Auditory Processing Disorders: Putting the “Neural” Back into Sensorineural Hearing Loss

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Introduction

It is always difficult to describe what we mean when we discuss auditory processing disorders. There are many different interpretations of what such a disorder looks like, what tests should be used to diagnose it, where the difficulties lie anatomically or physiologically, and how it should be treated to minimize the potential negative impact on the individual. There is no gold standard against which to test if an auditory processing disorder exists and little agreement on the relationship between auditory processing and language, learning, or attentional abilities. These issues and problems have made the evaluation of auditory processing skills highly individualized across clinics, a detriment to the homogeneity of practice to which we as a profession aspire.

In 2005 the American Speech, Hearing, and Language Association published a task force report on auditory processing (American Speech-Language-Hearing Association 2005). In that report it was suggested that “…(Central) Auditory Processing refers to the efficiency and effectiveness by which the Central Nervous System utilizes auditory information” (p. 2). The task force report further states that, “narrowly defined, (Central) Auditory Processing refers to the perceptual processing of auditory information in the CNS and the neurobiological activity that underlies that processing…” (p. 2). This implies that one should be studying not only the impact of such a disorder as would be evidenced in the processing of degraded or competing speech, but also that as clinicians we should study auditory perceptual abilities and electrophysiological markers of auditory system integrity. In their recommendations for the evaluation of auditory processing and disorders thereof, Jerger and Musiek (2000) recommend, among many behavioral tests, objective assessment, including such measures as auditory brainstem responses, middle and late auditory evoked potentials, and acoustic reflexes. Yet the use of these objective measures has been questioned (Katz et al. 2002) largely due to a lack of data supporting the presence of abnormal responses in individuals with auditory processing disorders and the lack of data showing a possible relationship between behavioral and objective measures. In clinical practice the use of electrophysiologic tests falls behind that of behavioral tests (Emanuel 2002).

We have undertaken a fairly large-scale study of auditory processing and related abilities in young children. Our approach includes an evaluation of auditory system integrity and an assessment of a wide range of behaviors. Only through evaluating both auditory and related behaviors and neural integrity will we better understand the relationship between the two. Here we present some of that physiologic data and a few case studies illustrating potential impacts on behavioral function.

Sixty-four children with suspected auditory learning disabilities were included in this study. Forty were male, 24 were female. Ages ranged from 7 to 17 years with a mean age of 9.97 years. Referrals came from local pediatricians, audiologist, teachers, principles, and parents. Each child was suspected of having difficulty learning through auditory modality and/or showed signs of problems with auditory attention. All children except one...
showed normal pure tone threshold bilaterally. One child had a mild hearing loss bilaterally at 8 kHz. Word discrimination scores in quiet were above 80% for all children.

**Acoustic reflexes**

The acoustic reflex can be useful for evaluating the status of the auditory system from the middle ear through to the brainstem and back to the cochlea on both sides. The reflex occurs in response to sounds usually between 80 to 100 dB HL and, while stimulation may be unilateral, the muscle reflex will be bilateral. Its presence depends upon an intact auditory nerve on the side receiving the stimulation, normal lower brainstem pathways, and an intact facial nerve on the side where the reflex is being measured via impedance changes in the middle ear. Elevated or absent reflexes can result from significant hearing loss in the stimulated ear due either to conductive or sensorineural problems, to disruption of low brainstem pathways, to impairment of the facial nerve and to conductive problems inhibiting measurement of middle ear reflexes on the side of the conductively impaired ear. Patterns of ipsilateral and contralateral reflex abnormalities have been a long standing tool in the audiologist's assessment battery assisting with the evaluation of both intra- and extra-axial brainstem lesions (Jerger and Jerger, 1975) as well as helping to evaluate sensory and auditory nerve function (e.g., Gelfand 2002). Reflexes may therefore provide useful information on possible neural dysfunction in children with suspected auditory processing disorders.

In our study acoustic reflexes were measured bilaterally for pure-tone stimuli at 500, 1000, and 2000 Hz, both ipsilaterally and contralaterally to the stimulated ear using a Grason-Stadler GSI 33 TympStar middle ear analyzer. A total of 12 reflex thresholds were estimated (three frequencies x ipsilateral and contralateral recording x right and left ears). Maximum intensity presented for measurement purposes did not exceed 110 dB HL. If no response was obtained at 110 dB HL, the threshold was noted to be absent.

