Behavioral, Electrophysiologic, and Otoacoustic Measures from a Child with Auditory Processing Dysfunction: Case Report

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Abstract

This case was selected to highlight the importance of the test battery approach in the assessment of a child with auditory processing deficits. The utility of behavioral, electrophysiologic, acoustic immittance, and evoked otoacoustic emission procedures, as well as the problems associated with interpreting these multiple measures with differing results, is discussed. This case was confounded by the possibility that both peripheral and central auditory problems existed. The outcome stresses the importance of examining the results of multiple auditory measures in the determination of the site of lesion and habilitation strategies.

Key Words: Acoustic immittance, auditory brainstem response (ABR), behavioral audiometry, central auditory processing, cortical auditory evoked potential (CAEP), evoked otoacoustic emission (EOAE), middle latency response (MLR), test battery

The selection of this case is intended to highlight the importance of the test battery approach (Jerger and Hayes, 1976; Gravel et al, 1989) in the audiologic assessment of children at risk for auditory disorders. The battery contributes not only to the delineation of the site of the auditory dysfunction but also to the documentation of capabilities (both strengths and weaknesses), which serve to direct and support recommendations for intervention.

CASE REPORT

Background

"P," aged 7 years, was referred for audiologic assessment by a pediatric neurologist. P's family had recently moved to our area. They were referred to our facility for neurologic work-up by a physician formerly at our facility. P had received routine audiometry (pure-tone, speech, and acoustic immittance assessment) at two other centers (one school based, the other associated with an ENT practice), beginning at 5 years of age. These evaluations were requested by both school personnel and P's parents, who were concerned about his responses to auditory input in the classroom and his problems in speech production. Results of those previous evaluations (a total of six audiograms were provided by his mother) were considered equivocal; results ranged from diagnoses of normal hearing to a mild-to-moderate sensorineural hearing loss. At one point, conventional hearing aids were considered but never recommended for use.

P had a normal birth history; at a very early age, however, it was apparent that his neuromotor abilities were compromised. P exhibits an unsteady gait, awkward fine and gross motor movements, and abundant, labored, and frequently unintelligible speech. He does not enjoy sports or physical activities. He is a shy child who does not enjoy interaction with other children; he is aware of his motor and speech limitations. P has been receiving occupational, physical, and speech-language therapy in the educational setting. When P was first evaluated, he was in a self-contained special education pro-
gram with mainstreaming for nonacademic activities.

While undergoing the battery of auditory procedures described below, P was simultaneously undergoing extensive speech evaluation at our facility. P's speech-production problems were considered extensive; in-depth phonetic and phonologic evaluation revealed problems with both the suprasegmental and segmental aspects of production. Patterns were suggestive of both motor-based (articulatory) speech errors (substitutions and distortions), as well as linguistically based (phonologic) deficits. Suprasegmental aspects of P's speech were characterized by a monotonic voice, a slow rate of articulation, and inappropriate stress patterns. While speech evaluation primarily examined aspects of production, our speech-language pathologist was concerned about P's language development on syntactic and pragmatic levels. Comprehensive language assessment was recommended to examine such things as word retrieval, auditory memory, turn-taking behaviors, and abilities to inhibit language production.

P's neurologic diagnosis remains undetermined. He shows signs of cerebellar involvement and cortical spinal impairment. Electroencephalographic (EEG) assessment revealed focal (left temporal region) abnormalities. He has shown no overt seizure activity; however, there has been concern over reported short periods of staring behavior. Results of an MRI were reported by the pediatric neurologist to have contributed little to his diagnosis. Medication has been tried in the past, targeted towards improving P's ability to focus his attention. Changes in his pharmaceutic regime have occurred on several occasions, in order to examine the effects of various drugs on P's symptomatology and school performance. At his most recent evaluation, his pediatric neurologist described P as "a diagnostic problem." He continues to be followed by pediatric neurology.

Auditory Evaluations

P (age 6 years, 10 months) was examined at Visit 1, using conventional play audiometric techniques. While motor responses were required from P, these were completed without difficulty. Visual and social reinforcement for correct responding was provided. Subjectively, this approach appeared to be motivating for P, and the technique maintained his attention during pure-tone testing. P was constantly encouraged and during assessment frequently cued to "listen." While some false-positive responses were made, the thresholds reported below were considered to be reliable.

