Maximum Length Sequences-Auditory Brainstem Responses from Children with Auditory Processing Disorders

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Abstract
This study was designed to evaluate maximum length sequences-auditory brainstem responses (MLS-ABR) in children with auditory processing disorders and to compare these results with a normal control group matched for age, intelligence, and gender. Although each waveform was analyzed for the presence of waves I, III, and V, the primary focus was wave V. Although absolute latency measures for wave V were obtained from all subjects, waves I and III were not always identified. Although the results showed latency increases for all waveforms in both groups, the only significant difference noted was an increase in wave V latency for both the left and right ears in the clinical group. These results suggest that the MLS-ABR may be useful in the assessment of auditory processing disorders. Implications for the potential use of the MLS-ABR in management programs are discussed.

Key Words: Auditory brainstem response, auditory evoked potentials, auditory processing disorders, maximum length sequences

Abbreviations: ABR = auditory brainstem response, ADHD = attention-deficit hyperactivity disorder, APD = auditory processing disorders, DD = Dichotic Digits Test, DP = Duration Pattern Test, DS = Dichotic Sentences Identification Test, ERP = event-related potential, FP = Frequency Pattern Test, LL = linguistic label, MLR = middle latency response, MLS = maximum length sequences, MLS-ABR = maximum length sequences-auditory brainstem response, MMN = mismatch negativity, SSI-ICM = Synthetic Sentence Identification-Ipsilateral Competing Message, TC = Time Compressed Speech Test, VA = Veterans Administration

One of the most unique challenges facing audiologists is the diagnosis of auditory processing disorders (APDs) (Baran and Musiek, 1999). Although there are a variety of methodologies used in assessment, such as observation, exclusion, behavioral testing, and electrophysiologic testing, it is the behavioral test battery that has received the most emphasis from audiologists (Jerger, 1998). In evaluating for APD, audiologists typically administer a battery of behavioral tests designed to assess the higher auditory centers thought to be involved in auditory processing—a protocol referred to as process-based assessment (Bellis, 1996). However, as noted by a number of authors (Jirsa and Clontz, 1990; Jirsa, 1992; Musiek et al, 1994; Jerger, 1998), there is much variability in those behavioral tests, and the normative data are quite disparate.

In an effort to enhance the objectivity in the assessment of APD, interest has focused on the use of electrophysiologic measures of the central auditory nervous system (Jirsa and Clontz, 1990; Kraus and McGee, 1994; Jerger, 1998). Although much of the research still must be considered preliminary, encouraging results have been obtained with a variety of electrophysiologic measures, including the middle latency response (MLR) (Jerger and Jerger, 1985; Jerger et al, 1988; Musiek and Berge, 1998), the P300 event-related potential (ERP) (Jirsa and Clontz, 1990; Jirsa, 1992), and the mismatch negativity (MMN) (Kraus et al, 1993; Kraus 1996; Chermak and Musiek, 1997; Dalebout and Stack, 1999). However, none of these measures provides a “gold standard” measure of...
APD (Jerger, 1998). Although the MLR provides information relative to the maturation of the auditory system, it is not always easy to observe—especially in children under 10 years—and may be influenced by unwanted myogenic activity (Jerger et al., 1998; Musiek and Lee, 1999). Although the P300 has been shown to be sensitive to APD (Jirsa and Clontz, 1990; Jirsa, 1992), the response is highly variable and dependent on the active participation of the subject in attending to a series of auditory stimuli. Although the MMN appears to have clinical potential (Kraus and McGee, 1994; Kraus, 1996), the waveform is difficult to identify and measure with accuracy, and until definitive clinical protocols are developed, its clinical usefulness is questionable (Dalebout and Fox, 2000).

As a result of these issues, the routine clinical use of electrophysiologic measures has not been widely adopted. An objective electrophysiologic measure is needed that is relatively unaffected by myogenic activity, does not require active subject participation, can be completed relatively quickly without inducing patient fatigue, and can be readily identified with minimal calculations.

