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EVALUATING TEST TIME IN SIMULTANEOUSLY RECORDED ABRs

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ABSTRACT

Currently, the gold standard procedure for objectively evaluating hearing in infants is the auditory brainstem response (ABR). We have previously explored a novel approach that involves recording multiple ABRs simultaneously in response to narrowband (NB) CE-Chirps centered at 500, 1000, 2000, and 4000 Hz in both ears. In the current study, we investigated the overall testing time when recording ABRs simultaneously compared to consecutively at the clinical discharge levels of 30 and 40 dB estimated hearing level (eHL) to the 4 NB CE-Chirps.

Simultaneous and consecutive ABRs were obtained from 21 young normal-hearing participants within one recording session. Response presence was determined using the recently developed Fmpi, an objective statistical detection method. Testing time was estimated as the total time to reach 95% probability of response present.

The results showed that, for each NB CE-Chirp considered individually, simultaneous ABRs had on average longer testing times compared with consecutive ABRs, a consequence of the overall reduced ABR wave V amplitude evoked by the novel more frequency-specific simultaneous approach. However, the total testing time (8 ABR measurements) was significantly shorter for the simultaneous than that of the consecutive approach.

Keywords: *electrophysiology, simultaneous, auditory brainstem response, test time*

1. INTRODUCTION

The incidence of hearing loss in newborns is approximately 1 to 3 per 1000 newborns, which makes hearing loss one of the most common birth disorders [1-4]. Newborn hearing screening programs have been employed to identify newborns who require follow-up diagnostic testing, to ensure necessary intervention and treatment facilitating language and cognitive development [5-6]. The Joint Committee on Infant Hearing [4] recommends that the diagnosis of hearing loss is made within the first 3 months of life. The current gold-standard diagnostic evaluation employes the Auditory brainstem response (ABR), where 4 separate audiometric frequencies are evaluated in each ear [7-8]. However, the time required to obtain the 4 frequency-specific thresholds in both ears often exceeds the available test time in the infant population [9]. This limitation often results in the necessity of more ABR sessions to obtain the full hearing assessment. Enhancements in the speed of the ABR test could potentially reduce the test time. A recent study has introduced a novel ABR method, where multiple ABRs can be obtained in both ears in parallel, named pABR [10]. The authors demonstrated the feasibility of recording ABRs in response to five tone bursts at 500, 1000, 2000, 4000, and 8000 Hz simultaneously. In their study, they also evaluated the acquisition time of the pABR and compared it to consecutive presentation [10]. A residual

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noise criterion of 20 nV was employed as stopping criterion. Averaging all 10 (5 per ear) tone-burst waveforms down to 20 nV residual noise required a median test time of 30.1 minute, whereas obtaining the 10 tone-burst waveforms using pABR only required 4.6 minutes. Further, when using a Signal-to-Noise Ratio (SNR)-based criterion to evaluate test time, five out of the nine test subjects had faster acquisition time with pABR, with a median pABR speed-up ratio of 1.45 at a high level of 75 dB peSPL (52 to 59 dB nHL), and of 2.99 at 45 dB peSPL (22 to 29 dB nHL).

In a recent study [11-12] we demonstrated that it is possible to obtain multiple frequency specific ABRs to NB CE-Chirp stimuli (mbABR) simultaneously at clinical stimulation levels.

The purpose of this study was to determine and compare the effectiveness—in terms of acquisition time— of the mbABR approach using the data collected in [11-12]. As mbABR and pABR have many similarities, we hypothesized that mbABR would yield an acquisition time advantage over consecutive ABR similar to pABR.

2. METHOD

2.1 Participants

Twenty-four normal-hearing participants (10 males) aged from 20 to 29 years (average age 25), participated in the study. All subjects had pure-tone audiogram thresholds equal to or better than 20 dB HL across the 125 to 8000 Hz range. Otoscopy was conducted to ensure that there was no wax obstruction and that the ear canal was suitable for insert earphone placement. The study was conducted under approval from the Science-Ethics Committee for the Capital Region of Denmark (H-1-2013-138).

2.2 Stimuli and procedure

Four frequency specific NB CE-Chirps LS [13-14] were presented at their corresponding clinical discharge levels of 30 dB estimated hearing level (eHL) and at 10 dB above (40 dB eHL). For adult participants, this corresponded to a 500 Hz NB CE-Chirp presented at 45 and 55 dB nHL, a 1000 Hz NB CE-Chirp presented at 40 and 50 dB nHL, and 2000 Hz and 4000 Hz NB CE-Chirp at 35 and 45 dB nHL, respectively [7, table 7]. The NB CE-Chirps were presented in both consecutive and simultaneous mode at a nominal rate of 40/sec. Jitter was introduced around the nominal rate from a uniform distribution spanning from -67% to +67% of the nominal stimulus interval. NB CE-Chirps had a 200 ms duration and were presented using alternating polarity.