Table 1 displays P's pure-tone air-conduction thresholds for each ear at Visit 1. Pure-tone averages (PTAs) of 13 dB and 18 dB HL for the right and left ears, respectively, were considered within normal limits. Acoustic immittance assessment revealed normal tympanograms in both ears. Ipsilateral acoustic reflexes were present from 500 through 4000 Hz at 90 dB HL bilaterally. Contralateral reflexes were not assessed. Evaluations completed at other facilities revealed the presence of contralateral acoustic reflexes at 500 through 4000 Hz at elevated levels (100 to 110 dB HL range) in the presence of normal tympanograms.

Assessment of P's speech thresholds (ST) and word-recognition abilities, however, were not consistent with the pure-tone findings. A ST of 35 dB HL was obtained in the sound field (using the Auditec recordings of Children's Spondaic Words). Speech-recognition assessment was completed informally using the Word

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Results were obtained at three visits (V).

*Indicates threshold was obtained in the sound field (binaural presentation).
Intelligibility by Picture Identification (WIPI) test (Ross and Lerman, 1970). This closed-set, picture-point response task was selected because of P's motor-speech disability. The WIPI was administered informally on a one-to-one basis using a normal conversational voice: the examiner was in the test booth, and no visual cues were available. P scored 76 percent on the WIPI, which is considered depressed for both his age and his measured hearing sensitivity. Thus, at the conclusion of the first assessment, P demonstrated relatively normal sensitivity for pure tones but reduced sensitivity for spondaic words and poorer-than-expected intelligibility of monosyllables presented at a suprathreshold (normal conversational speech) level.

P was scheduled for further audiologic and electrophysiologic assessments of his auditory function (Visit 2, completed at age 7 years). Tympanograms were normal bilaterally at this second visit. Measures were selected to further probe the apparent disparity in outcome suggested by pure-tone threshold assessment and those suggested by the results of the speech-threshold and word-identification tasks. Tests were selected to document P's peripheral hearing sensitivity and to provide further insight into his apparent difficulties in speech processing under both optimal and adverse listening conditions. Moreover, auditory measures were selected to guide recommendations for intervention.

Two speech measures were utilized for this evaluation. First, a simple test of phonemic discrimination was administered using recorded synthetic speech tokens (/ta/-/da/ contrast), exemplars of the voicing or voice-onset time (VOT) feature in speech. The task was for P to indicate each time a change syllable (in this case, /da/) was detected in an ongoing background of another speech syllable (/ta/) by pushing a manipulandum. The speech discrimination procedure was computer controlled. The audiologist signaled the computer to initiate a trial by depressing a hand-held button. Visual reinforcement was provided for correct responses only to the change trials. The computer program also provided control or no change trial intervals (probability of occurrence set at 40%). The discrimination test was presented in the sound field at 70 dB HL (see Gravel, 1989). After a training period, P's performance was examined for 20 trials. P's response to change trials was 100 percent (13 hits during 13 change trials). P's false-positive rate (responses to control intervals), however, was 75 percent (5 false alarms during 7 control trials). This outcome (high false-positive rate with high hit rate) provided little compelling evidence that P could reliably discriminate the phonemic contrast.

Next, a portion of the Pediatric Speech Intelligibility (PSI) test was administered (Jerger and Jerger, 1984). While the PSI was developed for children chronologically younger than P, the measure was selected because of the closed-set nature of the response task required by P's previously demonstrated performance difficulties. Only the five sentences pictured on response card “A” (Format II) were utilized in assessment. The standard test protocol for older children is for the primary PSI sentences to be presented at 30 dB HL. It was not until 50 dB HL in each ear during the practice session, however, that P's performance was judged to be optimum (asymptotic). Subjectively, P appeared to have periods during which he had no difficulty identifying the five simple sentences, while moments later, at the same presentation level, this ability deteriorated.

Figure 1 depicts P's results on the PSI in the contralateral competing message (CCM) condition, with the primary message held constant at 50 dB HL. Several interesting findings are evident in the figure. The PSI sentences in the CCM condition are usually presented at 0 and -20 message-to-competition ratio (MCR, in dB). Note, however, that P demonstrated severely reduced performance scores even for the easier of the two standard conditions (0 MCR). The standard PSI protocol had to be abandoned because of this performance deficit. P was as-

![Figure 1](image-url)
sessed using two more advantageous listening conditions: +10 and +20 MCR. Observe in Figure 1 that P’s performance for the left ear at the +20 MCR was equivalent to his score in the noncompeting condition; both were at 80 percent. Second, scores in the left ear were depressed regardless of listening condition, when compared to scores obtained when the right ear received the primary message. These results might be explained by the inherent variability of P’s overall performance, as noted previously. The result, however, also suggests a left ear weakness with an inability to inhibit competitive information presented at any level to the right ear. Regardless, P’s performance on a task that required the identification of simple sentences in a closed-set response format in the presence of background competition was markedly abnormal.

