

Use of Maximum Length Sequence Analysis In Newborn Hearing Testing

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Abstract

The use of maximum length sequence analysis (MLSA) with rapid click rates may be of clinical value in newborn hearing screening because a greater number of individual responses can be signal averaged without adding to test time. To examine the potential clinical value of MLSA in newborn screening, auditory brainstem responses (ABRs) from 50 premature newborns were studied. ABRs were acquired with conventional signal averaging at four stimulus intensity levels (50 dB, 40 dB, 30 dB, and 20 dB nHL) using a click rate of 33.3/sec. These responses were directly compared with the ABRs acquired with MLSA using a rate of 227.3/sec. MLSA and conventional signal averaging yielded similar results with no statistically significant differences in the number of responses detected. Across babies, the overall quality of the tracings slightly favored MLSA, particularly when recording conditions were poor. Though the results of this investigation do not support the use of MLSA as the primary technique in newborn screening in the neonatal intensive care unit (NICU), they do support consideration of the use of MLSA as an alternative technique when the responses obtained with conventional signal averaging are poorly defined.

Key Words: Auditory brainstem response (ABR), maximum length sequence analysis (MLSA), neonatal intensive care unit (NICU), newborn hearing screening, premature newborns

The use of maximum length sequence analysis (MLSA) permits click stimuli to be presented at very rapid rates during auditory brainstem response (ABR) testing. In contrast with conventional ABR signal averaging in which one response must be completed before the next stimulus can be presented, individual responses are allowed to overlap during MLSA testing. Overlapping responses can be recovered through the use of on-line cross-correlation techniques (Eysholdt and Schreiner, 1982, Burkard et al, 1990). MLSA permits the use of stimulus rates over 900/sec, which is 10 times faster than is possible with conventional ABR signal-averaging techniques.

MLSA with rapid click rates may have clinical value where test time is of major importance. Faster click rates may permit ABRs to be

acquired in a shorter period of time and thus shorten the testing session. Of potentially greater clinical importance, the use of MLSA may result in improved response clarity without adding to test time. This would be of significant benefit in test environments, such as the neonatal intensive care unit (NICU), where recording conditions are often unfavorable.

The potential for MLSA to provide higher response quality lies in the number of individual responses summated into the composite ABR. In conventional ABR testing of infants and children, a rate of around 30 to 40/sec is typical. With these rates, approximately 2000 click stimuli can be presented to the patient within a 60-second period. In contrast, using MLSA with a stimulation rate of 900/sec, 28,000 clicks can be presented to the patient in the same period of time.

If all factors could be held constant, the greater the number of individual responses comprising an ABR, the clearer will be the final response. Increasing the number of samples results in greater cancellation of background (non-stimulus related) activity and, as a result, the response can be more easily differentiated

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from this noise. Theoretically, the amplitude ratio of response to background noise improves with the square root of the increase in the number of individual responses that comprise the final response. In the example above, MLSA permits the acquisition of 14 times as many individual responses without adding to the length of the test session. This would suggest that MLSA may produce more clearly defined responses than can be obtained in the same period of time using conventional ABR testing techniques. As noted previously, this would be of significant benefit in newborn hearing screening in the NICU, where adverse recording conditions are often encountered and test time is of major importance.

An obvious concern about the application of MLSA in the NICU is whether the premature newborn has sufficient neural development to permit the use of MLSA with very rapid click rates. Recent reports have indicated that maturation is not a significant limitation in the application of MLSA. In a quiet test room, Lasky et al (1992) were able to record MLSA ABRs from healthy, full-term newborns over a wide range of intensities and rates up to 900/sec. Weber and Roush (1993) carried out MLSA testing on premature newborns in the NICU using three click rates (227.3/sec, 454.5/sec, and 909.1/sec) and observed that MLSA can be used with very young newborns even at the fastest click rate.

Though the feasibility of recording MLSA ABRs in the NICU has been demonstrated, the results in this test environment have not been directly compared with conventional ABR testing at different stimulus intensities. Weber and Roush (1993) conducted conventional ABR testing on their subjects to exclude babies with a hearing loss, but they did not directly compare the responses by the two techniques. Thus, it is not known if the MLSA technique provides any clinical advantages for newborn hearing screening.

There is reason to suspect that the clinical potential of MLSA in this application may be limited. It has been reported that MLSA recordings are intrinsically noisier than conventional ABRs and the response amplitude to noise ratio becomes poorer as the rate is increased (Marsh, 1992). As a result, one must question whether using MLSA to increase the number of individual responses comprising each ABR will actually result in an improvement in response detection or will merely serve to offset a poor initial response/noise ratio inherent in the technique itself.

