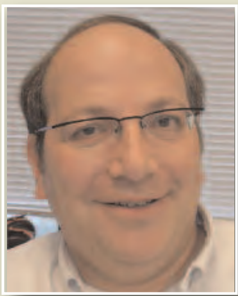
Noise Reduction to Achieve Quality ABR Measurement

By André Marcoux, PhD and Isaac Kurtz, MHSc, PEng
amarcoux@uottawa.ca



About the Authors
André Marcoux, PhD, adjunct professor, Department of Audiology and SLP, University of Ottawa; chief audiologist and president, The Sound Room Hearing Centres; www.thesoundroom.ca.
Isaac Kurtz, MHSc, PEng, vice-president of research and technology, Vivosonic Inc.; www.vivosonic.com.

ABSTRACT

Canada is a leader in the development of auditory brainstem response (ABR) technologies that enhance response detection. In this article, we examine the clinical challenges associated with ABR measurements and uncover advanced technologies developed by Canadian researchers and engineers that offer noise reduction capabilities essential for achieving quality ABR measurements. These advanced technologies are transforming hearing health care around the world.

Most audiologists would agree that noise is the foremost frustration with clinical auditory brainstem response (ABR) measurements. In this context, noise refers to interference from electromagnetic and myogenic sources which make it challenging to recognize and detect the true response in ABR waveforms. Whether employing ABR for neurodiagnostics, for estimating hearing ability, or for screening, noise is a common and persistent issue.

As an electrophysiological measurement which requires information be collected "far field," at a distance, ABR is extremely susceptible to contamination. With electrodes placed on the patient's scalp, minute responses of 0.05 to 0.5 microvolts are acquired from the auditory nerve and brainstem pathways. These minute responses travel to a recording device to be processed. From the point of data acquisition to processing of the signal, there is ample opportunity for the ABR to be contaminated by physiological artifacts from the patient, and extraneous artifacts and interferences in the environment. When the amplitude of the recorded response shows more than 20 microvolts, it is certain that what is shown is not ABR, but noise.

COMMON SOURCES OF NOISE (INTERFERENCE)

Noise is everywhere. ABR recordings are particularly vulnerable to interference from sources with frequencies of 20 to 30 Hz up to 2500 Hz – the frequency range of a typical ABR signal. Thus, it is helpful to recognize potential sources of noise and understand how they might be introduced into an ABR waveform.

Physiological Artifacts

There are numerous sources of physiological noise generated voluntarily or involuntarily by the adult or child being assessed. Muscular activity or movement, even from a fragile newborn, can produce significant artifact that interferes with the much smaller ABR. A patient who is relaxed and motionless still has small EMG activity in the area of the electrode sites such as the forehead, mastoids and scalp, as well as EOG arising from the eyes, ECG from the heart, and EEG from the brain. All of these sources lead to unwanted noise in the recordings. It is impossible to eliminate their effects entirely, but it is possible to significantly reduce them through good clinical practice and advanced ABR technologies.

Motion Artifacts

Artifacts due to motion are the result of electrode leads moving during data acquisition. Often this is caused by patient movement or when adjustments to the leads are made.

Recording Environment

Sources of extraneous noises in our environment are typically the most difficult to identify and mitigate. Frequently the presence of electromagnetic noise from nearby equipment, conducted power line noise, and radio frequency interference, all serve to contaminate the ABR recording. Without proper shielding of wires and/or the recording environment, electrode leads are prone to field artifacts. Inadequate grounding invites unwelcome electrical pickup from circuitries in the room and the influence of 50/60 Hz noise and harmonics can appear in the waveform.

CONSEQUENCES OF (TOO MUCH) NOISE

Too much noise in ABR recordings has a number of consequences. Here are the major ones.

Misinterpretation of ABR

Artifact and interference make it difficult to interpret waveforms and can result in reduced accuracy of wave recognition and latency measurement. When estimating hearing ability or hearing loss, specifically at lower stimulus intensity levels, the amplitude of the waveform may be similar to that of the noise making it difficult to interpret. Stapells[1] cautions that ABR recordings of insufficient quality may mean that an ABR wave V is identified as “present” when its amplitude is not significantly greater than the background noise. Or, a common mistake is to indicate a “no response” when the recording is too noisy and the residual EEG noise is greater than a typical threshold response.