Recently, Burkard (1994) described a new technique for obtaining auditory brainstem response (ABR) data based on advanced computer averaging and computational techniques. This procedure permits data collection using stimulus rates/sec that significantly exceed those currently in use. This is accomplished using a pulse sequence stimulus, referred to as the maximum length sequence (MLS), where each sequence is actually a series of pulses of uniform polarity and amplitude occurring at pseudorandom intervals rather than presented as discrete pulses (Nicolet Instrument Corporation, 1991). Unlike conventional stimuli used in other electrophysiologic procedures, MLS testing does not require an interstimulus interval greater than the response duration. Rather, through cross-correlating the response patterns with the stimulus sequence, the final response is obtained through mathematical derivations (Burkard et al., 1990; Nicolet Instrument Corporation, 1991; Musiek and Lee, 1997). As a result, individual responses are allowed to overlap permitting rates as high as 1000/sec (Nicolet Instrument Corporation, 1991).

Because the MLS protocol is a recent development in collecting ABR data (MLS-ABR), there has been limited research examining its clinical utility. However, available data do suggest a number of advantages to using this procedure (Burkard, 1994; Weber and Roush, 1995). These advantages are (1) decreased test time (Eysholdt and Schreiner, 1982), thus reducing patient fatigue; (2) increased test sensitivity related to the heightened temporal stress on the auditory system from the rapid stimulation rates approaching absolute neural refractory periods (Pratt et al., 1981; Burkard et al., 1990; Lasky et al., 1992; Burkard, 1994; Lina-Granado et al., 1994); (3) waveform morphology is similar to conventional ABRs, although latency values are increased and amplitude values decreased as a result of the increased click presentation rate (Yagi and Kaga, 1979; Pratt et al., 1981; Shanon et al., 1981; Eysholdt and Schreiner, 1982; Burkard et al., 1990; Burkard, 1994); (4) active subject participation is not required (Burkard et al., 1990; Burkard, 1994); and (5) the recording protocol is similar to ABR (Picton et al., 1992; Burkard, 1994).

Although the above support the premise that the MLS might be a useful diagnostic tool for evaluating aspects of the auditory nervous system, there has been no research specifically examining the sensitivity of the MLS-ABR to APD. Since, as noted above, the MLS places the auditory system under temporal stress, and since, as noted by Jerger (1998), temporal factors are thought to play a significant role in APDs, it seems reasonable to expect that the MLS protocol might be sensitive to some of those factors thought to be involved in processing disorders. Consequently, this study was designed to investigate these waveforms in children with APD.

Specifically, this investigation was concerned with the question of whether children with APD, confirmed through results from a behavioral test battery of central auditory function, could be differentiated on the basis of the MLS-ABR from a normal group matched as closely as possible for age and gender.

**METHOD**

**Subjects**

Thirty-seven children (20 males and 17 females) in the age range from 9.2 to 13.6 years with a diagnosis of APD, but with normal peripheral hearing (<20 dB at octave frequencies 0.5–8 kHz), normal word recognition scores (≥90%), normal immittance and reflexes, normal acoustic emissions, and normal intelligence (full-scale IQ > 85), were selected for the clinical group. These subjects were selected from an original population of 49 children referred with a ten-
tative diagnosis of APD from speech-language pathologists, psychologists, or pediatric neurologists. To be included in the study, subjects had to obtain positive results on at least two of the behavioral tests of central auditory function and have an ABR within normal clinical limits bilaterally. Of the 37 subjects, 6 had a concurrent diagnosis of attention-deficit hyperactivity disorder (ADHD) and were receiving appropriate medication, and 19 were diagnosed with a concurrent speech and language problem for which they were receiving therapy from the school speech-language pathologist. To minimize the influence of ADHD, subjects on medication were required to have taken their medication prior to all testing. Thirty-five age-matched children (20 males and 15 females) with no indications of perceptual or language deficits as reported by parents and school personnel, and with normal hearing and intelligence as defined above, were selected for the normal control group. This number was subsequently reduced to 30 (17 males and 13 females) when 5 of the subjects were unable to meet the criteria of normal performance on all behavioral tests of central auditory function. All 5 of these subjects were subsequently re-evaluated behaviorally and electrophysiologically with a resultant diagnosis of APD.