P received an auditory brainstem response (ABR) evaluation at Visit 2, the primary purpose of which was to confirm the presence of normal auditory sensitivity. The plan was to obtain ABR thresholds for 2000-Hz tones presented in notched noise (e.g., Picton et al., 1979; Stapells, 1989; Stapells et al., 1990), then to assess brainstem auditory pathway integrity (as measured by wave I–V interpeak latencies) by recording the ABR to 80-dB nHL clicks (Stapells and Kurzberg, 1991). Further testing would then proceed as results and patient state dictated. Stimulus and recording parameters for the electrophysiologic recordings are presented in Table 2.

P was sedated (by his neurologist, with 65 mg/kg of chloral hydrate). As soon as P was asleep, we attempted to record ABRs to 30 dB nHL 2000-Hz tones, a level which was 10 to 20 dB more intense than his behavioral thresholds. Normally, we expect to see responses to these tones at 20 dB nHL (Stapells, 1989; Stapells et al., 1990). No responses were present, however, even when the tones were presented at intensities as high as 80 dB nHL. Knowing the neurologic nature of the case and his normal behavioral thresholds, we switched to 80 dB nHL clicks. Shown in Figure 2A, the resultant waveforms demonstrate a clear neurologic abnormality. The click-evoked responses consisted primarily of normal-latency wave I (1.6 msec, solid triangles) and in some recordings a very degraded and prolonged later wave (open triangle), which may or may not be wave V. Some recordings showed only wave I. The latency of the later wave, about 7.7 msec, would give an abnormal interpeak latency of over 6 msec. The similarity of the recordings for rarefaction, condensation, and alternating clicks (“alternating” derived offline by averaging the ABRs to the rarefaction and condensation clicks) indicates that the waves I are not stimulus artifact or cochlear microphonic.

The absence of a clear wave V to the clicks explains the absence of brainstem responses to the tones, because wave V (and the negative peak following it) are usually the only features of the tone-evoked ABR (Stapells, 1989). In cases such as P, where wave I is clearly present but V is absent, the ABR is usually not an appropriate measure of auditory sensitivity, and electrocochleography should be considered if other thresholds (behavioral or other electrophysiologic) are elevated or unreliable. In P’s case, wave I was present in response to 40-

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*ABR were recorded to 80- and 40-dB nHL clicks (0 dB nHL = 30 dB peSPL). † At least two (and often three to four) replications obtained for ABR, MLR, and CAEP. ‡ ABRs were recorded to 80 to 20 dB nHL 2000-Hz tones (0 dB nHL = 26 dB peSPL). The 2000-Hz tones were presented in one-octave-wide notched-noise set 20 dB below the tone peSPL.
dB nHL clicks, a level at or close to the normal range for wave I recorded at the mastoid.

While P remained asleep, we also obtained middle latency response (MLR) and cortical auditory evoked potential (CAEP) recordings to the clicks presented to each ear. As shown in Figure 2B, no replicable waveforms are apparent in his MLR recordings. Digitally high-pass filtering the MLR waveforms at 22 Hz did not alter this finding. Although it is tempting to suggest the absent MLRs are related to the brainstem dysfunction indicated by the click-ABR results (absent ABR wave V with present wave I) and to P's auditory processing disorder, the absence of MLRs in P's case must, however, be interpreted as noncontributory, because several reports have indicated that absent MLRs are often recorded in normal children (e.g., Kraus et al, 1985; Stapells et al, 1988), especially when asleep.

In contrast to the absence of the ABR and MLR waves, while asleep P produced very repeatable CAEP waves to 70-dB nHL clicks presented to the left and right ears. These waveforms are shown in Figure 2C. Large-amplitude (7–10 μV) vertex-negative peaks, indicated by the filled diamonds, are seen at 480 msec (left ear) and 500 msec (right ear), with vertex-positive peaks preceding and following at about 250 and 750 msec, respectively. A less clear, lower-amplitude and later vertex-negative CAEP was also present in response to 40-dB nHL clicks presented to the right ear. Vertex-negative waves with such long latencies have been reported in sleeping subjects (e.g., Ujszaszi and Halasz, 1988). Because we did not carry out sleep staging and multichannel recordings, which are necessary to identify these peaks with any certainty and to determine their normality, we cannot state if these waves are "N1–P2," and cannot say if they are "normal." Nevertheless, the clear presence of P's repeatable CAEPs indicate cortical responsivity to these clicks at much lower intensities than indicated by his click- and tone-evoked ABR wave V results and are more consistent with his better behavioral audiometric results. Such results reinforce the conclusion of neurologic dysfunction.

