Repeatability and interpretation of ABR latency measurements

Author and Correspondence

Guy Lightfoot
Company Director
ERA Training & Consultancy.

E: admin@eratraining.co.uk

Headline
Latency in threshold ABR measurements

Introduction

Wave V latency is an important characteristic of the auditory brainstem response (ABR) that can inform interpretation of results and guide test strategy. Three aspects of wave V latency are commonly considered:

1. The absolute latency is expected to be within a pre-defined range, although this range may be very wide if variables including stimulus frequency, supra-threshold level, and patient age are not accounted for.
2. Repeated tests (replications) using the same stimulus are expected to yield a similar latency; this helps establish the repeatability and, therefore, the credibility of any response.
3. Stimulus intensity and wave V latency are inversely related, such that we expect longer latencies for lower stimulus levels (Burkard and Don, 2012). Evidence of this latency "input/output (I/O) function" is used to support the validity of the responses.

The presence of the above characteristics increases our confidence that a response is genuine. This is of particular importance near the ABR threshold, where the response is small and the signal to noise ratio (SNR) may be low; and complicate our interpretation of a clear response (CR). However, to make use of these latency characteristics, reference data describing their normal range is needed. Only then can latency be used to validate or refute a response.

Methods

In a recent study of a modified Fmp calculation, which is a statistical online analysis of the ABR recording from beginning to end (Lightfoot et al., 2023); babies under 12 weeks corrected age (mean 3.6 weeks) were tested using the method outlined in the British Society of Audiology's recommended procedure for ABR testing in babies (BSA, 2019). Analysis of the wave V latency data acquired for that study is presented here.

At 4 kHz, 86% of ears had ABR thresholds ≤30 dBeHL, whereas at 1 kHz, 80% of ears had ABR thresholds of ≤30 dBeHL. The stimuli used to establish their ABR thresholds were either 4 kHz narrow band level-specific CE-Chirps® presented at a rate of 49.1 stimuli/s (50 ears), or 1 kHz narrow band CE-Chirps® presented at 45.1 stimuli/s (41 ears). As described in the Fmp study method, the decision to cease data acquisition was not informed by the Fmp. Instead, for the first run at a given stimulus level, averaging continued until the residual noise fell to below 30 nV (15 nV if the waveform was a candidate for response absence). The second run was stopped when the response was visually judged to be at least three times greater than the noise (SNR ≥3). Wave V latency was recorded for each waveform containing a response. Filters of 33 Hz to 1500 Hz were used, as well as a digital low-pass display filter at 1500 Hz. Artefact rejection was 9.8 μV and noise-weighted (Bayesian) averaging was applied.

Results

The following data were analysed:

i. absolute wave V latency at threshold,
ii. wave V latency for the two replicates at the level taken as the ABR threshold, and
iii. wave V latency for the two runs at 10 dB above the level taken as the ABR threshold.

Absolute latency at threshold

Table 1 shows the latencies recorded at threshold using 4 kHz and 1 kHz stimuli. This is the mean of the two replicates. It is important to note that the stimulus was a narrow band CE-Chirp LS, which has inbuilt compensation for the travelling wave delay. For example, Table 1 shows 4 kHz and 1 kHz yield very similar wave V latencies. Had a tone pip stimulus been used, the latency would be longer by an amount corresponding to the travelling wave delay difference for 1 kHz and 4 kHz.

Table 1. Absolute wave V latency at threshold, ms (NB CE-Chirps LS).

	Mean	Standard deviation	95% range
4 kHz	9.41	0.89	7.66 to 11.15
1 kHz	9.31	1.05	7.25 to 11.37

The latency differences between replicates at the same stimulus level

Table 2 shows the analysis of wave V latency differences (latency jitter) between replicates at the same stimulus level. As expected, the mean difference of the replicates was almost zero. When calculating the 95% confidence interval, a mean difference of zero was assumed. Figure 1 shows an example of the latency jitter. To test whether the jitter observed at the two stimulus levels was significantly different, paired t-tests were performed and these confirmed there was no significant effect of stimulus level (4 kHz p=0.41 and 1 kHz p=0.13) even though, on average, more sweeps were used at threshold compared to 10 dB above. There was also no significant difference in the jitter observed at 4 kHz compared to 1 kHz (p=0.28). Because of these results, the latency jitter data were collapsed across the four conditions. Overall, the 95% range for latency jitter across replicates was ±0.61 ms.

The latency change from threshold +10 dB to threshold

Table 3 shows the analysis of wave V latency across stimulus levels at threshold and 10 dB above threshold. The latency shift associated with the 10 dB change in stimulus was somewhat larger at 1 kHz compared to 4 kHz (p=0.041). It is noteworthy that the range spans zero, the implication being that in a minority of cases, the latency I/O function can appear to go the "wrong" way. Figure 2 (the grand average of waveforms shown in Figure 1) illustrates a typical latency shift between threshold and 10 dB above, in this case 0.2 ms.

Discussion and conclusions

The BSA guidance for the interpretation of ABR tests in babies includes the requirement that the response must be "repeatable", without providing a clear definition or procedural guidance. This study provides information to assist the tester in that regard.

Table 2. Wave V latency differences between replicates at the same stimulus level, ms.