**Results and Discussion**

Figure 1 shows the distribution of reflex thresholds with both ipsilateral and contralateral stimulation. In an individual with normal hearing sensitivity, reflex thresholds should be present at levels of 85 to 100 dB HL (e.g., Gelfand, 2002). The mean ipsilateral reflex falls near 91 dB while the mean contralateral reflex falls around 99 dB, excluding the absent responses. The pattern of ipsilateral and contralateral abnormalities is most striking when the individual data are examined. Figure 2 shows average reflex threshold obtained with measurement ipsilateral to the ear of stimulation plotted against that obtained with measurement contralateral to the ear of stimulation. Thresholds that were absent were coded as 125 dB. Because what is shown are average thresholds, an individual may have some normal and some abnormal thresholds resulting in an average that is within normal limits. Still, note the large number of children who showed significantly elevated threshold averages with contralateral stimulation in the presence of normal reflex thresholds with ipsilateral stimulation and recording.

![Figure 1. Distribution of reflex thresholds for both ipsilateral (hatched bars) and contralateral (solid bars) elicited responses.](image1)

![Figure 2. Average ipsilateral reflex threshold for 500, 1000 and 2000 Hz plotted against the same three frequency average for reflexes elicited with contralateral stimulation. Triangles and circles represent data for left and right ear stimulation, respectively. Each symbol represents data from one child.](image2)
Twenty-eight of the 63 children showed normal reflexes at all frequencies for both ipsi- and contralateral stimulation and measurement. In 16 of the 63 children tested both ipsilateral and contralateral reflexes were abnormal. This suggests problems in the auditory periphery, either with the auditory nerve or the very low brainstem pathways. In 17 of the 63 children only contralateral reflexes were absent or elevated in the presence of normal ipsilateral reflexes. This pattern of results leads to the suspicion of efferent system disorders. Interestingly, only two children showed only ipsilateral reflex abnormalities and both were only at one frequency.

A Note on Middle Ear Status

One of the concerns in evaluating acoustic reflex thresholds is the condition of the middle ear and thus, the ability to accurately measure an acoustic reflex threshold. In 19 of the 35 children showing reflex abnormalities all middle ear measures were normal. Ten children had slight negative middle ear pressure, five bilaterally and five unilaterally. Compliance abnormalities were uncommon, occurring in only six children, two bilaterally and four unilaterally. Abnormal tympanometric gradients or middle ear volumes were non-existent. It is unlikely that these measures could be responsible for the high number of reflex abnormalities observed. Also, abnormal middle ear conditions would have an effect on the ability to measure both ipsilateral and contralateral reflexes when the probe was in the affected ear. Patterns of abnormalities in crossed reflexes in the presence of normal ipsilateral reflexes would be inconsistent with an explanation based upon measurement difficulties in the probe ear. Still, the role of chronic otitis in the maturation of the lower auditory system and auditory processing disorders is unclear.

Auditory Brainstem Responses

The ABR has proven its usefulness in audiometric assessment for a long time, non-invasively assessing afferent auditory activity from the eighth nerve to the upper brainstem. Clear responses with characteristic peaks at well-defined latencies post stimulus onset are dependent upon synchronous neural activity. When this is not the case, either because of mass occupying lesions, demyelinating diseases, or significant cochlear hearing impairment, responses will be delayed, have poor morphology, and/or be difficult to replicate. As such, the ABR provides another very useful, non-invasive tool for assessing the integrity of the auditory nervous system in children with suspected auditory processing disorders. Data evaluating ABR results in children with auditory processing and/or learning difficulties are limited. However, some studies have suggested delayed latencies, particularly in the later components, poor morphology and/or rate dependent abnormalities (e.g., Gopal and Kowalski 1999; Jirsa 2001; Purdy, Kelly and Davies 2002).

Auditory brainstem responses were measured in our laboratory using a Nicolet Biomedical Spirit 2000 Evoked Potentials machine. Gold EEG cup electrodes were placed at Cz and Fz positions and referenced to the left and right mastoids (denoted by A1 and A2). Fpz placement was used as the ground. The impedance of recording electrodes were monitored and maintained below 5 kHz. Click stimuli (of 100 microsecond duration) at a level of 80 dB nHL at various slow rates (11.1, 21.1, 27.7, or 31.1) and fast rates (57.7) were presented to each ear via an ER3A insert earphone. Click responses to 1500 repetitions were averaged for each waveform and a minimum of two replications were made. If the ABR response was poor, the rate of the presentation was reduced in an attempt to improve the recording. ABR waveforms were evaluated for latency of waves I, III and V and for V/I amplitude ratio.