Instrumentation

All testing was conducted in a shielded two-room IAC sound-treated suite (Industrial Acoustics Company). The peripheral audiology evaluations were conducted using the Madsen OB822 clinical audiometer, coupled to a Sony CE 315 CD player, with the signals transduced through Nicolet Model TIP-300 insert phones. Immittance measures were obtained with the GSI 33 Middle Ear Analyzer (Grason-Stadler, Inc.), and emission measures were obtained with the GSI 60 Distortion Product Otoacoustic Emissions System (Grason-Stadler, Inc). The behavioral central auditory test battery was recorded on the Veterans Administration (VA) compact discs (Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 1.0; Speech Recognition and Identification Materials, Disc 1.0) (Wilson, 1993) and routed through the two-channel clinical audiometer. All electrophysiologic measures were obtained using the Nicolet Spirit Averager (Nicolet Instrument Corporation). Gold-cup electrodes were used with the noninverted electrode placed at Cz, the inverted electrodes at A1 and A2, and the common at FPz. Interelectrode impedance was less than 3.5 kohms.

Test Stimuli

The MLS stimuli were generated using the Nicolet Maximum Length Sequence Software using an asynchronous binaural protocol (Nicolet Instrument Company, 1991). In this procedure, the stimuli were presented to both ears as a pseudorandom series of pulses not occurring simultaneously in both ears. This permitted responses to be mathematically extracted for each ear that were essentially similar to two individual monaural tests (Nicolet Instrument Company, 1991).

In the current investigation, the test stimuli were 100-μsec clicks delivered through the insert phones at 70 dB nHL at a rate of 909.1/sec (minimum interpulse interval = 0.55 msec). This presentation rate was based, in part, on research showing a positive relationship between high stimulation rates and auditory stress (Yagi and Kaga, 1979; Pratt et al, 1981; Shanon et al, 1981; Burkard, 1994; Weber and Roush, 1995). Additionally, results of a smaller pilot investigation examining various presentation rates suggested this rate to be most sensitive to APDs (Jirsa, 1996). All waveforms were replicated, and a total of 1000 replicated artifact-free sequences were recorded for each subject on each trial using a 12-msec time window. All responses were filtered online from 100 to 3 kHz, and all responses exceeding ±45 μV were rejected.

Although each waveform was analyzed for the presence of waves I, III, and V, the primary focus was wave V, which is the one most consistently observed at high presentation rates (Burkard et al, 1990; Burkard, 1994), is the most sensitive to rate changes in terms of latency measures (Yagi and Kaga, 1979; Hood, 1998), and is the most robust in terms of latency and intensity (Lasky et al, 1992). Because of the variability in ABR response amplitude (Hall, 1992; Hood, 1998) and its susceptibility to noise at high click rates (Picton et al, 1992; Burkard, 1994), only absolute latency measures were considered that were measured from stimulus onset to the appropriate peak. The author and two independent experienced electrophysiologic researchers scored all waveforms. In evaluating the waveforms, the scorers were blind as to the subject group and had to agree by consensus on the presence, absence, and latency of the waveforms for both subject groups.
The behavioral test battery consisted of the following: (1) the Dichotic Digits Test (DD) (Musiek, 1983), (2) the Dichotic Sentence Identification Test (DS) (Fifer et al, 1983), (3) the Frequency Pattern Test (FP) (Pinheiro and Ptacek, 1971), (4) the Auditory Duration Pattern Test (DP) (Musiek et al, 1990), (5) the Time Compressed Speech Test—65 percent compression (TC) (Wilson et al, 1994), and (6) the Synthetic Sentences Identification Test with the Ipsilateral Competing Message (SSI-ICM) (Jerger and Jerger, 1974). Although both the FP and DP tests evaluate aspects of temporal processing, they measure different parameters (Chermak and Musiek, 1997). Similarly, although both the DD and DS are tests of dichotic listening and have been shown to be sensitive to auditory dysfunction, they differ in linguistic content, with the digits having a lesser linguistic load than the sentences, and thus measure different aspects of processing (Chermak and Musiek, 1997). Each of the tests was administered according to the published instructions, including requiring both a linguistic labeling (LL) and humming response for the tests of temporal processing as recommended by Bellis and Ferre (1999). An abnormal result was defined as any score in either ear that fell below the range of normal responses. For the purposes of this investigation, based on our normative data, the following values were considered abnormal: (1) < 85 percent for the DS, (2) < 80 percent for the DD and the SSI-ICM, and (3) < 75 percent for the TC, the FP Test, and the DP.