Lengthy Measurement Period

In noisy environments, when conventional averaging of waveforms is used, measurement must continue for excessively long periods of time in order to accurately detect the response. This is problematic when assessing infants, children, or other patients who may be uncooperative. Only partial data may be collected and a follow on appointment must be arranged to complete the assessment adding to costs and inconvenience for all concerned.

Sedation of Infants and Young Children

Sedation or anesthesia is often used to minimize contamination of the ABR recording from myogenic artifacts present when infants and young children are awake and alert. There is an entire body of literature that examines the effects of sedation. For the most part it is safe, yet there remains a certain amount of risk related with its use. “Sedated ABR procedures are costly, time-consuming and require constant patient monitoring during the procedure.”[2] In a recent report by the Pediatric Sedation Research Consortium,[3] auditory brainstem response was identified as one of the procedures for which sedation was commonly used. Data from 114,855 pediatric sedations indicated that monitoring guidelines published by the American Academy of Pediatrics (AAP) were followed in only 52% of cases.

Time Spent Reducing Noise

“Electrical interference from feeding pumps, monitors, etc. is our #1 problem. Much more time is spent trying to solve electrical interference issues than in actual test time.”[2] When the source of noise cannot be identified or eliminated, the patient may need to be moved to a less noisy environment, or assessed in a shielded room or Faraday cage.

Cannot Complete Assessment

In some cases, it is simply not possible to reduce noise to acceptable levels to obtain quality recordings. This is a frequent occurrence in environments with high electromagnetic interference, such as the neonatal intensive care unit (NICU) or operating room (OR). Even when potential sources of interference have been removed and non-essential equipment powered off, noise may remain so high that testing must be abandoned.

CONVENTIONAL MEANS OF REDUCING NOISE

How is noise extracted from the response that we are trying to measure? Following good clinical practice, along with built-in noise reduction features of the ABR measurement instrument, it is possible to reduce noise in the ABR. Conventional methods for reducing noise are mentioned here.

Shielding

When noise and interference cannot be mitigated further by moving or powering off equipment in the test environment, shielding is sometimes the only means to ensure adequate immunity. This can be an effective, but costly solution to the problem of extraneous noise.

Natural Sleep and Sedation

Natural sleep and sedation are common approaches used with infants and young children to manage muscular activity. In general, it is preferable to assess an infant in natural sleep over the risks of sedation. Natural sleep often requires that an infant be deprived of sleep before the appointment, and still it may be necessary to wait for the infant to fall asleep before testing can proceed. Particularly in the case of older infants and young children, natural sleep is frequently not an option. Rather than manage the myogenic artifact arising from an active or uncooperative child, many clinics proceed directly to sedation, providing that sedation is not contraindicated and caregivers consent to this procedure.

Patient Posture and Positioning

To reduce muscular activity and provide support for the neck, adult patients are typically asked to lie supine on a bed, close their eyes, and relax as much as possible. In most cases, this is sufficient to minimize muscular noise. However, when patients are aware that the assessment seeks evidence of a tumour, they are understandably agitated and as a consequence generate undue levels of muscular artifact which is not easily extracted from the signal.

Electrode Impedance

To obtain cleaner recordings, it is common practice to scrub and exfoliate the skin of the patient with a mild abrasive before applying electrodes to the site. This serves to reduce electrode impedance which can significantly impact EEG quality. “The impedance does not affect the ABR itself, but the larger the impedance, the larger the amount of pickup of external electromagnetic interference and of artifacts from movement of the electrode leads.”[4] A low electrode impedance of 3 or 4 kOhm is often recommended, with impedance difference between electrode pairs not more than 1 kOhm. Acceptable ABR recordings can be obtained with higher impedances providing the impedance difference is balanced and symmetrical. This is needed for common-mode rejection, otherwise there is difficulty obtaining an acceptably low level of EEG noise when recording ABR.

Averaging

Signal averaging is possible because ABR is time-locked to the stimulus, with each repeated stimulation eliciting the same response. Noise, on the other hand, is very random and has no regular pattern. By presenting the same stimulation over and over again, and averaging the responses together, the ABR waveform should emerge from the noise. Increasing the number of stimulus presentations, or sweeps, improves waveform morphology. Averaging can be terminated as soon as a clear ABR waveform is visualized. Repeatability of the waveform is required to confirm the presence or absence of a response. If the measurement instrument has two recording buffers, repeatability is easily determined by visually comparing the averaged waveforms in each buffer. Statistical tools can further provide an objective validation.