Results and Discussion

Abnormalities in the ABR were much more prevalent than we had suspected a priori. These abnormalities took the form of delayed latencies, sometimes greatly exacerbated by increases in stimulus rate. Figures 3 and 4 show wave I and wave V latency, respectively, as measured with the faster stimulation rate (y-axis) plotted as a function of that measured with the slower stimulation rate (x-axis). Individual data for right and left ears are shown by squares and diamonds, respectively. Diagonal lines show the range of values expected if there is no significant change with increasing stimulus rate. For wave I, latency tends to remain fairly constant with changes in stimulation rate falling within a narrow range. In contrast, the variability in wave V latencies is much greater with many

1 Various rates of presentation were used to enhance replicability of ABR and/or to improve morphology of responses if at the standard rate (27.7) the response was questionable.
more children showing wave V latencies of 6.0 ms or later even at the slower stimulus rate. This is more than 2 standard deviations beyond expectations for normal hearing individuals (Schwartz, Pratt and Schwartz 1989). Note also the very large number of children, who, regardless of wave V latency at the slow rate, show increases in wave V latency of greater than 0.4 ms. Increases in latency of this magnitude, especially given that the fast repetition rate was only 57.7 clicks/seconds are highly abnormal and suggest a great deal of vulnerability in the synchrony of the lower auditory system.

There were also many waveforms that appeared to have a very abnormal morphology. Morphological differences are harder to quantify, but seem to be easily recognized by an experienced clinician. They usually consisted of poor replicability, missing waves, and reduced wave amplitudes. Abnormalities in morphology were observed in nearly half of the children examined in this group. Abnormal auditory brainstem responses may suggest a variety of problems arising from poor synchrony and integrity of the peripheral auditory system (Hall 1992). Generally, delays in wave V with normal responses to earlier components and/or rate dependent abnormalities are often associated with synchrony problems and are suspected to be associated with temporal processing deficits.

The trends in these data are useful in redirecting our attention from more “central” causes of problems to more peripheral ones, whether they arise in the synapse between sensory cells and the auditory nerve, in the auditory nerve itself, or in the lower brainstem pathways. By beginning with a strong foundation in electrophysiological test results we may be able to decrease the age of identification for auditory disorders well below the current age which appears to be several years into elementary school when the child has already shown significant evidence of academic failure and possibly suffered from the social and emotional consequences of that failure. While these results are preliminary, they suggest that examining the integrity of the lower brainstem pathways in children with auditory processing difficulties is warranted.

**Case Studies**

To illustrate ways in which these objective data may be useful for interpreting behavioral test performance we present three case summaries. Our overall test battery included, in addition to objective measures, basic and central auditory tests, and tests of cognitive, communication, and academic abilities. Collect-
ing all such measures in an individual child allows us to examine relationships between auditory and non-auditory abilities and to predict what may be contributing, physiologically, to some of these problems. Basic audiometry included pure tone thresholds at octave intervals from 250 to 8000 Hz and word discrimination in quiet using recorded materials. Traditional behavioral measures of central auditory processing used in our battery included the Staggered Spondaic Word Test (SSW; Katz 1998), the Auditory Fusion Test-Revised (AFT-R; McCroskey and Keith 1996), Words in Ipsilateral Competition (WIC; Ivey 1969), the Pitch Pattern Sequence Test (PPS; Pinheiro 1977) and Filtered Speech (FS; Willeford 1976). Tests of tests of language included the Oral and Written Language Scales for Children (OWLS; Carrow-Woolfolk 1995) and the Peabody Picture Vocabulary Test–III (PPVT; Dunn and Dunn 1997). To test phonologic abilities we used the Comprehensive Test of Phonologic Processing (CTOPP; Wagner, Torgeson and Rashotte 1999). Intelligence was tested using the Wechsler Abbreviated Scales of Intelligence (WASI; Wechsler 1999). Memory was evaluated with the Wide Range Assessment of Memory and Learning (WRAML; Sheslow and Adams 1990). Attention was evaluated with the Conners’ Rating Scales-Revised (Conners 2000), providing a description of attention related behaviors, and the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson and Nimmo-Smith 1999), which measures performance on tasks tapping selective and sustained auditory and visual attention skills in simple tasks and those that are more complex and therefore increase demands on the allocation of attentional resources. Academic achievement in spelling, reading, and arithmetic was evaluated with the Wide Range Achievement Test (WRAT; Wilkinson 1993). Test result summaries for the three case studies presented here are shown in figures 5 through 13.