### RESULTS

Mean performance, including standard deviations and range of scores, on the behavioral test battery for subjects in the APD group is shown in Table 1 and for the normal group in Table 2. Note that for all measures, with the exception of the two temporal patterning tests, results were obtained monaurally from each ear. As can be seen, although mean performance on all tests was below the normal range for the clinical group, there was also substantial performance variability on all tests that is consistent with published data (Jerger, 1998).

For all of the electrophysiologic measures, absolute latency was calculated at the apex of the waveform rather than at the shoulder or descending peak. As noted by Schwartz et al (1994), this protocol provides the most consistency and is less likely to be affected by alterations in the signal-to-noise ratio.

**Table 1 Mean Performance (% Correct), SDs, and Range of Scores on the Behavioral Test Battery for the 37 APD Subjects**

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD/LE</td>
<td>53.13</td>
<td>21.35</td>
<td>15</td>
<td>86</td>
</tr>
<tr>
<td>DD/RE</td>
<td>64.79</td>
<td>18.56</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>DS/LE</td>
<td>62.12</td>
<td>20.20</td>
<td>16</td>
<td>92</td>
</tr>
<tr>
<td>DS/RE</td>
<td>78.24</td>
<td>16.58</td>
<td>28</td>
<td>96</td>
</tr>
<tr>
<td>FP/LL</td>
<td>56.80</td>
<td>21.05</td>
<td>24</td>
<td>94</td>
</tr>
<tr>
<td>FP/HUM</td>
<td>72.54</td>
<td>14.65</td>
<td>38</td>
<td>100</td>
</tr>
<tr>
<td>DP/LL</td>
<td>45.27</td>
<td>22.96</td>
<td>12</td>
<td>90</td>
</tr>
<tr>
<td>DP/HUM</td>
<td>68.64</td>
<td>19.35</td>
<td>28</td>
<td>94</td>
</tr>
<tr>
<td>TC/LE</td>
<td>57.32</td>
<td>19.88</td>
<td>12</td>
<td>80</td>
</tr>
<tr>
<td>TC/RE</td>
<td>63.72</td>
<td>18.65</td>
<td>16</td>
<td>86</td>
</tr>
<tr>
<td>SSI/LE</td>
<td>52.34</td>
<td>18.12</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>SSI/RE</td>
<td>62.43</td>
<td>16.67</td>
<td>20</td>
<td>100</td>
</tr>
</tbody>
</table>

DD = Dichotic Digits, DS = Dichotic Sentences, DP = Duration Pattern, FP = Frequency Pattern, HUM = humming response, LE = left ear, LL = linguistic labeling response, RE = right ear, SSI = Synthetic Sentence Identification, TC = Time Compressed Speech.
One criterion for inclusion in this investigation was a normal ABR. All subjects produced the ABR bilaterally, with waves I, III, and V clearly identifiable. The latencies for these waveforms are shown in Figure 1. Note that there was no significant difference between groups for any of the waves, and all latencies were within clinically normal limits (LE/I: $t = 1.53$, $p = .14$; RE/I: $t = .79$, $p = .438$; LE/III: $t = .32$, $p = .754$; RE/III: $t = .47$, $p = .644$; LE/V: $t = .42$, $p = .678$; RE/V: $t = .58$, $p = .565$).

Each MLS waveform was analyzed for the presence or absence of waves I, III, and V. To facilitate component identification, wave I was identified as the largest positive peak between 1.5 and 2.8 msec, wave III was identified as the largest positive peak between 3.5 and 4.9 msec, and wave V was identified as the maximum positive peak between 5 and 9 msec (Picton et al., 1992). Since all tracings were replicated, if there were differences in latency between waves, an average was used. In all instances, there had to be a consensus between scorers for each latency measure.

All subjects in both groups produced an identifiable MLS-ABR wave V. Not all subjects, however, generated a measurable wave I or wave III. In the normal group, three subjects failed to produce measurable waves I and/or III bilaterally, whereas in the APD group, seven subjects failed to produce waves I and/or III in either ear. Representative waveforms from each group are shown in Figure 2.

