International Journal of Pediatric Otorhinolaryngology 78 (2014) 1352–1355

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

# Comparison between ABR with click and narrow band chirp stimuli in children

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ARTICLE INFO

*Article history:*
Received 19 February 2014
Received in revised form 14 May 2014
Accepted 20 May 2014
Available online 24 May 2014

*Keyword:*
ABR
Chirp
Click
Children

ABSTRACT

*Objective:* Click and chirp-evoked auditory brainstem responses (ABR) are applied for the estimation of hearing thresholds in children. The present study analyzes ABR thresholds across a large sample of children's ears obtained with both methods. The aim was to demonstrate the correlation between both methods using narrow band chirp and click stimuli.

*Methods:* Click and chirp evoked ABRs were measured in 253 children aged from 0 to 18 years to determine their individual auditory threshold. The delay-compensated stimuli were narrow band CE chirps with either 2000 Hz or 4000 Hz center frequencies. Measurements were performed consecutively during natural sleep, and under sedation or general anesthesia. Threshold estimation was performed for each measurement by two experienced audiologists.

*Results:* Pearson-correlation analysis revealed highly significant correlations ($r = 0.94$) between click and chirp derived thresholds for both 2 kHz and 4 kHz chirps. No considerable differences were observed either between different age ranges or gender. Comparing the thresholds estimated using ABR with click stimuli and chirp stimuli, only 0.8–2% for the 2000 Hz NB-chirp and 0.4–1.2% of the 4000 Hz NB-chirp measurements differed more than 15 dB for different degrees of hearing loss or normal hearing.

*Conclusion:* The results suggest that either NB-chirp or click ABR is sufficient for threshold estimation. This holds for the chirp frequencies of 2000 Hz and 4000 Hz. The use of either click- or chirp-evoked ABR allows a reduction of recording time in young infants. Nevertheless, to cross-check the results of one of the methods, we recommend measurements with the other method as well.



## 1. Introduction

For objective evaluation of hearing the measurement of auditory brainstem responses (ABR) is a valuable, well-established method especially in children. It has been shown to be applicable in natural sleep, in sedation and in general anesthesia [1]. ABR using click stimuli is regarded as the standard method but is not frequency specific. Therefore, frequency-specific stimuli such as tone bursts or chirp stimuli have been introduced. The use of chirp stimuli was first described by Dau et al. [2]. It has been shown repeatedly that chirps are more efficient than clicks in the recording of the ABR and of auditory steady-state responses (ASSR) [3]. In response to a brief stimulus, as, for example, a click, the cochlear travelling wave takes some time to travel from the base of the cochlear to its apical end. Therefore, the different neural units along the cochlear will not be stimulated at exactly the same instance in time and the neural activity across all auditory nerve fibers will be smeared. This lack of temporal synchrony can be partly addressed by an upward chirp stimulus, in which higher-frequency components are delayed in relation to lower-frequency components [4].

The resulting latency compensation theoretically results in simultaneous displacement maxima along the entire length of the basilar membrane; therefore, ideally all regions of the cochlear contribute to the ABR. Synchronous activation of neural units along the cochlear leads to larger ABR waves. The waves are generated by structures of the ascending auditory pathway. E.g. wave V is often allocated to the inferior colliculus [5].

Using chirp stimuli, wave V therefore is easier to detect than using click stimuli. Moreover, it offers the possibility of obtaining frequency-dependent hearing thresholds [4]. Therefore, the use of chirp stimuli fulfills the claim for hearing threshold detection in at

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http://dx.doi.org/10.1016/j.ijporl.2014.05.028
0165-5876/

least two different frequency ranges for follow-up diagnosis of children whose newborn hearing screening gave questionable results. And of course, the objective-hearing threshold assessment in different frequency ranges also enables the appropriate fitting of hearing aids in very young children.

However, Hall [6] stated that at high intensities there are mechanical factors that make the chirp even worse than the traditional click stimulus and that this might decrease the detection of wave V. In fact, the amplitude spectrum shows dependencies on the duration of the chirp stimulus at different stimulus levels. In 2010, Elberling et al. could demonstrate that shorter chirps produced the largest wave V amplitudes for higher stimulus levels [7]. However, the study was performed on adult subjects without hearing loss. For children with hearing loss, differences between the detection of wave V in ABR measurements using click and chirp stimuli have not been described to date. Especially for children with more than moderate hearing loss, an advantage or disadvantage of chirp stimuli to click stimuli due to easier or more difficult detection of wave V has not been described.

In this article we compare hearing thresholds derived with chirp and narrow band click ABR in 253 children over a large range of hearing loss.

