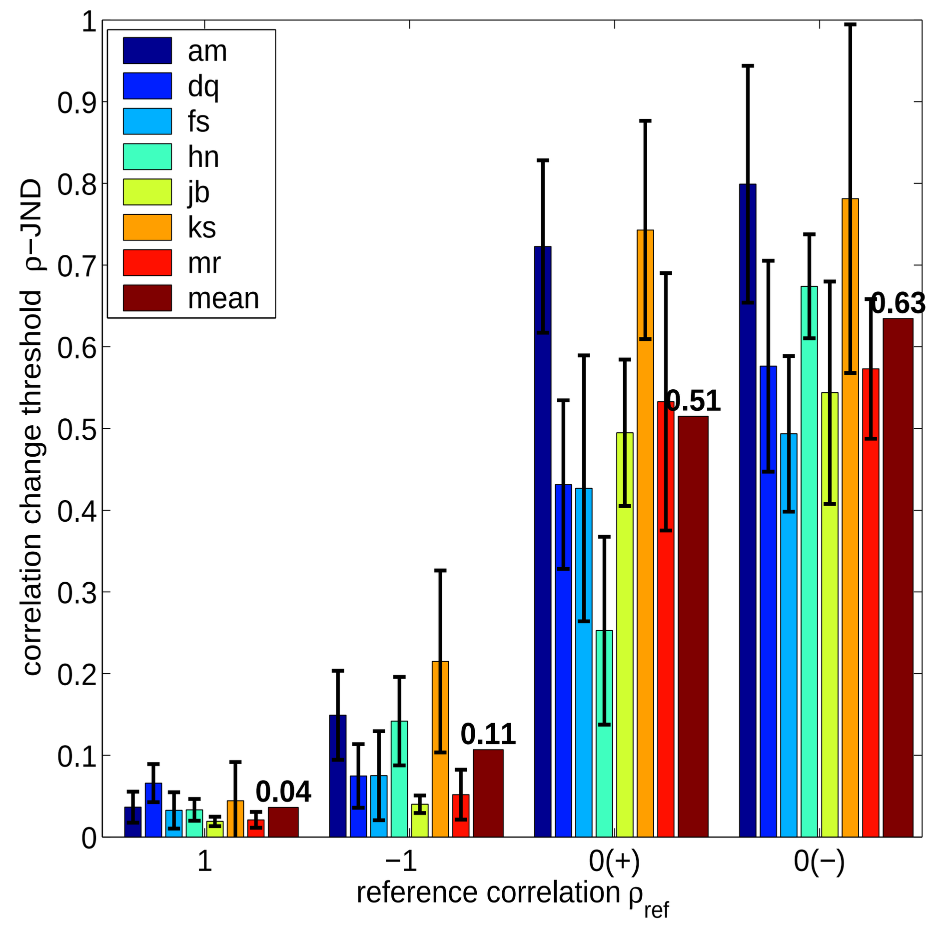


Fig. 1: Just noticeable differences for changes in interaural correlation (ρ-JND) from reference correlations $\rho_{ref} = 1$,0 and -1. For $\rho_{ref} = 0$ JNDs are measured both towards positive ρ ('0+') and negative ρ ('0-'). The intervals had a duration of 680 ms. In one of the intervals the middle 250 ms contained the test correlation ρ_{gap}. Comparison between subjects reveals large differences in individual ability to detect changes in interaural correlation. However, some subjects (fs, jb) perform well at any interaural configuration, while others vary a lot in performance level: subject hn is a good performer for correlation changes $1 \rightarrow (1-\Delta\rho)$ and $0 \rightarrow +\Delta\rho$ but can't deny difficulties when dealing with anticorrelated situations (ρ_{ref} or ρ_{gap} negative).