![Figure 1](image1)

**Table 2** Mean Performance (% Correct), SDs, and Range of Scores on the Behavioral Test Battery for the 30 Normal Subjects

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>DD/LE</td>
<td>92.67</td>
<td>7.64</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>DD/RE</td>
<td>87.61</td>
<td>6.78</td>
<td>83</td>
<td>100</td>
</tr>
<tr>
<td>DS/LE</td>
<td>92.06</td>
<td>5.32</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>DS/RE</td>
<td>94.94</td>
<td>5.98</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>FP/LE</td>
<td>93.56</td>
<td>5.89</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>FP/RE</td>
<td>97.34</td>
<td>3.89</td>
<td>86</td>
<td>100</td>
</tr>
<tr>
<td>DP/LE</td>
<td>89.11</td>
<td>6.86</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>DP/RE</td>
<td>94.56</td>
<td>5.12</td>
<td>84</td>
<td>100</td>
</tr>
<tr>
<td>TC/LE</td>
<td>80.89</td>
<td>5.20</td>
<td>75</td>
<td>92</td>
</tr>
<tr>
<td>TC/RE</td>
<td>82.39</td>
<td>6.45</td>
<td>75</td>
<td>97</td>
</tr>
<tr>
<td>SSI/LE</td>
<td>92.22</td>
<td>9.98</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>SSI/RE</td>
<td>91.67</td>
<td>8.78</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

DD = Dichotic Digits, DS = Dichotic Sentences, DP = Duration Pattern, FP = Frequency Pattern, HUM = humming response, LE = left ear, LL = linguistic labeling response, RE = right ear, SSI = Synthetic Sentence Identification, TC = Time Compressed Speech.

![Figure 2](image2)
Table 3  MLS-ABR Mean Latencies (msec), SDs, and Range of Scores for Each Ear (LE/RE) for Waves I, III, and V for the 37 APD Subjects

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave I/LE</td>
<td>2.01*</td>
<td>.419</td>
<td>1.54</td>
<td>2.70</td>
</tr>
<tr>
<td>Wave I/RE</td>
<td>1.97*</td>
<td>.359</td>
<td>1.59</td>
<td>2.66</td>
</tr>
<tr>
<td>Wave III/LE</td>
<td>4.42*</td>
<td>.389</td>
<td>3.80</td>
<td>5.39</td>
</tr>
<tr>
<td>Wave III/RE</td>
<td>4.39*</td>
<td>.481</td>
<td>3.61</td>
<td>5.81</td>
</tr>
<tr>
<td>Wave V/LE</td>
<td>7.26*</td>
<td>.647</td>
<td>6.21</td>
<td>8.83</td>
</tr>
<tr>
<td>Wave V/RE</td>
<td>7.29*</td>
<td>.594</td>
<td>6.25</td>
<td>8.88</td>
</tr>
</tbody>
</table>

* t = 1.60, p = .119; tt = .487, p = .629; tt = .341, p = .734.

The absolute latencies, including standard deviations and range of scores, on the MLS-ABR for subjects in the APD group are shown in Table 3 and for the normal group in Table 4. Note that for both groups, there were no significant interaural latency differences for any of the waveforms.

Table 5 summarizes the absolute latencies and standard deviations for waves I, III, and V averaged across both groups. These data are also shown graphically in Figure 3. The only statistically significant difference observed was an increase in wave V latency for both the left and right ears in the clinical group compared to the normal controls (LE: t = 3.98, p < .001; RE: t = 3.83, p < .001). At the same time, however, there was significantly more variability in the clinical group for this waveform (LE: F = 2.57, p = .016; RE: F = 2.3, p = .033). For the other waveforms, none of the intergroup latency differences approached significance.

DISCUSSION

The purpose of this investigation was to examine the MLS-ABR in children diagnosed with APDs and to compare the results to a group of age-matched normal controls. Results indicated that there were statistically significant differences between the two groups. Specifically, wave V latency in the clinical group was significantly longer than in the control group. However, because there was increased response variability in the clinical group, individual test data must be interpreted cautiously and in conjunction with the entire test battery. These results are consistent, however, with other studies using high presentation rates that demonstrated an increased sensitivity to lesions within the auditory nervous system as a result of the increased temporal stress (Yagi and Kaga, 1979; Shanon et al, 1981; Musiek, 1991; Burkard, 1994). Although no significantly different latency measures were observed for waves I and III, this was not totally unexpected. As noted by Hood (1998), there is less of a rate effect on the earlier waves than on wave V. Also, the fact that waves I and III were not always observed is consistent with other studies using high rates of stimulation (Eggermont and Odenthal, 1974; Buchwald and Huang, 1975; Pratt and Sohmer, 1976; Yagi and Kaga, 1979).

