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# A setup for simultaneous measurement of electrophysiological and psychometric temporal encoding in the auditory system

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ABSTRACT

*Background:* Simultaneous assessment of psychometric tasks and electrophysiological recordings is challenging because each requires specific technical and physiological preconditions.

Electrophysiological recordings require a comparatively long test time duration to gain sufficient signal-to-noise ratios, whereas test duration of psychometric measurements should be limited to prevent challenges to the attention of the subject. In order to investigate immediate correlation between both measurements a method is described, which combines electrophysiological and psychometrical measurements in a single test procedure. The test may be applied to subjects with deficits in temporal resolution (e.g. auditory neuropathy spectrum disorder, ANSD).

*New method:* Auditory steady state responses (ASSR) and a pitch discrimination task were combined in a single procedure. The setup employed two short-time ASSR sub-stimuli with different fixed modulation frequencies but same carrier frequencies (signal 1 and 2). Simultaneously to the recording of ASSR, the test subject had to determine the signal interval which generated the perception of higher pitch.

*Results:* The developed setup was successfully tested by means of an artificial EEG signal and in one human subject. ASSR signal as well as pitch discrimination performance.

*Comparison with existing methods:* To our knowledge the presented method has not yet been described elsewhere.

*Conclusions:* The feasibility of a setup to simultaneously perform a pitch discrimination task and electrophysiological measurements was demonstrated for the first time. The method provides the facility to apply sinusoidal amplitude modulated stimuli (SAM) with jittered modulation period lengths.



## 1. Introduction

The aim of simultaneous measurement of electrophysiological and a pitch discrimination task is to investigate the potential correlation between both entities. This aim may be achieved with sequential measurement as well, nevertheless a simultaneous measurement may contain a higher potential to reveal such a correlation. Provided there exists a high correlation between both, it is conceivable that complex and attention-dependent behavioral tasks might be substituted with objective electrophysiologic measurements (Fig. 1). The more peripheral the neural generators of the electrophysiological responses, the less neural processing takes place, and it is more likely that the electrophysiological measure reflects a basic step in the ascending auditory system for temporal processing and estimating pitch (Gockel et al., 2011; Krishnan and Plack, 2011; Greenberg et al., 1987).

### 1.1. Auditory steady state responses

In auditory brainstem response (ABR) recordings transient acoustic stimuli are used which trigger neural responses in different parts of the auditory system (Jewett and Williston, 1971; Brown et al., 1994; Bahmer et al., 2008). The amplitude and latency of neural response peaks are evaluated for diagnostic purposes. The valuation of ASSRs is performed in the complex frequency domain in contrast to time domain based evaluation of ABRs (Lins and Picton, 1995). To generate ASSRs, continuous stimuli are presented, leading to summate periodic neuronal responses. Amplitude-modulated (AM) pure tones may be used as

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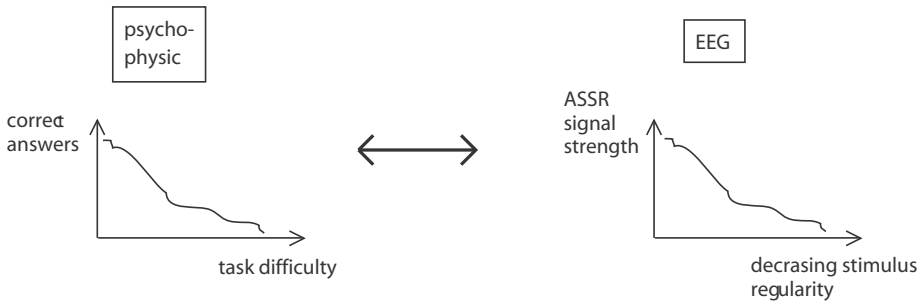


**Fig. 1.** Both psychophysical performance and auditory steady state response (ASSR) signal strength decrease similarly with increasing task difficulty and corresponding decreasing stimulus regularity.