One month later, P returned for further behavioral assessment (Visit 3, at age 7 years, 1 month). Once again, the WIPI was administered. At this assessment, however, both an auditory only and a combined ("look and listen") performance score were obtained. As at Visit 1, P demonstrated only fair performance (76%) in

Figure 2 ABR (A), MLR (B), and CAEP (C) recordings obtained during sleep. ABR recordings show clear and normal wave I (filled triangles) and absent or degraded and prolonged later wave, possibly wave V (open triangles). MLR recordings do not show replicable responses. CAEP recordings show long-latency vertex-negative peak (filled diamond). RARE = rarefaction clicks; COND = condensation clicks; ALT = alternating clicks, calculated offline by averaging responses to RARE and COND clicks. Positivity at the vertex indicated by an upward deflection. Time scales: 15 msec for ABR; 90 msec for MLR; 1000 msec for CAEP. Amplitude calibrations: 0.25μV for ABR; 1.0μV for MLR; 8.0μV for CAEP.

the auditory only condition. P's performance, however, improved to 96 percent correct in the visual-plus-auditory condition. Subjectively, when the combined cues were available, P demonstrated observable improvement in both speed and ease of responding. P was also evaluated using the Goldman-Fristoe-Woodcock (GFW) Test of Auditory Discrimination (Goldman et al, 1970). The GFW (a closed-set, monosyllabic picture-point task) was presented at an overall
presentation intensity of 70 dB HL in the sound field. P responded correctly to GFW practice items. During the test phase, 3 items (of 30) were missed in the Quiet condition, while 21 of 30 items were missed in the Noise subtest (+9 MCR; cafeteria noise used as competition). Although encouraged, P did not even attempt a response on well over half of the trials in the Noise condition.

At two follow-up assessments (Visits 4 and 5) over the next 18-month period, the pure-tone thresholds displayed in Table 1 were obtained. Tympanometry revealed normal middle ear function at those assessments. Results would be considered no worse than a mild hearing loss, although the configuration of the audiogram was rising on one occasion (Visit 4) and relatively flat at the other (Visit 5). P's ST at Visit 4 remained approximately 10 dB disparate from his pure-tone findings. This fluctuant response pattern is characteristic of those obtained at previous facilities, when audiometric PTAs varied from 20 to 40 dB HL (with normal tympanograms) over six different assessments.

By the time P returned for Visit 4, we had obtained equipment to allow us to record transient-evoked otoacoustic emissions (TEOAEs) and had begun investigations in normal and hearing-impaired subjects. We recorded TEOAEs to clicks and to brief tones during Visit 4 while P was awake. We used the ILO88 TEOAE system developed by Kemp et al. (1986), changing the default parameters and stimuli to give a 30-msec analysis sweep and a 33/sec stimulus rate (Abdo et al., 1992, 1993). The longer analysis sweep (and resulting slower stimulus presentation rate and longer-duration clicks) was chosen to better assess responses from low-frequency regions (Abdo et al., 1992). The longer analysis sweep (and resulting slower stimulus presentation rate and longer-duration clicks) was chosen to better assess responses from low-frequency regions (Abdo et al., 1992). The system's other default parameters were used, including the nonlinear stimulus cancellation procedure (Kemp et al., 1986). Responses were recorded to 75- to 85-dB peSPL 120-msec clicks and to 500- and 2000-Hz tones with rise/fall times equalling 2 cycles and plateaus equaling 1 cycle. TEOAEs were windowed offline using 20-msec windows (clicks/2000 Hz: 0–20 msec; 500 Hz: 10–30 msec). Tone-evoked TEOAEs were digitally filtered using a one-octave-wide band-pass centered on the tone frequency.