Case 1 – CAFF

CAFF is an 8-year old male in grade 3. He was referred to our project from his school where there were concerns about his academic progress. At the time he was receiving support for both reading and math and had been removed from an intensive second language program. His mother reported him to be confused in noisy places, awkward and clumsy, and frequently daydreaming. His father was diagnosed with a learning disability in university and has had difficulty with reading and math. The child is healthy. His data are shown by the diamond symbols in the figures.

**Intelligence and Academic Achievement**

This is a bright child. WASI scores are shown in figure 5. Full IQ was 124, placing him at the 95th percentile for his age. This score was consistent with the PPVT standard score of 117, which suggested a very good verbal vocabulary and placed him in the 87th percentile for his age. Academically he was achieving below the expectations these scores would predict. WRAT standard scores for Spelling, Reading, and Arithmetic, although good, were below expectations at 80, 99, and 93 respectively. The spelling score was particularly low. This discrepancy between IQ and academic achievement would be consistent with a learning disability.

![Figure 5](image-url)

**Figure 5.** Intelligence (WASI), Verbal language (PPVT), Achievement (WRAT), Language (OWLS) and Phonology (CTOPP) standard scores for the three children whose case studies are presented in this paper. Data for CAFF, CAFH, and CACN are shown by the diamonds, squares, and triangles, respectively. Scores at 100 suggest age-appropriate performance. Scores below 85 are significantly reduced.

**Language and Phonology**

Language standard scores derived from the OWLS, also shown in figure 5, were age appropriate at 96, 113 and 104 for listening comprehension, oral expression and written expression respectively. Phonological awareness was quite good, with a standard score of 103.
but performance on phonologic memory (standard score of 82) was low. The phonologic problem may be expected to impact on his ability to internally store and manipulate the sounds of speech potentially impeding his ability to decode new words. Rapid naming was within normal limits (94). Of the three cases presented in this paper, this child showed the best language performance and, with the exception of phonologic memory, he did well on phonologic measures.

Figure 6. Conners for the three children. Scores in the range of 45-55 are average, 56-60 are borderline. Scores of 60-65 are mild and possibly significant. Scores above 65 are significant.

### Attention and Memory

Figure 6 shows scores on the Conners’ rating scales. Scores above 60 are considered mild and possibly significant. Scores above 65 are considered significant. This child was described as having significant attention problems. Scales for cognitive/inattention (associated with inattentiveness, academic difficulties, concentration troubles and poor organization), the ADHD index and the DSM-IV indicators fell within the significant range. The ADHD index is best at identifying kids at risk for a diagnosis of ADHD, especially if scores are high on the DSM indicator scales, which in this case were.

When attention was evaluated using a performance measure, the TEA-Ch, as shown in figure 7, there was less evidence of significant problems. On this test a score of 10 places the child at the 50th percentile. Scores below seven place the child below the 20th percentile. For this child performance was within age expectations with the exception of two subtests that tested divided attention (Test 4) and auditory sustained attention in a very boring task (Test 9). On these tasks performance was slightly low. There was a slight drop in performance on atten-

![Figure 6](image6.png)

![Figure 7](image7.png)

![Figure 8](image8.png)
Auditory Processing Disorders: Putting the "Neural" Back into Sensorineural Hearing Loss

To summarize, this child had high potential but low achievement suggesting a learning disability. He had good speech and language skills with the exception of phonologic memory and only very subtle attention and memory deficits.

Audiometric Results

Pure tone testing showed no threshold in either ear from 250 to 8000 Hz that exceeded 5 dB HL. Word discrimination in quiet was 100% in the right ear but slightly reduced at 88% in the left. Immittance results showed Type A tympanograms bilaterally and all measures, shown in Table 1, were normal.

Acoustic Reflexes

Reflex thresholds are shown in Table 2. Elevated reflexes are shown in italics.

All left contralateral reflexes were elevated as was the 2000 Hz right contralateral. With the exception of the 2000 Hz left ipsilateral which was slightly elevated, all other ipsilateral reflexes were measured at normal levels.