The present study was undertaken to examine this question by comparing conventional and MLSA ABR techniques in the NICU. Of specific interest was whether the MLSA technique provides more clearly defined ABRs than can be obtained in the same length of time with conventional signal-averaging techniques. The focus of the study was on the quality of responses obtained in a given amount of test time, and no attempt was made to examine the reduction in test time itself.

METHOD

Subjects

Fifty premature newborns in the NICU at Duke University Medical Center served as subjects. Because their health status required the specialized services of the NICU, all were considered to be at risk for hearing loss and were candidates for clinical ABR hearing screening. Consistent with the hospital's clinical hearing screening protocol, babies were evaluated when their health status had stabilized and were as close to discharge as possible. Conceptional age at test ranged from 28 to 45 weeks, with a mean age of 36.9 weeks.

Procedures

In most instances (43/50), testing was performed in either the NICU or a level II (step-down) nursery. Seven babies were tested in their room on the pediatric ward following discharge from the NICU. Both conventional and MLSA testing were performed using commercially available evoked potential equipment (Nicolet Spirit). Surface-recording electrodes were positioned at midline forehead (Fz) and the earlobe of the stimulated ear, with the common electrode located on either the back of the hand or the foot. An insert earphone (Etymotic Research ER-3A) was used to present monaural click stimuli generated by a 100-microsecond electrical pulse.

For conventional ABR testing, responses to 2000 clicks were averaged at each of four stimulus intensity levels (50dB, 40 dB, 30 dB, and 20 dB nHL) using a stimulus rate of 33.3/sec. With these stimulus parameters, it required 60 seconds to acquire each ABR. MLSA testing was performed using a rate of 227.3/sec. This rate was selected based on an earlier investigation of three click rates (227.3/sec, 454.5/sec, and 909.1/sec) (Weber and Roush, 1993). In that

study, the authors found that the slowest click rate elicited the most clearly defined responses from premature newborns. Due to the irregular interclick interval inherent in MLSA, 7200 clicks were presented in the 60-second-long acquisition period for each ABR. The order of conventional and MLSA and ABR testing was counterbalanced across subjects.

For both averaging techniques, the initial stimulus intensity level was 50 dB nHL. For both rates, the 0-dB level was based on normal adult behavioral threshold to the slow click rate. This allowed the p e SPL level to be held constant across rates. After the initial 50-dB level, stimulus intensity was decreased in 10-dB steps until the 20-dB level was reached. However, if it was clear that no detectable response was present at one of the higher intensity levels, no further testing was performed with that technique. This flexible protocol was used to minimize total test time and thus reduce the likelihood of possible changes in subject state. Whenever there was any question about the presence of a detectable response, testing continued.

An additional variation in the test protocol was used to minimize test time. A single ABR at any intensity level was accepted as a response if the resulting tracing had clearly defined waves I, III, and V. For both conventional and MLSA testing, the examiner was permitted to overlay up to three tracings at any level in an effort to improve response detection. If the baby's arousal state changed significantly during testing, this was viewed as an unacceptable biasing of the results and the baby's data were not included in the study.

Off-line digital filtering (150 Hz–3000 Hz) was performed on all of the tracings, and absolute latencies for ABR waves I, III, and V were measured whenever the waves could be identified with confidence.

RESULTS

Typical tracings for the two analysis techniques are shown in Figure 1. For both analysis techniques, ABR component waves I, III, and V can be identified at the higher stimulus levels, and waveform morphology is similar. As expected, absolute latencies are longer for MLSA due to the faster click rate. In Figure 1, the tracings show detectable responses down to 20 dB nHL for the MLSA technique, while no response is apparent at this level for conventional signal averaging. Table 1 shows the percentage of subjects for whom each component wave of the

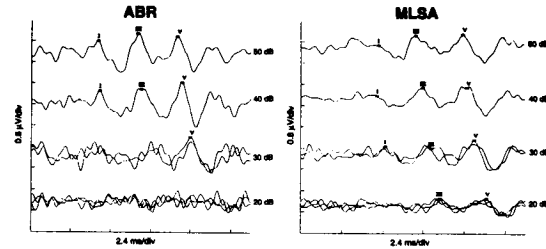


Figure 1 Auditory evoked potentials from a premature newborn (conceptional age at test: 33 weeks) acquired with conventional signal averaging (ABR) and MLSA. Across the four stimulus intensity levels (50 dB, 40 dB, 30 dB, and 20 dB nHL), the waveform morphology is similar for the two techniques. For this newborn, a response can be detected at the 20 dB nHL level with MLSA but not with conventional signal averaging.