The fact that the MLS protocol did reflect sensitivity to APD suggests that the temporal stress placed on the auditory system by high presentation rates is more pronounced in those with auditory processing deficits compared to those with normal auditory function. In this respect, the MLS-ABR may be providing an electrophysiologic measure of temporal processing ability, a process not thought to be assessed by other commonly used electrophysiologic measures such as the MLR, MMN, or P300. The MLR, which is probably the most frequently used electrophysiologic procedure in
Table 5  MLS-ABR Mean Latencies (msec) and SDs for Each Ear (LE/RE) for Waves I, III, and V Compared across Subject Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Wave I</th>
<th>Wave III</th>
<th>Wave V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LE/1</td>
<td>RE/1</td>
<td>LE/III</td>
</tr>
<tr>
<td>Normal</td>
<td>1.98 (.41)</td>
<td>1.99 (.35)</td>
<td>4.24 (.34)</td>
</tr>
<tr>
<td>APD</td>
<td>2.01 (.42)</td>
<td>1.97 (.36)</td>
<td>4.42 (.39)</td>
</tr>
<tr>
<td>t</td>
<td>.24</td>
<td>.31</td>
<td>1.81</td>
</tr>
<tr>
<td>p</td>
<td>.81</td>
<td>.76</td>
<td>.08</td>
</tr>
</tbody>
</table>

assessing APD, provides gross measures from the auditory cortex (Liegeois-Chauvel et al, 1994; McGee and Kraus, 1996; Musiek and Berge, 1998) and, as such, may be sensitive to lesions within the auditory cortex (Musiek and Berge, 1998). The P300 has also been shown to be sensitive to APD (Jirsa and Clontz, 1990), but it is distinguished from the MLR, as well as most other evoked potentials, in that it is an endogenous response (often referred to as an event-related potential), whereas the others are exogenous. Whereas exogenous potentials reflect the auditory sensory pathways, endogenous potentials reflect an interaction on the part of the subject with the auditory signal. As such, they call into play such cognitive processes as selective auditory attention and decision-making skills. Because subjects are required to actively participate in the P300 process, results can be influenced by inattention or fatigue. Although the exact generator sites of the P300 are not known for certain, the response is presumed to represent deep cortical and subcortical structures of the brain, including the hippocampus, posterior parietal lobe, and the temporoparietal junction (Courchesne, 1978; Musiek et al, 1992; Musiek and Berge, 1998). Like the P300, the MMN is an event-related potential, but unlike the P300, the MMN is elicited without active subject participation. The MMN reflects the detection of a change in the acoustic signal that has been stored in short-term memory (Niätänen, 1995). As such, it has been suggested that it may be useful in the electrophysiologic assessment of auditory discrimination ability (Kraus, 1996; Kraus et al, 1996). In addition, because the MMN appears to reflect precognitive neurologic processes, it may be potentially useful in differentiating individuals with auditory neural encoding problems from those with higher cognitive difficulties (Dalebout and Stack, 1999).

Thus, although it is evident that the current battery of evoked potential measures provides substantial information regarding the auditory processes, these measures are not primarily sensitive to temporal processing factors within the auditory system. Yet, as noted by Jerger (1998), there is an accumulation of evidence suggesting that deficits in temporal processing are one of the primary factors in APD. The current results suggest that the MLS may present an electrophysiologic methodology for assessing this critical process through sensitivity to preattentive temporal abnormalities within the auditory nervous system. Specifically, since the ABR generators range from the distal portion of the auditory nerve to multiple ipsilateral and contralateral generator sites in the lateral lemniscuses (Musiek and Lamb, 1992), the MLS-ABR may be sensitive to temporal coding problems at a neurophysiologic level. If such were the case, the MLS-ABR potentials would provide electrophysiologic data regarding temporal processing not available from other measures and would complement the overall assessment process. As noted by Musiek (2000), although management must focus on cortical change, the impact of the entire auditory system must be considered when making a diagnosis. Clearly, one of the critical functions of the auditory system is the detection, decoding, and use of temporal information. How well the auditory system is able to respond to the ongoing temporal fluctuations of the acoustic signal is critical. The MLS may provide an electrophysiologic mechanism for examining how well the auditory system is fulfilling this task without the confounding processes of attention and phonemic detection concerns that are inherent in the behavioral tests.