LAEP for $\rho_{ref} = 0$

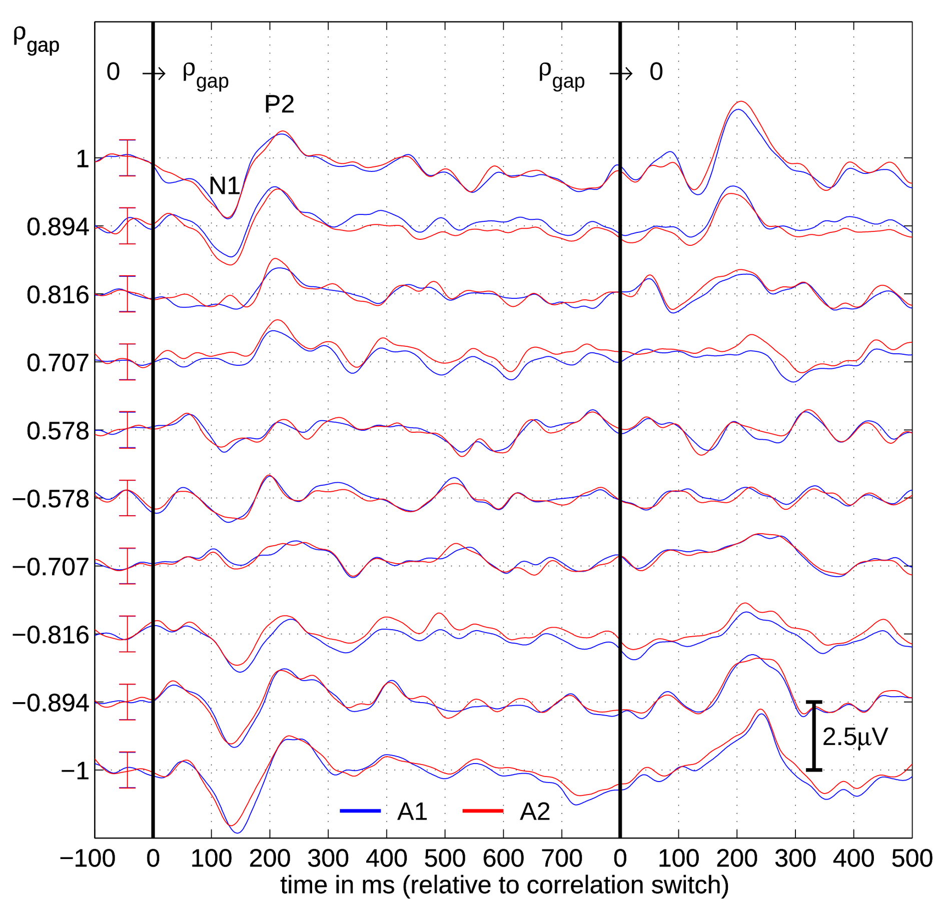


Fig. 2: LAEP for correlation changes $\Delta\rho$ from and back to an uncorrelated reference $\rho_{ref} = 0$. The duration of the 'binaural gap' is 800 ms. Recordings show potentials at the left mastoid (A1,blue) and right mastoid (A2,red) versus vertex for a single subject (am, 1000 sweeps). Errorbars denote ± 2 standard errors of the mean (± 2 S. E. M.). Comparison of the potentials at channels A1 and A2 yields no evidence for hemispheric differences. Responses to positive and negative correlations cannot be observed for ρ_{gap} smaller than 0.707 and 0.816, respectively, and are in good agreement with psychoacoustical JNDs. The asymmetry between positive and negative ρ_{gap} is therefore weak.