P's TEOAE results are presented in Figure 3, and indicate both ears produced emissions, albeit somewhat reduced in strength compared to other normal-hearing subjects (Abdo et al., 1992). The left ear produced clear emissions (i.e., reproducibility > 50%; Kemp et al., 1986) to the 2000-Hz tones (Figure 3, left), but none to the clicks (Figure 3, left) or to the 500-Hz tones (Figure 3, left). The left ear responses to clicks are somewhat noisier than P's other TEOAEs and at 42 percent did not quite reach the 50 percent reproducibility criterion. This may be due to P being somewhat more acoustically noisy during left ear testing. When filtered using a 1000- to 2500-Hz bandpass, however, the reproducibility of the left ear click-evoked TEOAE improved to 62 percent. The right ear produced clear emissions to all three stimuli (Fig. 3, right).

P's TEOAEs are consistent with near-normal cochlear sensitivity and rule out a moderate or worse sensorineural loss. Their reduced amplitude, especially for the left ear, may indicate mild abnormality (for reviews, see Kemp et al., 1986; Probst et al., 1991). These results are essentially consistent with P's behavioral audiogram and his ABR wave I and CAEP thresholds (< 40 dB nHL), which indicate normal or near-normal sensitivity. Considered together, TEOAE, ABR waves I and V, MLR, and CAEP results, combined with behavioral results, point to neurologic dysfunction in the brainstem structures and possibly in cortical structures, with normal or near-normal peripheral sensitivity.

RECOMMENDATIONS FOR INTERVENTION

Based on our test battery, several recommendations were made for P in the educational setting. First, since any amount of competition causes P's compromised speech processing abilities to plummet, it was recommended that an FM listening system (low gain and output, Walkman-type earphone arrangement) be used in the classroom in order to optimize the signal-to-noise ratio, even though we presume P has grossly normal peripheral hearing sensitivity (Stach et al., 1987; Edwards, 1991). No environmental microphone (EM) option was recommended for the FM unit, as the "open" earphone arrangement was felt to be sufficient for monitoring peers and his own speech. Moreover, it was recommended that the overall acoustic climate of the physical classroom arrangement be controlled as much as feasible.

It was further recommended that P's teacher ensure that visual cues (speech, gestures, pictures, etc.) be available to P as much as possible during class instruction. It was suggested that the teacher cue P verbally when material was
being directed to him, that questions be repeated and presented information queried to ensure P had comprehended. The incorporation of a specific auditory training program into P's already scheduled speech therapy sessions was suggested and was to consist of specific discrimination and recognition and comprehension tasks at the phonemic, syllabic, word, sentence, and discourse levels. The model suggested by Erber (1982) was recommended as the basis of the program. Finally, it was recommended that all therapy be conducted in an optimal listening environment.

In sum, we recommended that P be provided with an intervention approach commonly used with hearing-impaired children: (1) the use of FM amplification; (2) control of the acoustic environment; (3) teaching technique modifications; and (4) specific auditory training. These recommendations were conveyed to P's educational setting by both written report and personal visit to the school by the audiologist. A meeting with P's teacher, the speech-language pathologist, the director of special education, and P's parents was arranged. While agreeing with the other recommendations, the school was reluctant to carry out our recommendation for the FM system. His teacher did not feel that P required the device in the classroom and felt it would "single him out" in the setting. While an appeal was made for at least a trial with the device, the recommendation remains unaddressed.

**CONCLUSION**

We have reported previously that children with higher-order auditory disorders may present dilemmas in diagnosis that require the clinician to look "beyond the audiogram" in their assessments (Gravel et al, 1989; Stapells and Kurtzberg, 1991; Gravel and Wallace, 1992; Abdo et al, 1993). Other groups have also presented cases with similarly interesting and difficult diagnostic dilemmas (e.g., Starr et al, 1991; Berlin et al, 1993). In P's case, behavioral pure-tone thresholds were normal, whereas standard speech measures suggested a mild hearing loss. TEOAE measures indicated near-normal cochlear function bilaterally, while
the ABR and CAEP results suggested neurologic dysfunction with CAEP threshold (<40 dB nHL), much better than indicated by the ABR wave V threshold (>80 dB nHL). Finally, more-complex behavioral speech measures demonstrated that P’s speech-processing disorder was exacerbated in background competition levels typically encountered in educational settings. While P’s “diagnosis” remains incomplete, the in-depth behavioral, electrophysiologic, and otoacoustic emissions tests completed have proven to be valuable in our understanding of the nature of P’s auditory disability and in the planning of intervention. We intend to follow up with further studies to examine the left–right performance asymmetries suggested by the PSI performance function as well as the physiologic (TEOAE and CAEP) findings. Our question is whether under dichotic conditions, one ear’s input (the left’s) might hinder P’s processing of complex speech.

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Auditory Processing Dysfunction/Gravel and Stapells


