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DIAGNOSING HEARING LOSS USING AIR- AND BONE-CONDUCTED PARALLEL AUDITORY BRAINSTEM RESPONSES

Melissa J. Polonenko[1*] **Ross K. Maddox**[2]

[1] Department of Speech-Language-Hearing Sciences, University of Minnesota, United States
[2] Kresge Hearing Research Institute, Department of Otolaryngology – Head & Neck Surgery, University of Michigan, United States

ABSTRACT

The auditory brainstem response (ABR) is an essential tool in screening for and diagnosing infant hearing loss to support optimal language acquisition through early intervention. The parallel ABR (pABR) paradigm measures responses to frequencies from 500–8000 Hz in both ears all at once, rather than the traditional methods of single-frequency measurements in one ear at a time. Our preliminary work in ten adults with maximally varying configurations of sensorineural hearing loss shows that the pABR provides highly accurate thresholds more than twice as fast as serial ABR. Furthermore, our recent work in a group of twenty adults with normal hearing shows that bone conduction pABR measurements are feasible, which is also a necessary part of diagnosing hearing loss by determining the relative contributions of conductive and sensorineural hearing loss. Given these air- and bone-conduction results, the pABR holds promise as a viable clinical tool for objective threshold estimation and diagnosis of hearing loss.

Keywords: *evoked potentials, hearing loss, diagnostics*

1. INTRODUCTION

Early diagnosis of and intervention for hearing loss are critical for facilitating language acquisition. Many countries worldwide use the auditory brainstem response (ABR) to estimate hearing thresholds in infants and other people who cannot complete standard behavioral audiometry. Although the ABR is effective for diagnosing hearing loss [1,2], the auditory-specific responses recorded on the scalp are small compared to the background noise, so the infant must be resting quietly, constraining the exam's duration. Exams often finish with incomplete information, requiring the family to return, further delaying diagnosis and risking attrition. Therefore, faster tests are needed.

The parallel ABR (pABR) was created to address this time constraint by measuring responses to all frequencies in both ears all at once [3]. Compared to traditional methods of single-frequency measurements in one ear at a time, the pABR is a median of 3x faster at a soft level (51 dB peSPL) in adults with normal hearing. Previous studies have also shown better place specificity for the pABR's responses than serial methods [4,5], which may improve estimates of severe hearing losses that require the use of higher levels.

The pABR's accuracy and speed, however, have not yet been tested in people with hearing loss. Neither has the pABR been tested through bone conduction, which is also an essential part of diagnosing the conductive versus sensorineural components of hearing loss. This paper presents preliminary findings for all three: the accuracy and timing of air conduction testing in adults with hearing loss and bone conduction testing in adults with normal hearing.

2. METHODS

2.1 Air conduction testing in adults with hearing loss

Seventy adults with widely varying sensorineural hearing loss configurations were recruited under an approved sIRB protocol between the Universities of Minnesota and Michigan. This paper presents findings from a subset of ten

[*] *Corresponding author*: *mpolonen@umn.edu*

adults chosen based on maximally different audiometric configurations, who first underwent pABR testing and then returned for testing using traditional serial ABR methods with clinical equipment. Ages ranged from 29 to 69 years.

In the first session, a threshold search was done using the pABR with a real-time custom interface before determining behavioral thresholds with standard audiometry. pABR thresholds were estimated using a leave-one-out regression between the pABR threshold levels in dB nHL and behavioral thresholds in dB HL, a correction step that is routinely done in the clinic. For the second session, the experimenter was blinded to the participant's hearing loss. A threshold search was conducted for each frequency in each ear separately using clinical protocols that were matched as closely as possible to the pABR stimuli. Time to diagnose 10 (pABR, 0.5–8 kHz in both ears) or 8 (clinical, 0.5–4 kHz in both ears) thresholds was compared.

2.2 Bone conduction in adults with normal hearing

Twenty young adults with normal hearing (aged 19 to 31 years) were recruited under the same sIRB protocol. To keep the session under 3 hours, bone conduction was only completed in one ear. Both the ear and order of air- and bone-conduction were counterbalanced across participants.

Air- and bone-conduction behavioral thresholds to the pABR stimuli were measured to determine the correction factors to match levels in dB sensation level (SL) due to the different voltage output for the two transducers. Then ABRs (Fz referenced to A1 and A2, ground at Fpz) were recorded to pABR stimuli (~40 stimuli/second) while participants reclined and rested in a darkened sound booth. An intensity series from 20–70 dB peSPL (~0–50 dB nHL calibrated to an air-conducted 1 kHz tone) was completed using ER2 insert earphones (air) or a B71 bone vibrator (bone) with contralateral masking (400 stimuli/second) through an earphone. Ten minutes of data were collected for each intensity and transducer, totaling 120 minutes. Waveform morphologies for each transducer were compared by their wave V amplitudes and latencies at similar dB SL levels.

3. RESULTS

3.1 The pABR is accurate and faster than serial ABR

Overall, the pABR provided highly accurate thresholds (Fig. 1). There was a 95% confidence interval of 0.78–0.93 for the correlation between behavioral and pABR-estimated thresholds (Fig. 1A). Fig. 1B shows the distribution of threshold differences—most differences (72%) were within one step size (±10 dB), and 90% were within ±15 dB.