## 2. Methods

### 2.1. Subjects

Data was obtained from 253 children (95 females, 158 male), aged from 3 months to 18 years (3.7 years on average, see Fig. 1). ABRs were performed when newborns did not pass the hearing screening, when psychoacoustic and acoustic hearing testing were pathologic not only due to middle ear effusions, or when follow-up ABR was necessary for children with hearing loss. The older children included in the population were mentally challenged. Both ears were measured in every subject. This leads to results on 506 ears. For the correlation analysis we further do not differentiate between the left and right ear.

### 2.2. Stimuli and procedure

Standard 100 $\mu$s clicks and narrow band (NB) CE chirps® with center frequencies at 2000–4000 Hz have been used [8].

Most measurements were performed during general anesthesia using propofol, some were performed in natural sleep or sedation with melatonin [9]. The test subjects were placed on a couch in a noise-absorbing test room which is electrically shielded.

Measurements of ABR with click and chirp stimuli were performed consecutively. First, click stimuli were used for threshold and waveform analysis and then NB-chirp stimuli for threshold estimation based on wave V estimation [10]. All measurements were analyzed by two experienced non-blinded audiologists. Knowledge about previous hearing tests was given in order to keep the measurement time and therewith the duration of general anesthesia as short as possible.

The chirp-evoked ABRs are recorded with the Interacoustics Eclipse EP25 ABR system®. The click ABRs were measured either with the identical system or the ZLE-ABR system each with alternating polarity. Both systems had calibrated outputs and used similar transducers: ear tone ABR3A. Filter settings and stimulation rates within the two ABR recording machines were adjusted accordingly.

The electrophysiological signal is picked up differentially between two electrodes—one applied high on the midfrontal area $F_z$ and the other on the ipsilateral mastoid $M_1$ or $M_2$; an electrode at the lower midfrontal area $F_{pz}$ serves as ground. The EEG is band-pass filtered (lower cut-off frequency 100 Hz, upper cut-off frequency 3000 Hz, filter slopes of 12 dB/octave).

The chirp stimuli are presented at a rate of 44.1 Hz, the click stimuli at a rate of 19.2 Hz and delivered through a pair of ABR3A earphones. The contralateral ear was masked by broad band noise at −20 dB relative to stimulus level. We decided to use contralateral masking because some of the test subjects suffered from asymmetrical hearing loss. To achieve a standardized procedure across all subjects we generally applied contralateral masking. Please note that when using insert earphones contralateral masking might be unnecessary in the majority of patients. Overmasking has to be avoided necessarily as the waveform morphology may be affected [11].

The individual ABR waveform is first determined above individual hearing threshold. Later on, stimulus amplitude is successively reduced by 10 dB increments until wave V disappears. When the threshold is roughly estimated in this way, increments were reduced to 5 dB for increased resolution. When the threshold is assumed to be within a 5 dB step, the arithmetic mean between the upper and the lower step was taken as the final threshold estimate.

The work has been carried out in accordance with ethical principles stated in the Declaration of Helsinki in its latest version.

### 2.3. Data analysis

Each ABR threshold estimate is determined by wave V, which is the most salient response peak [10]. When the response peak is identified, the peak-to-trough amplitude and the peak latency are measured from each recording.

Results were analyzed in a Matlab (The MathWorks, Inc., USA). For correlation analysis, Pearson product-moment correlation coefficients were derived. As a criterion of significance, a 95% confidence level ($p < 0.05$) was considered as significant (*) and a 99% confidence level ($p < 0.01$) as highly significant (**).

## 3. Results

### 3.1. Correlation of all measurements using click and chirp stimuli

Correlation analysis of all data for click versus NB-chirp stimuli with 2 kHz or 4 kHz centre frequencies were highly significant ($r = 0.94$, $p < 0.001$, respectively) (see Figs. 2 and 3).

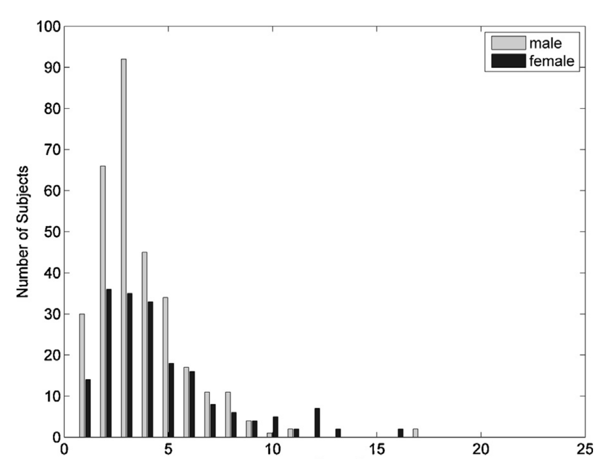


**Fig. 1.** Age and gender distribution.