All recordings were obtained in a sound treated and electrically shielded test booth, where the participants were instructed to relax on a bed. First, simultaneous ABRs were acquired at both the discharge and discharge level +10 dB, with a balanced testing order across participants. Then, consecutive ABRs were obtained in a balanced order for the four NB CE-Chirps at both the discharge level and discharge level +10 dB. Lastly, a retesting of simultaneous ABRs was conducted at the discharge level. For the purpose of this study, only the retest data set was used because of a lower residual noise.

At discharge level all ABRs were obtained in both ears on all participants (N = 48 ears). However, only 20 subjects had consecutive and simultaneous ABRs collected at discharge level +10 dB (N = 40 ears).

2.3 Apparatus

ABRs were recorded using a clinical Interacoustics Eclipse system paired with an RME Fireface UC soundcard and custom MATLAB interface [15-16] for control of both stimulus presentation and the collection of ABRs into distinct buffers for each NB CE-Chirp, aligned with the jittered stimulus presentation. EEG activity was captured using disposable surface electrodes at Fz to M1 or M2, with an electrode placed on the cheek serving as ground. For offline analysis, the EEG was band-pass filtered from 83 to 3000 Hz (finite impulse response Kaiser filter, 65 dB stop-band attenuation and 1 Hz transition between pass and stop bands).

RadioEar IP30 insert earphones were used for stimulus presentation. Calibration of NB CE-Chirps was performed using the root-mean-square sound pressure levels defined by [17] for each NB CE-Chirp presented at a rate of 20/sec.

2.4 Data Analysis

21 complete data sets were available for comparison of simultaneous and consecutive ABR at discharge level and 19 data sets at discharge level +10 dB.

The Fmpi-detector was chosen as the objective statistical detector and applied to all data [18]. The Fmpi builds on the clinically well-known Fmp-detector [19] and statistically assesses whether the F-value—a proxy of the SNR—is significantly different from what would be expected from a noise-only recording. If the estimated F-value is high, there is a high probability that a response is present. While Fmp assumes a general (conservative) criterion value for determining significance, the Fmpi estimates the correct criterion value for the individual recording from the noise

properties, leading to faster detections. For this analysis, the stopping criteria was a 95% probability of a response being present. For the consecutive method, per participant total test times were derived by adding the individual test times (i.e., the time to reach a 95% response probability of each individual condition) for each frequency and ear, whereas the maximum test time across all NB CE-Chirps was used for the simultaneous method. Per participant total test times were then used to perform an Analysis of variance (ANOVA) via a Linear mixed effects (LME) model. Here, the total test time (in a log-scale) was set as the dependent variable, the *Condition* (with levels: *Simultaneous* and *Consecutive*) and *Presentation level* (with levels: *Discharge* and *Discharge +10 dB*) as the independent factors, and the *Participant* as the random factor.

3. RESULTS

In Figure 1a, the total test time for each subject is presented for both consecutive (black points) and simultaneous ABR (pink points) at discharge level and discharge level +10 dB. At discharge level the median total test times were 3.25 min for consecutive and 2 min for simultaneous. At discharge level +10 dB the median total test times were 3 and 2.40 min, respectively. On average, simultaneous ABR is 1.55 times faster than consecutive ABR. In the statistical analysis, only the factor *Condition* was significant, confirming a significantly higher performance (lower total test time) for simultaneous than consecutive recordings ($F(1, 55) = 15.49$, $p < 0.001$).

Figure 1b, shows a scatterplot comparing the total test times for simultaneous and consecutive ABRs at both discharge level (orange points) and discharge level +10 dB (magenta points). Points above the identity line correspond to cases where the consecutive total test time was shorter than simultaneous one. However, the vast majority of points fell under the identity line, indicating faster ABR detections for simultaneous testing.

To further examine the test time required for each individual frequency, ear, method, and stimulation level, Figure 2 shows the normalized test time distribution, in which 100% corresponds to the maximum test time across all measurements, for all these variables and for each participant. Here, it can be seen that the lower frequencies (500 and 1000 Hz) took longer for the simultaneous than the consecutive (Interquartile range for consecutive and simultaneous in Figure 2). Despite the simultaneous having this extra measurement time at the low frequencies, which drives the overall test time in the simultaneous recording, the full test is much shorter than in the consecutive mode (Figure 2 top panels).