LAEP for $\rho_{ref} = -1$

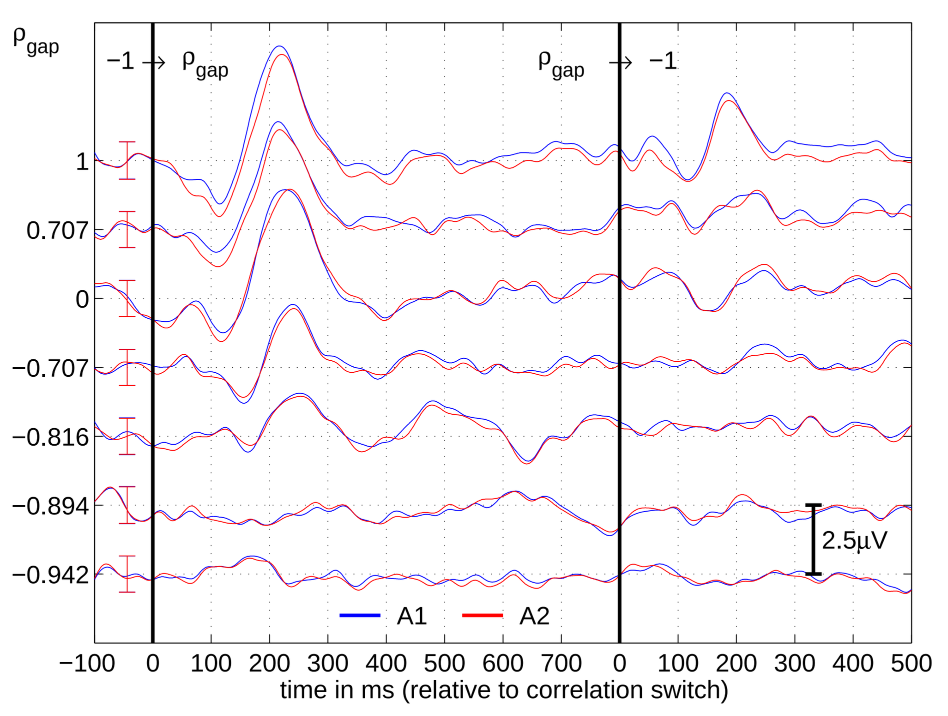


Fig. 3: LAEP for correlation changes $\Delta\rho$ from and back to an anticorrelated reference $\rho_{ref} = -1$ for subject am (1000 sweeps). A response is detectable for all $\Delta\rho$ larger than 0.184 in accordance with the psychoacoustic JND. With increasing $\Delta\rho$ response latencies decrease and amplitudes increase. In this condition the N1 amplitude is small compared to $\rho_{ref} = 0$ (Fig. 2) and $\rho_{ref} = 1$ (Fig. 4). However, the peak-to-peak amplitude P2-N1 does not differ much between $\rho_{ref} = 1$ and $\rho_{ref} = -1$ and is larger compared to $\rho_{ref} = 0$.

LAEP for $\rho_{ref} = +1$

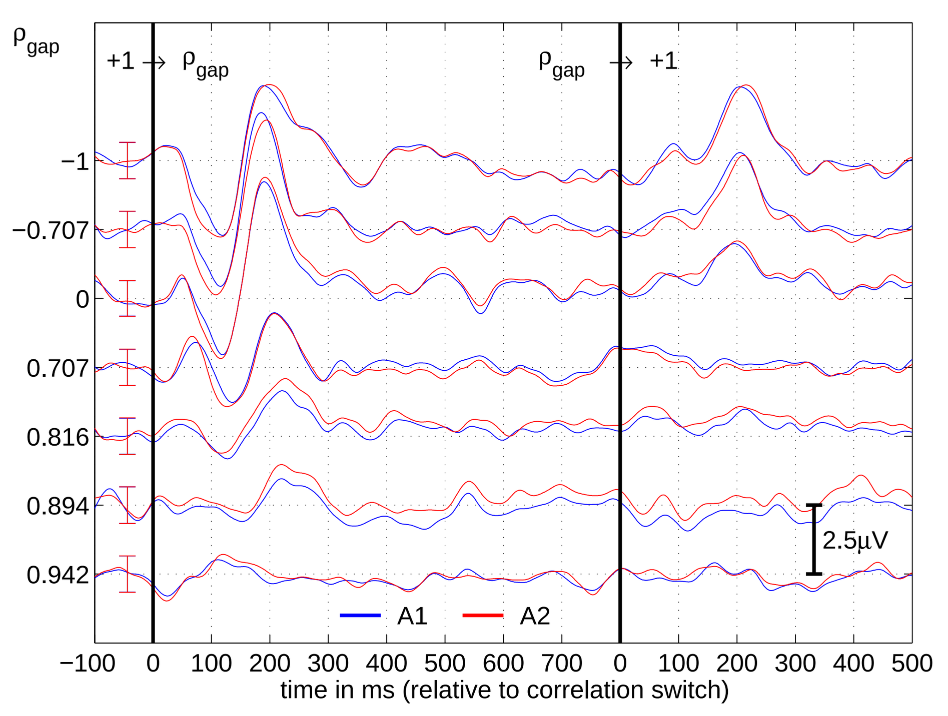


Fig. 4: LAEP for correlation changes $\Delta\rho$ from and back to a diotic reference $\rho_{ref} = +1$ for subject am (1000 sweeps). In this condition there is a mismatch between psychoacoustic and objective thresholds: the JND is 0.037 while the objective threshold is between 0.058 and 0.106. N1 and P2 latencies are shorter in comparison to both other ρ_{ref}. AEP do not only depend on the size of the correlation switch, but also on the reference condition, i.e., the perceptual context (compare the uppermost traces in Figs. 3 and 4).

