Optimization of Auditory Brainstem Response (ABR) Test Time Using Level Specific (LS) CE-CHIRP®

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Abstract:

Introduction: The duration of the auditory brainstem response (ABR) test is influenced by the time taken to acquire the ABR signals. The ABR acquisition time has the potential to be reduced by using Level Specific (LS) CE Chirps® stimulus as it possesses better spectral synchrony than the traditional click stimulus. Objective stopping criteria such as those based on the signal-to-noise ratio (SNR) can be employed to evaluate the time efficiency of the LS CE Chirps® stimulus. Using this technique, the test time for both the ABRs elicited by LS CE Chirps® and click stimuli can be compared based on the fastest stimulus to reach an appropriate SNR. To date, only one study has scientifically investigated the use of LS CE Chirps® to reduce the ABR test time. **Aim:** This study aims to compare the number of averages required to reach the specified SNRs between the ABRs elicited from LS CE Chirp® and click stimuli in normal-hearing adults. **Methodology:** A repeated measures research design was used involving 15 adult subjects. ABRs were acquired at four intensity levels (80, 60, 40, and 20 dB nHL) and two stimuli (LS CE Chirps® and click stimuli). The ABR signal averaging was stopped when the multiple points F-ratio (Fmp) value reached 3.1.

Results: The number of averages between the ABR elicited from LS CE Chirps® and click stimuli were statistically compared. The number of averages to reach Fmp at 3.1 was lower in the ABRs elicited using LS CE Chirps® to those produced by click stimuli at all intensity levels. **Conclusion:** This study demonstrated that ABRs arising from LS-CE-Chirps® stimuli could be acquired faster than ABRs elicited from click stimuli. **Implication:** The use of LS-CE-Chirps® stimulus has the potential to reduce the ABR acquisition time in comparison to the traditional click stimulus.

Keywords: LBP, sedentary lifestyle, university students

Introduction:

Auditory brainstem response (ABR) is one of the useful tests to estimate hearing in infants or difficult-to-test populations and to determine any lesions in the central auditory nervous system. Since its first discovery, the ABR has been typically elicited using a brief stimulus, such as a click (Jewett & Williston, 1971). ABR has been widely used in various aspects of audiology applications but the ABRs elicited from click stimulus have a limitation given that the stimulus is only effective to stimulate the basal region of the cochlear that corresponds only to high-frequency hearing (Gorga et al., 1988). To overcome this issue, a few studies have attempted to develop an alternative stimulus in ensuring the neural synchrony responses that could include the entire cochlear region (Dau et al., 2000; Shore & Nuttall, 1985).

Currently, the ABRs from chirp stimuli have become one of the most popular strategies to estimate thresholds due to their benefits in improving neural synchrony over the traditional click stimulus (Kristensen & Elberling, 2012). Chirp stimulus was developed by Dau et al. (2000) as an extension of the original works of Shore and Nuttall (1985) who used tone bursts that exponentially increased the frequencies in compound action potential (CAP) testing. The equation to produce the rising tone-burst stimulus was based on a linear cochlear model which resulted in a larger CAP amplitude. Given the larger CAP amplitudes (wave I and II) reported by Shore and Nuttall (1985), Dau et al. (2000) developed a chirp stimulus using a travelling wave-delay approach in which the onset of the frequency components was arranged based on the tonotopicity at the cochlear. The low frequencies that are tuned towards the apical region require a longer distance to achieve the travelling wave peak than the high-frequency component which is presented first. This is followed by the mid and high-frequency components possessing the shortest distance to travel to the basal region, which is to be presented next. This time-delay approach aims to ensure that all stimuli arrive at the cochlear concurrently, thus ensuring a simultaneous displacement of the basilar membrane. These events will produce optimum neural synchrony from the auditory nerve fibres that hypothetically lead to an increase in the ABR wave amplitudes.