Conventional averaging techniques typically weight all sweeps equally so that sweeps with higher amplitudes (high noise) have the same impact on the waveform morphology as sweeps with lower amplitudes (less noise and closer to an ABR). Note that more advanced “weighted” averaging techniques, such as Kalman Weighted Averaging, weight sweeps according to noise content so that noisy responses have less of an impact on the waveform morphology.

Artifact Rejection

When conventional averaging is used, it is typical to set an artifact rejection level of a certain voltage such as 20 microvolts. Sweeps with amplitudes greater than the rejection level are deemed to have too much noise and are not included in the averaging. While this reduces the impact of noisy responses on ABR morphology, too many rejected sweeps can prolong recording time. As sweeps are rejected, more data must be collected for sufficient averaging to occur.

Pause Equipment

Signal processing and noise cancellation techniques are usually inadequate to overcome the effects of myogenic artifact such as a baby stirring or a child squirming. When patient movement causes too much noise, it may be more practical to simply pause data acquisition until the movement subsides.

ADVANCED ABR TECHNOLOGIES THAT REDUCE NOISE

Noise in ABR measurements can be significantly reduced through innovative technologies developed by researchers and engineers in Canada. The three technologies described here have been developed by Vivosonic Inc., a leader in technologies that enhance ABR detection.

The combination of these technologies effectively minimizes the need to sedate infants and young children for ABR assessment,[5] is effective in managing electrical and artifacts in places with high electromagnetic interference such as the NICU6–8 and OR,[2] permit ABR measurement via tele-audiology,[9,10] help to identify false indications of noise-induced hearing loss,[11] and provide more accurate ABR under non-ideal conditions compared to conventional methods.[6,7,12,13]

“We were able to get valid passing newborn hearing screenings on infants that were awake and in electrically complex locations (running isolette and being held by a parent/nurse).” And,

Figure 1. Amplitrode with built-in pre-filtering and amplification at the recording site.

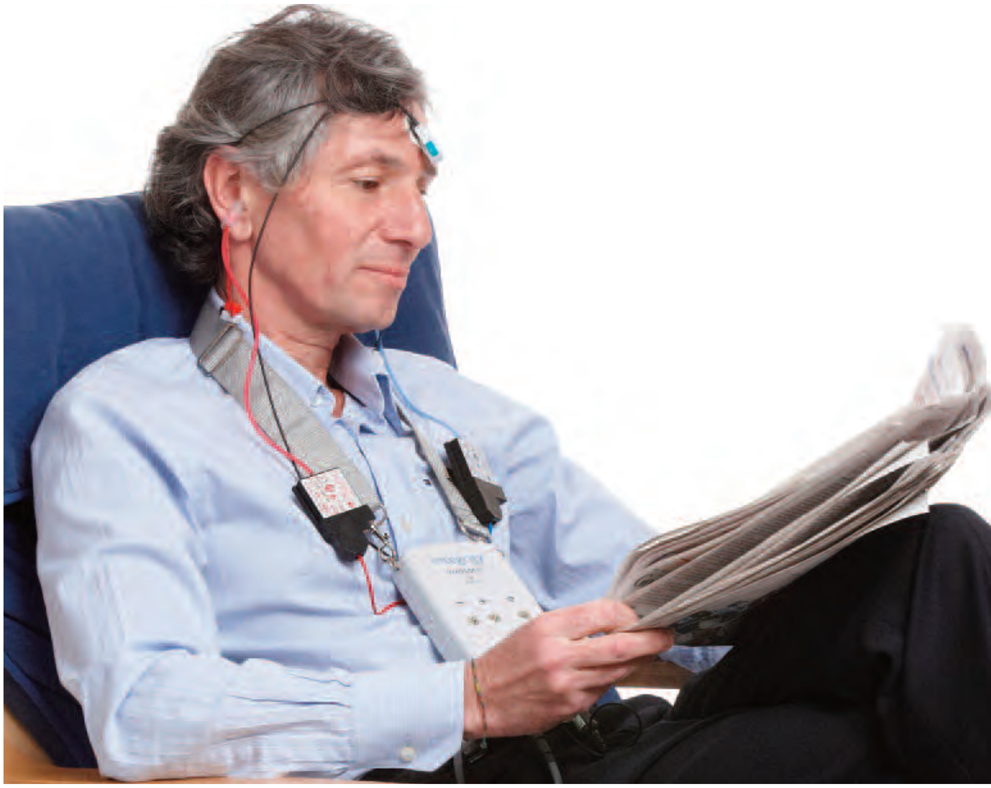


Figure 2. VivoLink wireless technology provides convenient testing.