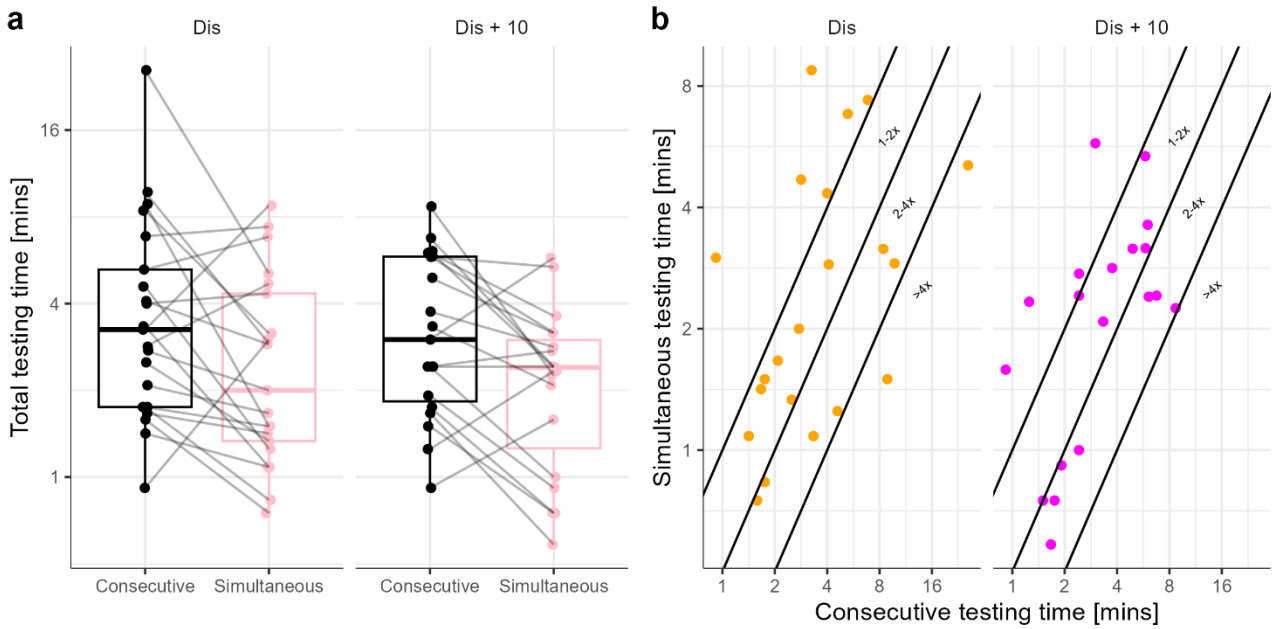

Figure 1 (a): Total test time for consecutive (black points) and simultaneous ABR (pink points) at discharge level and discharge level +10 dB. Boxplots show the median (bold vertical lines), Q1-Q3 interquartile ranges (boxes), and whiskers for 1.5 interquartile range from the hinge. **(b)** Scatterplot of acquisition times for simultaneous and consecutive ABR at both

discharge level (left panel, orange points) and discharge level +10 dB (right panel, magenta points). Points above the identity line correspond to cases where the consecutive total test time was shorter than simultaneous one, while when data points fall below the identity line the total test time was shorter with simultaneous testing. In both panels, each point corresponds to a single-subject measurement.