Various types of chirp stimuli have been described in the literature, including intensity-dependent chirp known as level-specific (LS) chirp (Elberling et al., 2010; Elberling & Don, 2008; Kristensen & Elberling, 2012). LS chirp, also known as LS CE Chirps®, was invented by Claus Elberling (CE). This term was used throughout the paper as reported in recent publications (Cargnelutti et al., 2017; Di Scipio & Mastronardi, 2018; Dzulkarnain et al., 2020; Dzulkarnain et al., 2018; Dzulkarnain et al., 2017). The ABRs from LS CE Chirps® reflect an improvement of the traditional chirp stimuli in which the duration of the chirps depends on the intensity levels. In the previous version of-chirp stimulus, the long duration of presenting the chirp stimuli resulted in the reduction of the earlier ABR waves (waves I and III). The ABRs wave V amplitudes were also smaller than the ABRs to click stimuli at suprathreshold levels (Rodrigues et al., 2013; Sabet et al., 2014). In the ABRs to LS CE Chirps® stimuli, the duration of stimulus presentation is adjusted, where it is very brief for high-intensity levels and longer for mid and lower-intensity levels (Elberling et al., 2010; Elberling & Don, 2008; Kristensen & Elberling, 2012). The use of LS CE Chirps® was reported to increase both ABR wave V amplitude at low, moderate, and high-intensity levels (Cargnelutti et al., 2017; Di Scipio & Mastronardi, 2018; Dzulkarnain et al., 2020; Dzulkarnain et al., 2018; Dzulkarnain et al., 2017). Likewise, the ABRs elicited from LS CE Chirps® stimuli were also able to elicit reliable waveforms consisting of waves I and III (Dzulkarnain et al., 2020; Dzulkarnain et al., 2017; Kristensen & Elberling, 2012). Specifically, the ABRs to LS CE Chirps® reportedly generated robust ABR wave I and III amplitudes in comparison with the ABRs generated by a click stimulus (Dzulkarnain et al., 2017) while offering promising findings for neurodiagnosis and neuromonitoring (Cargnelutti et al., 2017; Di Scipio & Mastronardi, 2018).

Despite the potential of LS CE Chirps®, their test-time efficiency in generating ABRs in comparison to the traditional ABRs using click stimulus is not supported by scientific evidence. To date, only one study has scientifically investigated the abilities of the ABRs elicited from LS CE Chirps® in reducing the ABR test time (Dzulkarnain et al., 2020). Auditory brainstem response testing was stopped based on the fixed residual noise level at 40nV as recommended by Don and Elberling (1996). The findings revealed no difference in the test time (calculated based on the number of averages) between the ABRs elicited from LS CE Chirps® and click stimuli at various stimulus repetition rates. Dzulkarnain et al. (2020) proposed that the lack of differences in the ABR test time could be due to the usage of residual noise level as the stopping criterion in recording the ABR. If the residual background noise of the recording is the same during recording, the time to acquire the ABR signals would technically be the same regardless of the stimulus types. One of the best methods to decide on stopping the ABR testing is by continuing the signal averaging process until a specified signal-to-noise ratio (SNR) is achieved (Don & Elberling, 1994; Elberling & Don, 1984). This is based on the fact the ABR test time depends on the number of averages during the signal averaging processes that are proportionate to the signal-to-noise ratio (SNR). F-ratio at single points or multiple points (Fsp or Fmp) is an SNR estimation technique that has been discussed in the literature and used clinically (Don & Elberling, 1994; Elberling & Don, 1984). When using F-ratio, the signal averaging will be continued until the F-ratio reaches a certain specified value indicating that the ABR signals are well above the residual noise level. For instance, F-ratio that is equalled to 3.1 indicates 99% confidence that the ABR is present above the noise floor. The F-ratio of 3.1 is considered a conservative SNR estimation stopping criterion and the ratio can be adjusted to a 95% or 90% confidence level with a less conservative SNR estimation (Elberling & Don, 1987). Given the ability of ABRs to LS CE Chirps® in producing higher wave V amplitude, hypothetically it will be able to reach the appropriate SNR faster than the ABRs to click stimulus. Hence, this study aims to compare the number of averages required to reach the specified SNR based on the Fmp values between the ABRs elicited from LS CE Chirps® and click stimuli in normal-hearing adults.

Materials and Methods:

Participants

A total of 15 adult subjects (nine males and six females), aged between 19 to 25 years, participated in this study using a convenient sampling method. Only participants up to 25-year-old were recruited in line with previous findings reporting that ABR results may change as a function of age after 32 years old (Konrad-Martin, Dille, McMillan, Griest, SMcDermott, Fausti et al., 2012). All participants had normal hearing, with Type A tympanogram and normal acoustic reflex thresholds at 500, 1000, and 2000 Hz at all stimulations bilaterally.