Experiment II

Short changes in interaural correlation ('binaural gaps')

Thresholds for t_{gap}

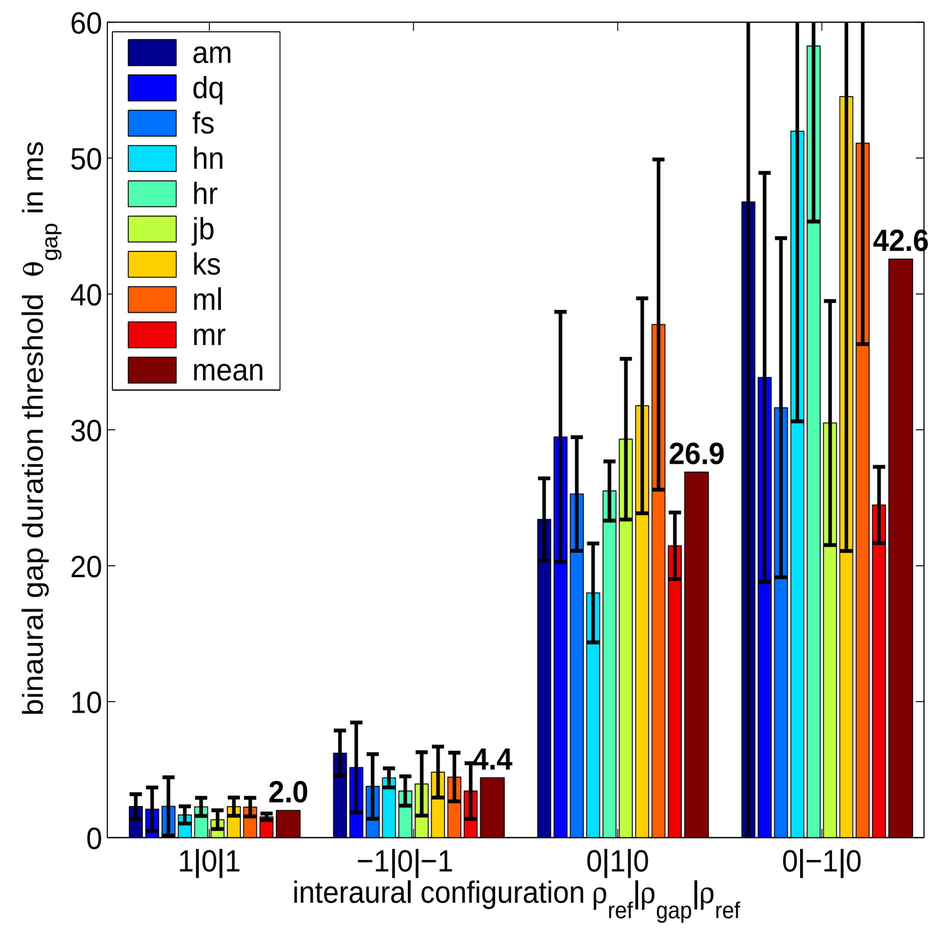


Fig. 5: Thresholds θ_{gap} for the duration of binaural gaps, measured for four configurations of interaural correlation change. For any of the four tasks, comparison between subjects reveals large differences in individual ability of binaural gap detection. However, some subjects (jb, mr) perform well at any interaural configuration, while others vary a lot in performance level: subjects hn and hr show impressive $0|+1|0$-results but are among the worst performers in the $0|-1|0$-task. Performance in t_{gap} experiments is consistent with performance found in ρ-JND tasks for all subjects and interaural configurations. However, for zero reference correlation the asymmetry between $\rho_{gap} = 1$ and -1 is more pronounced than in Experiment I.