"Accurate recordings were obtained regardless of whether or not the baby was awake, asleep, in a crib or running isolette."[7]

"There is much less, if any, interference from monitors and other OR equipment. Test time is easily cut in half."[2]

AMPLITRODE

This patented technology provides two distinct innovations: filtering of the ABR before amplification, along with amplification of the signal directly at the recording electrode site (Figure 1). By prefiltering the signal, the effects of EOG, ECG, motion artifact, and RF are almost completely eliminated. Gain adjustments are no longer needed, and the risk of signal saturation is reduced. Furthermore, by amplifying the signal "in situ" (at the recording site), sources of noise from the recording environment are reduced. Instead of an unamplified signal travelling along the electrode leads picking up electromagnetic noise and other contamination, the result is the recording of a more robust ABR signal.[14]

In contrast, the of lack in-situ amplification in conventional systems means that amplification occurs after the signal has had to travel from the electrode, along a cable, all the way to a preamplifier. With the cables acting as an antenna, there is a great deal of opportunity for noise to be introduced from sources present in the recording environment. Line noise and additional wires also contribute to contamination of the signal. Now, when the signal reaches the preamplifier, it is contaminated with all sorts of noise which is subsequently amplified.

The patented Amplitrode eliminates many of the problems related to extraneous noise by prefiltering and amplifying immediately at the site of data acquisition, before the signal has had a chance to pick up undesirable noise.

WIRELESS TECHNOLOGY

Technology that can provide complete wireless communication between the recording platform and the electrodes has valuable benefits. As a battery-powered unit, the VivoLink is immune to line noise. Furthermore, elimination of wires reduces susceptibility to electromagnetic interference in the recording environment. Overall, this means there is less noise to manage which translates to very clean waveforms in very little time.

Wireless recording also makes it possible to collect data while a baby is held, strolled, or nursed – untethered to equipment. In the case of high-risk babies in the NICU, the VivoLink enables babies to be tested inside an incubator while the recording platform remains outside. The incubator may even be closed shut while testing is in

Figure 3. SOAP Adaptive Processing enables ABR without risks of sedation.

progress, with the recording platform up to 10 metres (30 feet) away. This technology also permits children and adults the freedom to move and be tested in comfort (Figure 2).

SOAP ADAPTIVE PROCESSING (AN EVOLUTION OF KALMAN WEIGHTED AVERAGING)

This is perhaps the most innovative technology for noise reduction in evoked potential responses. SOAP Adaptive Processing is a combination of patented and proprietary technologies that adaptively reduce the myogenic and electromagnetic noise in ABR. It is an evolution of signal processing algorithms that use Kalman Weighted Averaging. Together with the Amplitrode and VivoLink wireless technology, SOAP provides superior response detection under non-ideal conditions and facilitates non-sedated ABR measurement (Figure 3).

As with Kalman Weighted Averaging techniques, there is no artifact rejection. Instead, sweeps are included in the recording and assigned a weighting based on its noise content. Groups of sweeps with less noise are assigned a much greater weighting than sweeps with higher amplitude noise. Thus, noisy responses have less of an impact on the waveform morphology. By including all sweeps, and by weighting them according to the noise content, we can actually obtain a much clearer ABR waveform in less time.

In addition to averaging, adaptive processing methods are used throughout the measurement. The system recalculates all weightings according to the noise content and the relationship between sweeps (covariance). This very active and unique dynamic weighting system provides much cleaner waveforms in much less time.

FINAL THOUGHTS

Mastering ABR measurement is a worthwhile undertaking in order to provide a comprehensive diagnostic picture of auditory function. Good clinical practice combined with technological advancements can help to overcome frustrations with noise in data acquisition and interpretation, and ultimately aid in obtaining quality ABR measurements.

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