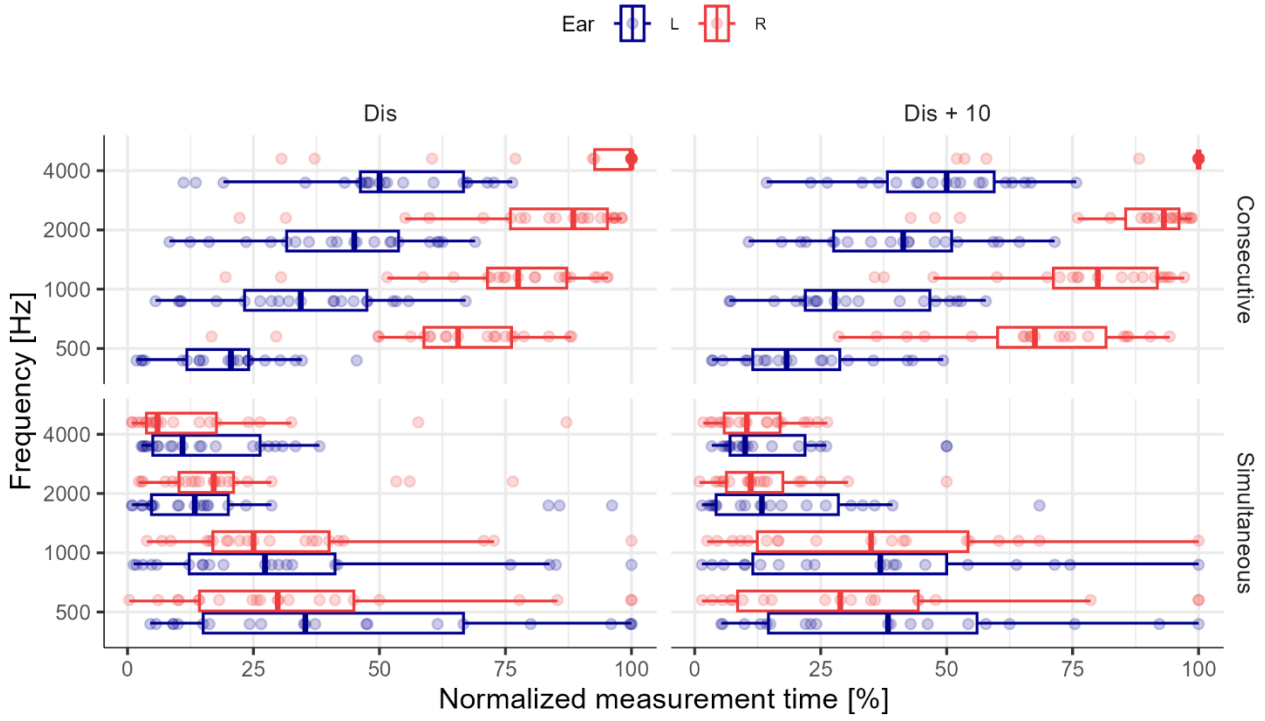

Figure 2: Normalized measurement time (in %) at both discharge level (left panels) and discharge level +10 dB (right panels) for consecutive (top panels) and simultaneous (bottom panels) recordings. The individual center frequencies of the NB CE Chirp are indicated in the vertical axes. A normalized scale was used, such that the longest test time across subjects represents 100%. Red represents the right ear and blue the left ear. Individual points correspond to single-subject data. Boxplots show the median (bold vertical lines), Q1-Q3 interquartile ranges (boxes), and whiskers for 1.5 interquartile range from the hinge. For the purpose of graphical representation, consecutive measurements are shown first for the left ear and then for the right ear, from low to high center frequencies.

4. DISCUSSION

In this study, it was demonstrated that using a simultaneous ABR collection approach in response to NB CE-Chirps results in significantly reduced test time compared to classic consecutive ABR data collection. However, speeding up the test by presenting 8 NB CE-Chirps (4 in each ear) instead of one at a time in each ear, does not speed up the test by a factor of 8. The result from this study shows that on average it takes 1.55 times longer to reach all 8 Fmpi-detection criteria for the consecutive than for the simultaneous ABR. This result is in line with findings from pABR using 0 dB SNR as stopping criterion [10].

In Figure 1a it was observed that the lower level (discharge level) showed a larger difference in median values between simultaneous and consecutive, than at the higher level (discharge level +10 dB). The larger difference at the low level was expected, based on pABR, which showed a larger speed-up ratio at a low level of 45 dB peSPL compared to 75 dB peSPL [10]. In pABR and mbABR, previous experimental and modeling studies have shown that presenting multiple stimuli together has the advantage that they act as maskers for each other [10, 11-12, 20-21]. This changes the ABR waveform morphology especially at the

lowest test frequency, where smaller wave V responses are observed compared to consecutive presentation. As the intensity is increased, the spread of excitation on the basilar membrane broadens towards higher frequencies [23]. This leads to a larger masking effect at higher levels resulting in larger difference in response amplitudes between consecutive and simultaneous stimuli presentation. In turn, this greater masking effect reduces the speed-up benefit from simultaneous presentation, as is seen in the present study as well as those from pABR.

In Figure 2 it was observed that the recording at 500 Hz drives the total test time for simultaneous ABR. This result indicates that further time optimization could be gained in threshold seeking by applying a level-varying approach. In this scenario, data collection at higher frequencies could be continued at other levels, while the 500 Hz is still averaging to a satisfied criterion. However, the interaction among frequency bands, that provides a positive effect in terms of more place-specific response, could be reverted to a negative effect if a change in level of one stimulus, and the concomitant change in spread of excitation, affects the underlying response waveform of another frequency ABR still in progress. This suggests a recommended maximum level difference among stimuli presented simultaneously.

The target population for simultaneous ABR is infants referred for diagnostic evaluation. Infants exhibit distinct waveform morphologies due to the ongoing maturation of the auditory system [24-25]. Therefore, the time advantage of using simultaneous ABR demonstrated here requires validation in the infant population.

5. CONCLUSION

The present study investigated whether there were observable and significant changes in test time when presenting NB CE-Chirps simultaneously compared to consecutively, using clinically relevant repetition rates, presentation levels, and an Fmpi-detector for response evaluation. The results showed a significantly reduced test time when recording the NB CE-Chirps simultaneously.

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