In the current investigation, subjects in the normal control group also evidenced latency shifts with the MLS protocol compared to the standard ABR. This finding was not surprising. In normal ears, high stimulation rates will result in latency shifts, more pronounced for the later...
waves, resulting from changes in neural receptor function in terms of adaptation and fatigue (Don et al, 1977). Additionally, there may well be an accumulative effect where one wave is influenced by the preceding wave as well as overall decreased synaptic efficacy (Pratt and Sohmer, 1976). These effects are exacerbated in cases of auditory system lesions (Yagi and Kaga, 1979). As noted by a number of authors (McDonald and Sears, 1970; Rasminsky and Sears, 1972; Pratt et al, 1981; Shanon et al, 1981; Burkard et al, 1990; Picton et al, 1992; Burkard, 1994; Musiek and Lee, 1997), lesions within the auditory system affecting neurons will result in an extension of the refractory periods and desynchronization of the firing patterns, especially at high rates with the auditory system under temporal stress. These are critical neurologic processes involved in the analysis of temporal data emanating from the acoustic signal.

In conclusion, these results showed statistically significant differences in the MLS-ABR latency potentials between children with audiologically confirmed APDs and an age-matched control group. Although these findings suggest that the MLS-ABR may be potentially useful in the assessment of APD, much more research is needed. Data relating to specificity and sensitivity of these measures alone and in conjunction with other behavioral and electrophysiologic tests are needed. Although behavioral tests are classified roughly by the process or processes evaluated, so too are electrophysiologic measures. Additional investigations should focus on the relationship between the MLS-ABR and the MLR, MMN, and P300 and, because of the inherent variability in these measures, should include analyses of both group and individual data. The development of an electrophysiologic battery to complement behavioral measures is most desirable. As noted by Musiek and Berge (1998), electrophysiologic tests provide objective measures of physiologic processes and are not compromised to the extent that behavioral measures are by significant language disorders or learning disorders or by children too young to respond reliably to behavioral tests. In addition, electrophysiologic measures may provide data not available behaviorally. In the case of the MLS-ABR, data might be available to more fully quantify and understand temporal processing deficits at the preattentive level. To this end, research should focus on examining the MLS-ABR in a more restricted subject base. The fact that in the current investigation, no attempt was made to define the subject base by the process or processes affected or by controlling for comorbidity in terms of speech and language involvement, attention-deficit disorder, or specific academic difficulties may have contributed to the significant degree of variability observed in the APD group. If, as suggested, the MLS-ABR is an electrophysiologic measure of temporal processing abilities, then it may not be sensitive, or as sensitive, to deficiencies in the other auditory processes such as auditory closure or dichotic listening. Future research efforts should focus on a more defined subject base to look at specific auditory processes or specific related conditions.

Finally, the use of the MLS-ABR in the management of children with APD might also be explored. As discussed by Musiek and Berge (1998), electrophysiologic measures offer unique advantages in the treatment of APD by providing information relative to the monitoring of neurologic status in therapy programs. This information, when combined with behavioral findings, provides a much more comprehensive status report on the efficacy of the management program than behavioral measures alone. In addition, electrophysiologic measures could provide information necessary for more clearly establishing therapy goals and objectives (Jirsa and Clontz, 1990; Jirsa, 1992; Musiek and Berge, 1998). Although there are some data available on the clinical efficacy of the P300 (Musiek et al, 1990; Jirsa, 1992) and the MMN (Kraus et al, 1995), there have been none published focusing on the MLS-ABR. If subsequent research shows the MLS-ABR to be efficacious in the clinical setting, this might provide an objective means of developing and monitoring management programs for children with temporal processing problems, which probably constitute the largest number of children diagnosed with APD (Tallal et al, 1996).

REFERENCES