	Mean	Standard deviation	95% Range	Mean Sweeps/run
4 kHz, Threshold	0.0246	0.28	-0.55 to +0.55	4037
4 kHz, Threshold +10 dB	0.0346	0.20	-0.39 to +0.39	2864
1 kHz, Threshold	0.05	0.35	-0.69 to +0.69	3604
1 kHz, Threshold +10 dB	-0.05	0.42	-0.82 to +0.82	2740
All	0.017	0.31	-0.61 to +0.61	3311

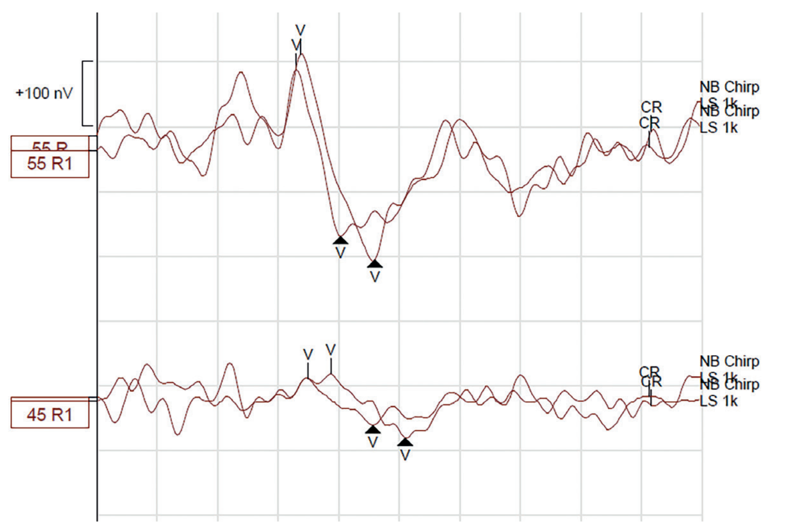

Figure 1. An Example of wave V latency differences (latency jitter) between replicates at the same stimulus level. Time scale: 2 ms per division.

For absolute latency at threshold, the range offered in Table 1 is applicable only to babies under 12 weeks and for narrow band CE-Chirps LS. Wave V latencies outside the range could be valid but should be subject to additional scrutiny, for example be subject to a blocked stimulus trial.

Wave V latency jitter, which is shown here to be in the range ±0.61 ms, is almost certainly the result of residual noise in the averaged waveform, rather than any genuine change in the response over time. Greater latency jitter is likely to be seen when residual noise is high, for example at the start of an averaging run, when only a few sweeps have been acquired, or in poor recording conditions. Figure 1 is a good example of latency jitter which, at threshold, is 0.73 ms and just outside the 95% range. Whenever this occurs, further averaging or a blocked stimulus run could be applied to increase confidence that the response is genuine.

The latency change over 10 dB will comprise two mechanisms: a genuine latency shift and jitter associated with residual noise. It is clinically important to note the potential influence of latency jitter. Although the trend is

Table 3. Change in absolute Wave V latency across stimulus levels at threshold and 10dB above threshold, ms.

Threshold to Threshold +10 dB	Mean	Standard deviation	95% Range
4 kHz	0.47	0.35	-0.21 to +1.16
1 kHz	0.64	0.55	-0.44 to +1.72

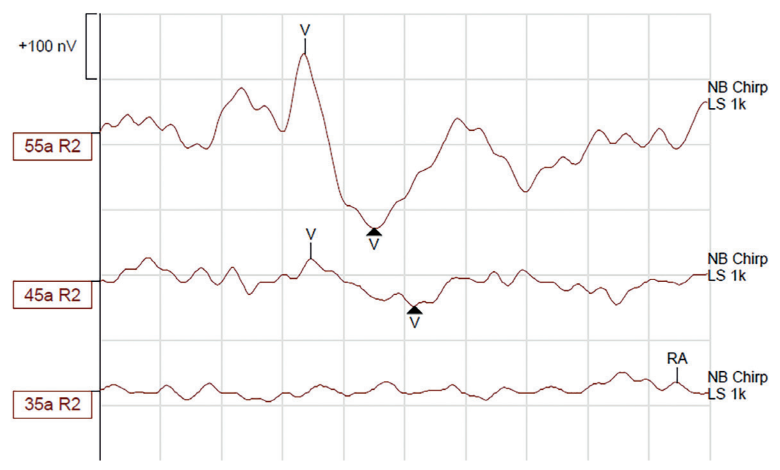

Figure 2. An example of the typical latency shift between threshold and 10dB above. Time scale: 2 ms per division. RA: response absent. In this case the latency shift from 55dB to 45dB was 0.2 ms.

for wave V latency to increase with decreasing stimulus intensity, the measured latency at threshold can occasionally be slightly earlier than at 10 dB above threshold, influenced by residual noise. As such, it would be inappropriate to always reject a response when this pattern is seen. However, it would be prudent to apply additional scrutiny, for example to make use of a blocked stimulus trial.

References

BSA (2019) *Recommended Procedure Auditory Brainstem Response (ABR) Testing in Babies*. Available at: https://www.thebsa.org.uk/wp-content/uploads/2019/06/OD104-81-Recommended-Procedure-for-ABR-Testing-in-Babies.pdf.

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'Take-home' message
Latency measurements are affected by residual noise

Edited for Audacity by
Alan Sanderson, PhD
Manuel Loureiro, MSc