Procedure

The study protocol received unconditional approval from the Research Ethics Committee with reference identification approval (IREC 2018-286). Each participant's ABR was recorded in a sound-treated electrophysiology room at an audiology clinic of IIUM. The ABR tests were conducted with a two-channel Interacoustics Eclipse module using ipsilateral and vertical montages. Participants' skin was cleaned using Nu-Prep skin preparation gel and Ambu Neuroline 720 disposable. Silver chloride electrodes were placed using ipsilateral and vertical electrode configurations. The first channel recorded responses of the right ear ipsilateral configuration while the second channel recorded responses from the vertical configuration. Only the ABRs from the ipsilateral configuration were taken for analysis while the ABRs from the vertical configuration were used to cross-check the location of the wave V. Participants were advised to either sleep or avoid substantial body movements throughout the testing to ensure a consistent background noise during the recording.

The impedance level was examined and maintained below 5 kΩ for each electrode site and not exceeding 2 kΩ for inter-electrode impedances. The ABRs were recorded by presenting 0.1 ms alternating polarity of the click and LS CE Chirps® stimuli to the right ear at the intensity of 80, 60, 40, and 20 dB nHL through Eclipse ER-3A insert phone. Offset contralateral masking noise was presented to the left ear at 40 dB lower than the tested ear stimulus presentation level. The stimulus repetition rate to elicit ABRs for both stimuli was set at 33.3 Hz. The sequence of the tests was randomised using a random generator application software. The ABRs were recorded in 14 milliseconds time window for all the stimuli and intensity combinations. The ABRs were averaged using the Bayesian averaging technique until the recording reached the target Fmp of 3.1. The number of averages for each ABR recording to reach the target Fmp values at 3.1 (99% confidence level) were then noted for each participant. The Fmp formula was calculated from the ratio of the variance in the ABR total signal (noise and ABR) while the variance of the residual noise was computed at multiple points

(Elberling & Don, 1984). The ABRs were filtered using a 100–3000 Hz band-pass filter and a 12-decibel (dB)/octave slope function to remove any unwanted activities unrelated to ABRs. The sensitivity of the amplifier was set at ± 50 µV artefact rejection level of ± 20 µV.

Waveform analysis

All recorded ABRs were verified for their presence or absence using the Fmp stopping criterion by a consensus agreement from two qualified audiologists. The main variable in this study was the number of averages needed for each ABR to reach the target Fmp value at 3.1. Thus, the main variable was determined by observing the signal averaging process for each of the ABR recordings. The Eclipse evoked potential system performed the signal averaging process for every 100 stimulus presentation instead of for every single or smaller sub-averages. As a result, the number of averages needed to achieve Fmp = 3.1 observed in the present study was rounded to the nearest hundredth, indicating the possibility of overestimating the actual number of averages. Apart from the quality estimation from the Fmp values, SNR was also computed from the ratio of ABR wave V amplitude and the residual noise levels. All the ABR waveforms from each intensity level achieved SNR either equal to or higher than 3:1, thus indicating that the Fmp values were consistent with the SNR calculation.

Data Analysis

The statistical analysis was conducted using IBM Statistical Package for Social Science (SPSS) version 20. The data for the number of averages were not normally distributed, thereby violating the assumptions of employing parametric statistics. Additionally, this issue could not be addressed by data transformation. Hence, the Wilcoxon signed-rank test was conducted at a 95% confidence level to identify significant differences in the number of averages between the ABRs to click and LS CE Chirps® stimuli at each intensity level. The effect size for non-normally distributed data was also computed to support the p-value. The effect size (r-value) was computed from the ratio of the z-score divided by the square root of the sample size (Rosenthal et al., 1994). Effect sizes of moderate (r > 0.3) to large (r > 0.5) were considered significant to indicate that differences existed between the two variables.