ABR could be identified by conventional signal averaging and MLSA. These values may be somewhat higher than the reader's own clinical experience. At least in part, this is due to the requirement that, to compare the two measurement techniques, each baby must have remained quiet throughout the entire test session. As a result, data from the all-too-common restless and fussy babies are not included in this study.

For each ABR component wave, a chi-square test (2×4) was performed across the four intensity levels to compare the number of detectable waves obtained with the conventional versus MLSA techniques. For wave I ($\chi^2 = 1.96$), wave III ($\chi^2 = 1.08$), and wave V ($\chi^2 = 1.5$), $p > .05$, indicating no significant differences in the frequency of occurrence for any of the three component waves.

Table 2 shows the percentage of detectable responses (defined as the presence of at least one component wave) for the two techniques. Again, no statistical differences were found when the two techniques were compared across the four

Table 1 Percentage of ABR Component Waves Detected with Conventional Signal Averaging and MLSA

	50 dB	40 dB	30 dB	20 dB
Wave I				
Conventional	86	82	80	36
MLSA	84	88	74	27
Wave III				
Conventional	94	86	86	46
MLSA	92	92	74	44
Wave V				
Conventional	94	82	86	52
MLSA	88	88	72	52

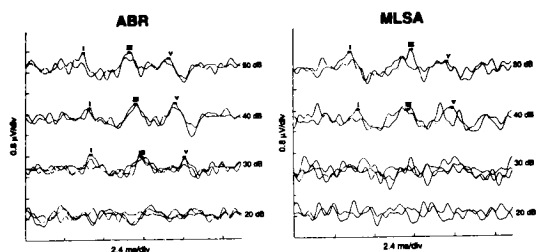


Figure 2 Responses from a newborn (conceptional age at test: 40 weeks). This infant passed the conventional ABR hearing screening at 30 dB nHL but failed at this level with MLSA.

intensity levels ($\chi^2 = 0.148, p > .05$). Though there is a 10 percent difference between techniques at the 30-dB level, the percentage of detectable responses is identical at three of the four click intensity levels (50 dB, 40dB, and 20 dB). If the absence of a response at a 30 dB nHL click stimulus level is used to define screening failure, 3 of the 50 babies (6%) failed the conventional ABR screening and 8 babies (16%) failed when MLSA was used. Of the eight MLSA failures, six demonstrated clear conventional ABRs at the 30-dB screening level. The tracings from one such baby are shown in Figure 2. Two babies failed the hearing screening by both techniques. Of these two babies, one passed on follow-up testing with conventional ABR testing and the other, on retesting at 4 months corrected age, was found to have a significant bilateral sensorineural hearing loss.

One baby failed the conventional screening but demonstrated a clear ABR by MLSA. This baby received a conventional ABR retest 3 days later and passed at the 30-dB screening level. Thus, the false positive rate for the initial screening was 4 percent for the conventional ABR technique and 14 percent for MLSA.

When three judges evaluated the quality of the responses, conventional signal averaging yielded the clearest response 20 percent of the time. No significant difference was noted for nearly half (48%) of the subjects. For nearly one-third of the babies (32%), more clearly defined responses were obtained with MLSA.

Table 2 Percentage of Detectable Responses at Four Stimulus Intensity Levels

	50dB	40dB	30dB	20 dB
Conventional	96	94	94	60
MLSA	96	94	84	60

This improvement with MLSA tended to occur when there were high levels of electrical interference or muscle artifact.

DISCUSSION

When the responses obtained with MLSA are directly compared with tracings recorded with a conventional ABR technique, the results are very similar. As expected, the absolute response latencies are longer with MLSA because of the more rapid stimulus rate. With this exception, the responses are so similar that it is impossible to use waveform morphology to distinguish between conventional and MLSA tracings. In terms of response detection, MLSA provides no consistent advantage over conventional signal averaging in the NICU. Therefore, when test time is controlled, the clinician is just as efficient using a conventional ABR protocol as he/she would be using MLSA with a much faster click rate. Because test time was balanced across techniques, this investigation did not investigate possible time savings through the use of MLSA. Predictions based on data from this study, however, suggest a modest benefit at best.

In the NICU, the MLSA technique does not provide a consistent improvement over traditional ABR screening. However, it can serve as a back-up technique that may be of clinical value when test conditions are not conducive to conventional signal averaging. In the presence of high levels of electrical interference or muscle artifact, switching to MLSA may result in an improvement in response clarity. This benefit, however, does not justify its use as the primary signal averaging technique in the NICU.

Acknowledgment. The authors wish to thank Karen Harkins for her assistance in data analysis.

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