LAEP for different gap durations t_{gap}

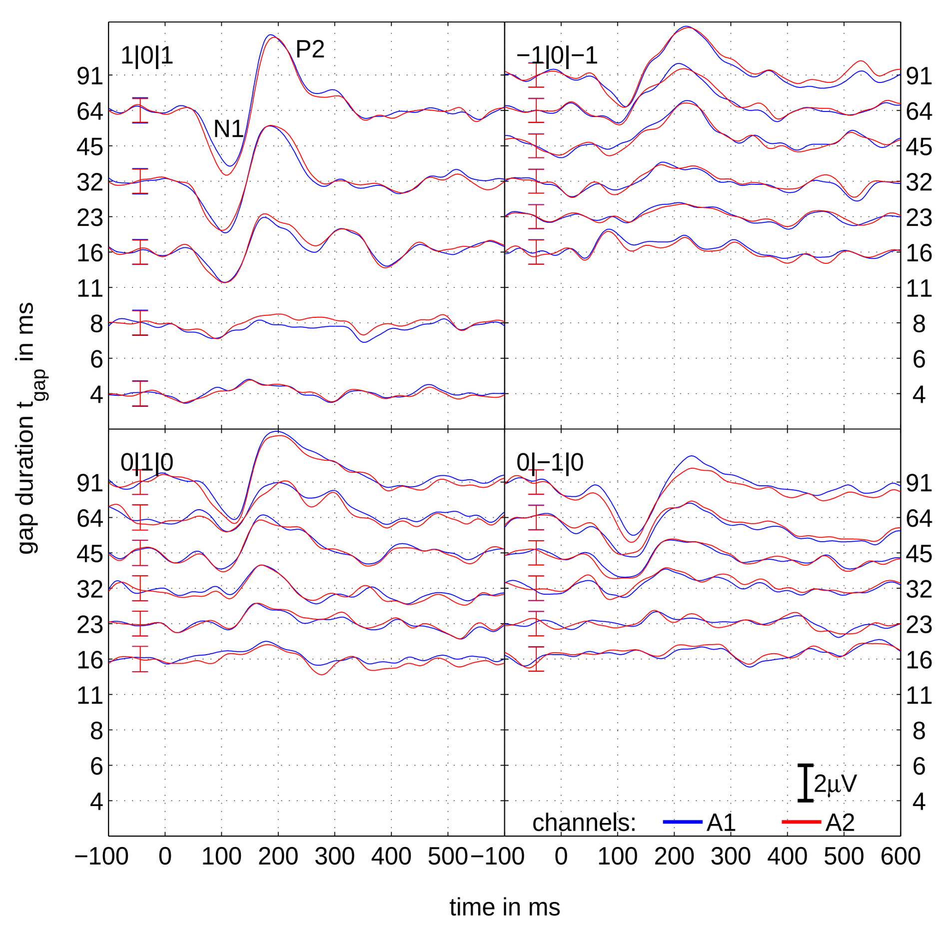


Fig. 6: LAEP for different gap durations t_{gap}, measured for 4 configurations of interaural correlation change for one subject (am, 1000 sweeps). Data at left- and right-hemispheric electrodes does not differ significantly, i.e., no evidence for hemispheric dominance in binaural processing is found. Largest responses and lowest thresholds are observed for the 1|0|1-condition. For $\rho_{ref} = \pm 1$ the AEP thresholds are about five times larger than the psychoacoustic thresholds. For $\rho_{ref} = 0$ objective and subjective thresholds match closely. With increasing gap duration, i.e., with easier detectability of the gap, N1 and P2 latencies tend to *increase* for all conditions. The reason could be a superposition of the responses to two ρ-changes in short consecution.