Results:

Table 1 summarizes the median, interquartile range (IQR) and effect sizes of the number of averages for both ABRs from click and to LS CE Chirps® to reach Fmp of 3.1. Figure 1 illustrates the ABR waveforms from both stimuli obtained from one of the participants. Resultantly, the number of averages to reach Fmp of 3.1 was higher in the ABRs to click than those obtained from LS CE Chirps® stimuli at 60 and 40 dB nHL (z = -2.85 to -3.06, p < 0.05) with a large effect size (r > 0.5). No significant differences were identified for ABRs at 80 and 20 dB nHL (z = -1.794 to -1.792, p > 0.05) but the effect size was moderate (r = 0.46). Both p-values and effect sizes of the analyses demonstrated that the number of averages required to reach the target Fmp of 3.1 was less in the ABRs from LS CE Chirps® compared to those from click stimulus. The differences were relatively small at suprathreshold levels (80 and 60 dBnHL) with only 100 average differences. The differences were relatively higher at lower intensity levels with 400 and 800 number of averages differences at 40 and 20 dBnHL, respectively.

Discussion:

The present study aimed to compare the number of averages required to reach the specified signal-to-noise ratio (using Fmp) between the ABRs elicited from LS CE Chirps® and click stimuli in normal-hearing adults. The finding indicated that the ABRs to LS CE Chirps® recorded a less number of averages to reach the specified Fmp in comparison to those from click stimuli at both high and low-intensity level

Table 1 Median number of averages to reach Fmp= 3.1 for both ABR LS CE Chirp® and click stimuli. Inter-quartile range (IQR), 75th and 25th percentiles (pctl) are included. The statistical analysis is on the two last columns.

Intensity (dBnHL)	Median	IQR	75th pctl	25th pctl	Median	IQR	75th pctl	25th pctl	Z - score	P – value	Effect size (r)
	CLICK ABR				LS CE CHIRPS ® ABR						
80	200	200	400	200	100	100	200	100	-1.79	0.07	0.46
60	300	600	800	200	200	100	200	100	-2.85	0.00	0.75
40	500	1000	1200	200	100	200	300	100	-3.06	0.00	0.79
20	1300	1000	1700	700	500	1600	1800	200	-1.79	0.07	0.46

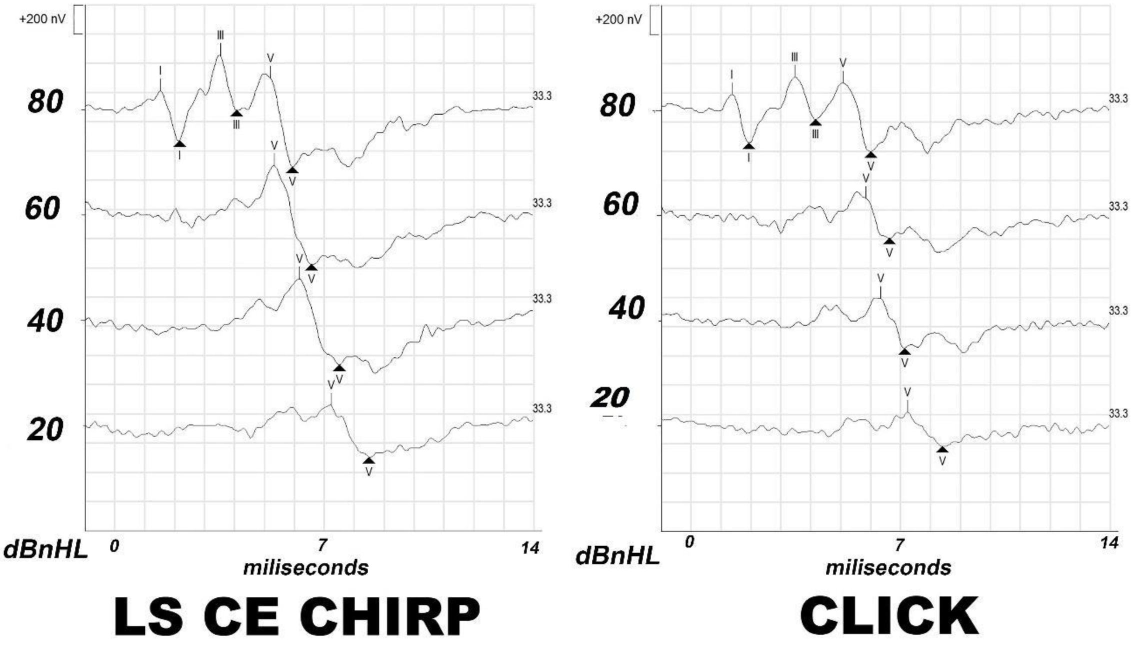

Figure 1: Example of auditory brainstem response (ABR) waveforms at multiple intensity levels for LS CE Chirps® (left panel) and click (right panel) one of the study participants.