stimuli. Neural generators, related to the depth and frequency of the amplitude modulation, are triggered. A continuous pure tone with amplitude modulated envelope between 2 and 400 Hz evokes a steady-state response at the modulation frequency (Chambers et al., 1986; Kuwada et al., 1986; Rees et al., 1986; Lins et al., 1996; Picton et al., 1987). It is commonly reported that modulation rates between 75 and 110 Hz are best suited to assess hearing thresholds. At these modulation rates, the ASSR is not significantly influenced by sleep (Cohen et al., 1991; Lins et al., 1995; Mühler et al., 2014), and, in normal hearing adults, responses to a 1-kHz stimulus can be recorded down to a stimulus level of 26 dB SPL (Lins et al., 1996). Evoked responses derived with continuously presented AM stimuli are analyzed in terms of both spectral energy and phase at the modulation frequency and its integer multiples (Chambers et al., 1986; Kuwada et al., 1986; Picton et al., 1987; Bahmer and Baumann, 2010). At modulation rates between 75 and 110 Hz, there is little change in the amplitude of the responses when multiple stimuli are presented compared to single stimulus presentation and carrier frequencies differ by one octave (Lins and Picton, 1995). In order to save recoding time, an alternative to a single stimulus application is the simultaneous measurement of responses to several AM stimuli (named MASTER stimulus) with each stimulus with different modulation and carrier frequency (Regan and Cartwright, 1970; John and Picton, 2000; John et al., 1998; Lins and Picton, 1995; van Dun et al., 2008).

Statistical procedures determine whether a response is significant by comparing the response level and/or the phase at the particular modulation frequency to the noise level and/or phase at adjacent frequencies. The reliability of repeated measurements can also be assessed by comparing the statistical analyses. In order to restrict AEP to a predefined tonotopic region, masking noise with a certain spectral gap (notched noise) has to be presented in addition to transient click stimuli. ASSR-stimuli do not need the application of masking since the spectral power of carrier and side bands is restricted to a narrow frequency region (Lins et al., 1996). ASSRs as well as tone pip evoked ABR allow the assessment of functional deficits in different frequency regions of the cochlea. By using frequency-specific stimuli, different frequency regions are activated and can be evaluated separately.

In order to develop new AEP recording procedures or to test the impact of alternative stimuli, affordable research platforms have been introduced using LabView or C/C++ (John and Picton, 2000; van Dun et al., 2008). The method presented here is implemented in Matlab 7.6.0.324 R2008a (The MathWorks Inc., Natick, Massachusetts) interfaces with other hardware components. The software presented here (see Appendix for excerpts) differs from so far introduced other research platforms since ASSR recording and a pitch discrimination task are running in parallel. Commercially available platforms offer only stimuli restricted to clinical routine tasks. In addition, access to raw EEG or analysis data is not available which make research applications and evaluations difficult.

### 1.2. Pitch discrimination tests

Frequently, pitch discrimination tests are designed as alternative forced choice experiments. Several signal alternatives are presented consecutively, and the listener has to detect the deviant interval, or the interval perceived higher or lower in pitch. In addition, adaptive procedures are often employed, which reduce or increase the frequency difference between standard and deviant interval depending on reliability of subjects' decision (example application described in Bahmer and Baumann, 2013). At a certain frequency difference subjects will asymptotically reach a minimum frequency difference threshold which defines the "just noticeable difference" (JND). AM stimuli may be applied in pitch discrimination test (Lee, 1994). In addition, randomized alteration (jitter) of the frequency of the modulator can serve as a stimulus parameter that potentially influences both pitch discrimination performance as well as the signal strength of auditory steady state responses.

### 1.3. Tested hypotheses

In the present report, it is tested whether the simultaneous measurement of electrophysiological responses in an ongoing psychophysical task is feasible. Specifically, it was tested whether:

- signal presentation and simultaneous recording via external audio-interface (RME ADI-8 DS) is free of distortions,
- the customized analysis procedures (Matlab routines) of the recorded signals operates successfully,
- ASSR generated by stimuli consisting of sinusoidal amplitude modulated signals (SAMs) modulated with either 200 or 250 Hz are detectable in simultaneous a pitch discrimination experiment,
- concatenated EEG recording windows as short as 2 s are sufficient to detect auditory steady state potentials,
- continuous stimuli containing jittered modulation cycles can be generated and integrated in the setup.

## 2. Experiment 1: evaluation of simultaneous pitch discrimination and ASSR

### 2.1. Rationale

The pitch discrimination experimental setup described here (see Section 2.2) applies a two alternative forced choice procedure with fixed stimuli (see Fig. 3). A fixed stimulus design was necessary because auditory steady state responses are recorded in parallel. A certain amount of recording time is necessary to detect the stimulus generated response signal in the EEG.



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