N1 and P2 amplitudes

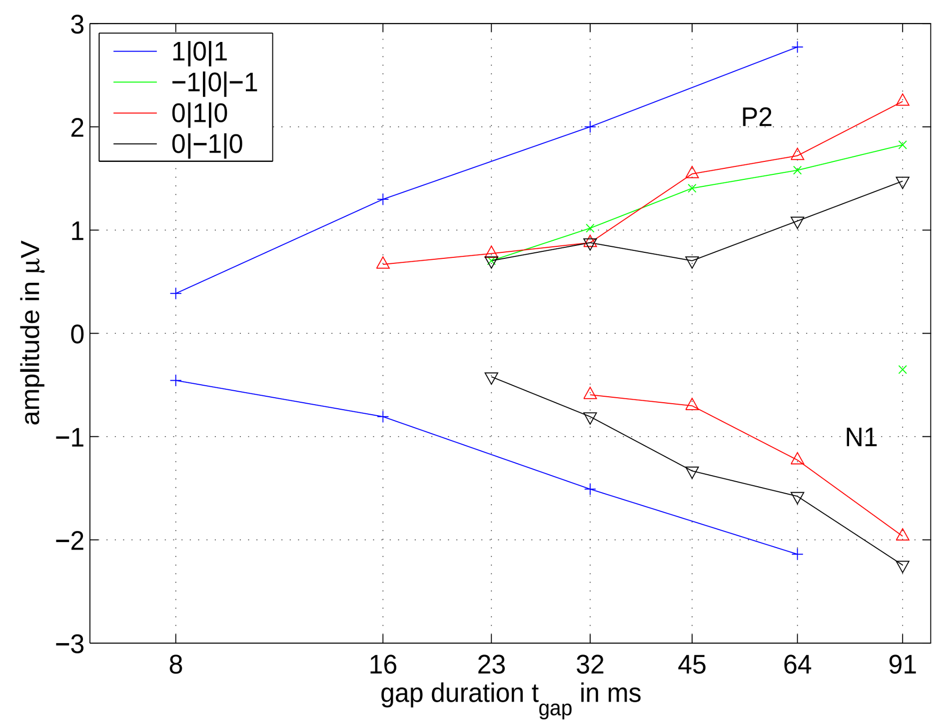


Fig. 7: N1 and P2 amplitudes (mean over 7 subjects) as function of the duration of the binaural gap. For the given range of binaural gaps (8 - 91 ms) the N1 and P2 amplitudes increase roughly linear with the logarithm of the gap duration. The slope is similar for all interaural configurations, whereas the offset corresponds to the degree of difficulty of the related detection task, e.g., a longer gap duration is necessary in the 0|1|0-condition compared to the 1|0|1-condition to evoke the same AEP magnitude.

Binaural equivalent rectangular duration

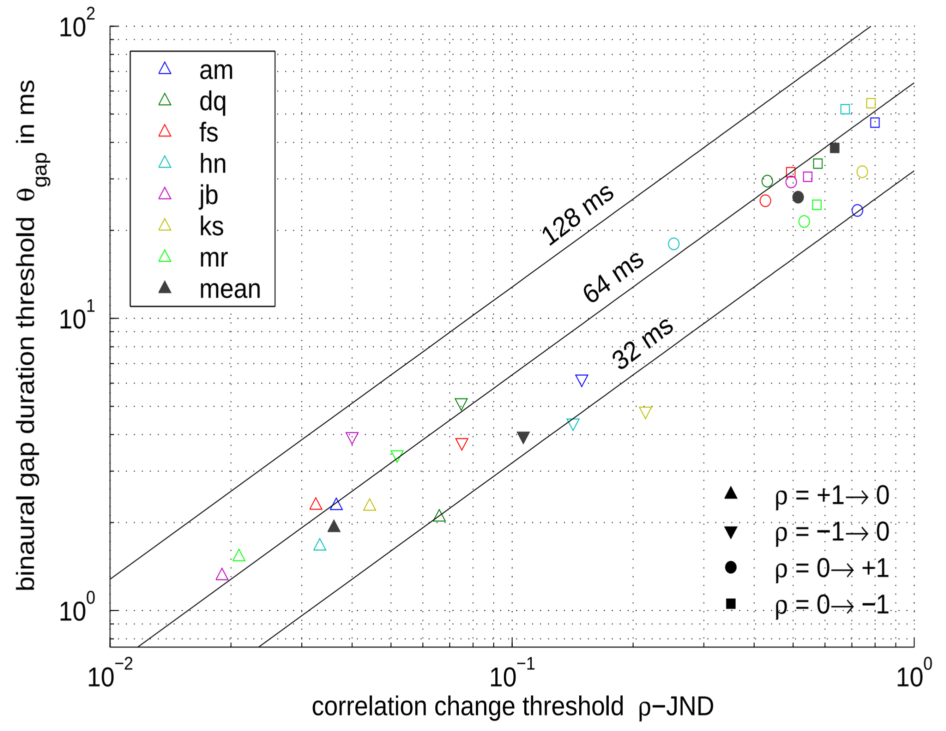


Fig. 8: Scatterplot of psychoacoustic thresholds θ_{gap} versus ρ-JND. Evaluating ρ on the signal waveform [1] and assuming a rectangular window of length ERD (equivalent rectangular duration), all threshold pairs (ρ-JND; θ_{gap}) would match the relation $\theta_{gap} = \mathrm{ERD} \cdot \rho$-JND. The slopes (ERD) of the three lines correspond to binaural equivalent rectangular durations of 32, 64 and 128 ms, respectively. ERD-estimates from [2] are between 30 and 200 ms, in the present study ERD ranges between 30 and 75 ms.