The number of average differences was relatively small at suprathreshold levels and higher at lower intensity levels. Based on the stimulus repetition rate used in this study (33.3 Hz), time savings of 3 and 24 seconds per recording could be expected for suprathreshold levels and lower intensity levels, respectively. Despite the modest time savings provided at suprathreshold, the present findings support the use of LS CE Chirps® with Fmp analysis in the audiology clinic for a threshold-seeking approach as this strategy could save time, especially when testing difficult-to-test populations.

The finding also supports the notion by Dzulkarnain et al. (2020) that the use of SNR as an ABR stopping criterion has the potential to obtain time-efficiency of ABRs to LS CE Chirps® as compared to the fixed residual noise level. Specifically, their study involved 13 normal-hearing adults that were tested using both ABRs to click and LS CE Chirps® stimuli at multiple intensities and stimulus repetition rates. By using SNR as the stopping criterion, the test can be stopped as soon as the optimum SNR is reached. The tester is not required to continue extra averaging in obtaining a very minimal residual noise level (e.g., 40 nV) or a fixed number of averages that are being used traditionally (e.g., stop until 4000 averages). Dzulkarnain et al. (2020) used fixed residual noise level as a stopping criterion and no significant differences in the number of averages were noted between ABRs to LS CE Chirps® and click stimuli. This finding might be due to the use of residual noise level, which does not consider the improvement in the SNR provided by the LS CE Chirps®, but rather the amount of residual noise in the ABRs elicited by both stimuli. If the background noise is the same, there is a high possibility that the time to reach the specified residual noise level could be the same between the ABRs elicited from both stimuli.

The present study also reiterates the previous recommendation by Madsen et al. (2018) on either stopping the ABR test based on a fixed SNR or a fixed residual noise level. According to Madsen et al. (2018), both techniques could produce accurate ABR findings. Nevertheless, stopping based on a fixed residual noise level could lead to further improvement in the ABR wave V amplitude accuracy, whereas stopping based on the fixed SNR could result in further improvement in the ABR wave V latency accuracy. Indirectly, this implies that one may choose to use fixed SNR as stopping criteria for the threshold-seeking approach as it only relies on the presence or absence of the ABR rather than its amplitude or latency accuracy that are typically used for neurodiagnostic purposes. The idea to stop based on SNR for the threshold-seeking approach is further substantiated by the time savings provided as demonstrated in this study. The time savings provided further support for the use of LS CE Chirps® in audiology clinics in addition to other benefits reported in the literature, such as the ABRs to LS CE Chirps® producing larger wave I, III, and V amplitudes compared to those from click or other types of chirp stimuli (Dzulkarnain et al., 2020; Dzulkarnain et al., 2018; Dzulkarnain et al., 2017; Kristensen & Elberling, 2012).

Conclusion:

In summary, the ABRs to LS CE-Chirps® are advantageous to optimise the ABR testing time when Fmp is employed as a stopping criterion to determine the number of averages for signal averaging. In future, the same technique (LS CE-Chirps® and Fmp) can be further investigated in children to measure the time savings provided in a larger sample size. Notably, the number of averages does not solely depend on the type of stimuli but also on the amount of background noise, particularly from the subjects. The variation of noise had the potential to influence findings. The background noises were not systematically controlled across the stimulus and intensity combinations. For instance, the amount of background noise could be inconsistent when testing for different stimuli and intensity combinations. Hence, the number of averages to reach Fmp can be possibly lower or higher depending on the level of background noise. In addition, the number of averages to reach Fmp of 3.1 reported in the present study were rounded to the nearest hundredth. This might explain the slightly higher number of averages, thereby indicating a likelihood of an extra signal averaging process for certain stimuli and intensity combinations. These 100 sub-average step sizes for signal averaging imply a possible deviation of 1 to 3 seconds in the actual test time given the 33.3 Hz stimulus repetition rate used in this study. Conclusions drawn from this study are limited only to the participants, equipment, stimuli, and recording parameters used in the research. Caution must be taken before extrapolating these findings beyond the research participants and all the factors mentioned earlier.

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