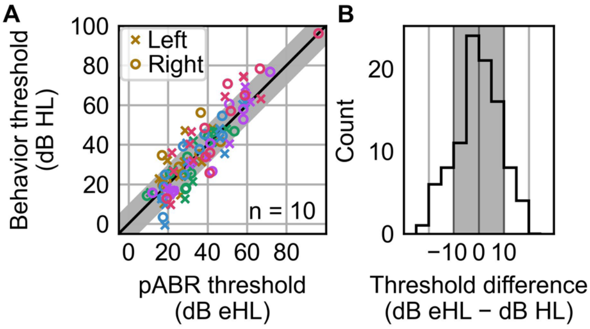

Figure 1. (A) pABR-estimated thresholds are highly correlated with behavioral audiometric thresholds. Jitter applied for visualization (±2.5 dB). Shaded regions represent differences within a step size of ±10 dB. Colors represent frequency: 0.5 kHz (gold), 1 kHz (green), 2 kHz (blue), 4 kHz (purple), 8 kHz (pink). (B) Histogram of pABR-behavioral threshold differences.

Next, the time required to obtain a complete set of thresholds was calculated (Fig. 2). The pABR was faster in all participants, with a mean ± SD testing time of 27.8 ± 8.2 minutes to estimate 10 thresholds versus 69.7 ± 20.9 minutes to estimate 8 serial thresholds, for a significant time reduction of 41.9 ± 20.0 minutes (paired t-test, $t(9) = -6.6$, $p < 0.001$). The median speedup ratio was 2.5x (ranged from 1.4x to 4.2x).

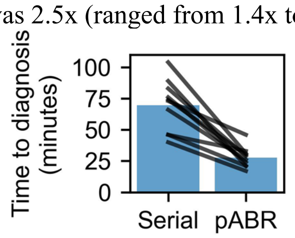

Figure 2. pABR versus serial ABR threshold estimation times. Lines show individuals and bars show the mean.

3.2 pABRs are similar for air- and bone-conduction

Sound played with the same output voltages from the headphone amplifier produced higher behavioral thresholds for bone- vs air-conduction, consistent with the higher force levels required to drive the vibrator. Insufficient force was generated to obtain clear responses above threshold for 8 kHz, which was consequently removed from the analysis. The mean correction factor to convert levels to dB SL was 35 dB for bone- and 25 dB for air-conduction. The levels for bone-conduction were ~5 dB quieter at 0.5 and 4 kHz.

Clear responses were obtained with both transducers at 4 levels (5, 15, 25, 35 dB SL). Wave V peak amplitudes and latencies across all participants and levels are shown in Fig. 3. Wave V metrics correlated between air- and bone-conduction, with a 95% confidence interval of 0.59–0.82 for amplitude and 0.91–0.96 for latency. Overall, compared to air-, the mean ± SE wave V peaks for bone-conduction were smaller by 0.014 ± 0.002 µV ($t(278) = -6.2$, $p < 0.001$) and shorter by 0.198 ± 0.068 ms ($t(278) = -2.9$, $p = 0.004$).

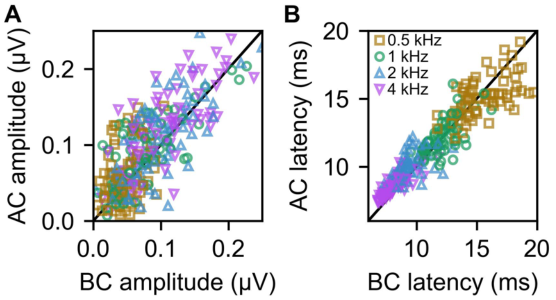

Figure 3. Wave V peak (A) amplitude and (B) latency across participants for stimuli conducted through air (AC) and bone (BC) across 5–35 dB SL levels.

4. DISCUSSION

Preliminary work from the two studies presented in this paper show the feasibility of using air- and bone-conducted pABR stimuli for accurately diagnosing hearing loss.

The pABR provides highly accurate threshold estimates in a subset of adults with widely varying hearing loss (Fig. 1) that are on par with serial ABR [2]. It is also substantially faster in a clinical-like setup than the current serial ABR (Fig. 2), which could facilitate the collection of more complete information during clinical translation of this method. Together with previous work in adults with normal hearing [3], data from all seventy adults in the study will provide further support for the pABR as a viable method for objective threshold estimation across the range of hearing.

Preliminary work in adults with normal hearing shows that bone-conduction pABR measurements are also feasible. Although air- and bone-conduction wave V metrics differed overall (Fig. 3), their responses generally aligned given the 10-dB step sizes. Due to the different voltages required to drive the bone vibrator, the actual dB SL levels were ~5 dB quieter for some frequencies (halfway between step sizes), which could contribute to the smaller responses. Further analyses of the data will reveal the necessary corrections that can be applied to future experimental paradigms to ensure similar output levels are used for both transducers. The larger study provides the necessary behavioral threshold and ABR response information to adjust the frequency-specific stimulus voltage outputs to adequately drive the bone vibrator to produce similarly sized responses. This work represents an important step towards creating a pABR paradigm that includes both air- and bone-conduction so that both the sensorineural and conductive components of hearing loss can be diagnosed.

Given these air- and bone-conduction results in adults, the pABR holds promise as a viable clinical tool for objective threshold estimation and diagnosis of hearing loss while addressing the primary drawback of current methods: speed. This preliminary work represents an important step towards translating the pABR for diagnosing hearing loss and taking the next steps to validating the method for use in infants and other populations that require objective testing.

5. ACKNOWLEDGMENTS

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