Results

- In both experiments, psychoacoustic thresholds are smallest for the diotic reference condition, larger for the anticorrelated reference, and largest for the uncorrelated reference. For $\rho_{ref} = 0$ psychoacoustic performance is better for changes in ρ towards positive correlations compared to changes towards negative correlations (Figs. 1 and 5).
- In both experiments, LAEP amplitudes are smaller for $\rho_{ref} = 0$ than for $\rho_{ref} = \pm 1$ (Figs. 2, 3, 4, 6).
- In both experiments, changes from $\rho_{ref} = -1$ and $\rho_{ref} = 1$ yield different waveform morphologies (small N1 for $\rho_{ref} = -1$) and shorter latencies for $\rho_{ref} = 1$ (Figs. 3, 4, 6).
- In Experiment I peak-to-peak amplitudes P2-N1 do not differ significantly for changes in the positive versus the negative range of ρ (Figs. 3, 4).
- Experiment II revealed the largest LAEP components for the diotic reference. The N1 component for $\rho_{ref} = -1$ is small whereas in the 'reversed' $0|-1|0$ condition the N1 component is more prominent than P2 (Figs. 6, 7).
- Time constants from modeling the psychoacoustic data are between 30 and 75 ms for all stimulus conditions (Fig. 8).

Summary and conclusions

- Specific binaural LAEP without any monaural contribution can be recorded using stimuli with changes in interaural correlation.
- The general findings concerning the detectability of different interaural configurations from recent psychoacoustic research [1, 2] match with our psychoacoustic results. However, the range of the ERD estimate in the present study (30 - 75 ms) is much narrower than reported in [2] (30 - 200 ms).
- The concept of a temporal window appears to be a suitable to describe the sluggishness in binaural processing.
- LAEP are similar at left (A1) and right (A2) recording site, i.e., no differential hemispheric processing and therefore no evidence for hemispheric dominance in binaural processing is found in this study.
- For an uncorrelated reference ($\rho_{ref} = 0$), objective binaural gap duration thresholds and psychoacoustic thresholds θ_{gap} are similar. For correlated and anticorrelated references ($\rho_{ref} = \pm 1$), gap durations about five times longer than the psychoacoustic thresholds are necessary to elicit a significant LAEP.
- AEP to changes to the reference correlation are smaller than AEP to changes to the test correlation. The upper traces in Fig. 3 ($\rho_{ref} = -1$, $\rho_{gap} = 1$) and Fig. 4 ($\rho_{ref} = 1$, $\rho_{gap} = -1$) demonstrate this 'context' effect.
- The general LAEP pattern described by Jones et al. [4] for changes between $\rho = 1$ and $\rho = 0$ is corroborated in the present study. However, responses do not exclusively reflect any perceptible change in the interaural configuration. First, LAEP amplitudes increase with increasing gap duration and increasing difference between ρ_{ref} and ρ_{gap}. Second, waveform morphology differs for different reference correlations indicating an at least partly stimulus-specific response.

References

[1] Akeroyd M.A., Summerfield A.Q., 1999. A binaural analog of gap detection. J Acoust Soc Am 105(5), 2807–2820.

[2] Boehnke S.E., Hall S.E., Marquardt T., 2002. Detection of static and dynamic changes in interaural correlation. J Acoust Soc Am 112(4), 1617–1626.

[3] Culling J.F., Colburn H.S., Spurchise M., 2001. Interaural correlation sensitivity. J Acoust Soc Am 110(2), 1020–1029.

[4] Jones S.J., Pitman J.R., Halliday A.M., 1991. Scalp potentials following sudden coherence and discoherence of binaural noise and change in the inter-aural time difference: a specific binaural evoked potential or a "mismatch" response? Electroencephalogr Clin Neurophysiol 80(2), 146–154.

[5] Riedel H., Granzow M., Kollmeier B., 2001. Single-sweep-based methods to improve the quality of auditory brain stem responses. Part II: Averaging methods. Z Audiol 40(2), 62–85.

[6] Riedel H., Kollmeier B., 2002. Auditory brain stem responses evoked by lateralized clicks: is lateralization extracted in the human brain stem? Hear Res 163(1-2), 12–26.

[7] Riedel H., Kollmeier B., 2002. Comparison of binaural auditory brainstem responses and the binaural difference potential evoked by chirps and clicks. Hear Res 169(1-2), 85–96.