Auditory Brainstem Responses

Figure 9 shows ABRs elicited with a slow rate of stimulation (21.7/sec). Wave latencies, shown in Table 3, were normal for wave I but delayed for waves III and V. Changes with increasing repetition rate were mild in the left ear, although not clinically significant with a change of 0.24 ms. Replicability and morphology of the waveforms was very good at the slower rate although the V/I amplitude ratios were low at .88 and .69 for left and right ears, respectively. With increasing stimulus rate the morphology of all waves deteriorated.

Central Auditory Tests

Given the questionable neural integrity evidenced by both elevated acoustic reflex thresholds and de-
layed latencies on the ABR, and the reduced phonologic memory scores on the CTOPP, it was not surprising to see several significant results for standard central auditory tests. Data are shown in figures 10 and 11. Performance was greater than 2 standard deviations below expectations for the SSW in the competing conditions, the PPS bilaterally, and the Auditory Fusion test, especially at the lower frequencies. Words in ipsilateral competition and filtered speech results were age appropriate or only 1 standard deviation below expectations.

Summary

This is a bright, healthy child who presents with difficulties learning. Measures of auditory neural integrity (acoustic reflexes and the auditory brainstem response) suggest what may be mild abnormalities in the lower auditory pathways. The potential effects of this are shown in his reported difficulty in noise, the scattered reduced auditory processing test results and possibly in the poor phonologic memory. Many of this child’s behaviors suggest attentional problems, yet performance on tests of attention shows only minor difficulties. It is possible that the auditory difficulties may be reflected in the described behaviors that are deemed to be attentional. The achievement-intelligence discrepancy would flag this child as learning disabled, yet the root of this disability may very well lie in, or at least be exacerbated by, the poor auditory system integrity.

Case 2 – CAFH

CAFH is a 10-year old male in grade four. He was referred to us from a local audiologist who had seen him recently and the year previously. Both times the child was screened for central auditory processing difficulties using the SCAN (Keith 2000). Performance was worse the second time. The child was receiving special help at school including an Individualized Education Program, a tutor twice a week, and had received speech pathology services for four years for treatment of a moderate-to-severe receptive language delay. The child suffered from breathing difficulties at birth, allergies and occasional dizzy spells that were thought to arise from middle ear problems. His mother reported
him to have difficulty hearing even in typical one-on-one conversations and to be confused in noisy places. She reported speech problems, difficulty learning and remembering, and problems with coordination as the primary concerns. This child was also reported to be introverted and not good in groups or with strangers. His performance on the test measures is shown by the solid squares in the figures.

**Intelligence and Academic Achievement**

On the WASI, figure 5, this child showed a large split between verbal and performance IQ with standard scores of 77 and 106, respectively. The verbal score fell more than 1 standard deviation below age expectations while performance was age appropriate. Academic achievement also showed substantial discrepancies both with intelligence scores and among the three subtests. While the word reading scores was good (94), spelling (82) and arithmetic (79) performance was more than one standard deviation below age expectations. These results are consistent with a learning disability.

**Language and Phonology**

Scores on the PPVT were low (77) placing him at the 6th percentile for his age group, but consistent with the WASI verbal IQ score. Language scores were quite low. Standard scores for listening comprehension (64) and oral expression (58) placed him more than 2 standard deviations below age expectation. Written expression (87) was also low but much better, suggesting he was able to use conventions, syntactical forms and communicate meaningfully in written form. Scores were below expectations for phonologic memory (73) and borderline for awareness (85) subtests, the latter of which had been a focus of speech therapy for the last two years according to reports. Rapid naming was very good (124). These results suggest significant language and phonologic difficulties affecting most areas.

**Attention and Memory**

This child showed no indications of attentional problems as described on the Conners’ and shown in figure 6, with scores on all scales falling within the normal range. This child performed according to age expectations on seven of the nine subtests when evaluated using the TEA-Ch, shown in figure 7. On two “dual-task” subtests he performed below age expectations. One of these tasks (Test 4) required simultaneous auditory and visual attention (for which he scored > 2 standard deviations below expectations) and the other (Test 6) assesses sustained attention while performing a second task, therefore assessing the ability to allocate attentional resources. On composite tests of attentional control-switching, selective, and sustained attention, he scored 11.25, 12.0, 8.4, respectively placing him very high. Memory scores on the WRAML, shown in figure 8, were quite good for visual tasks but below age expectations for verbal tasks including the number/letter memory and story memory. Overall, the suggestion is of some very mild attentional difficulties when dual processing is required and, consistent with his language problems, some difficulties with verbal memory tasks.

**Audiometric Results**

Pure tone testing showed thresholds within the normal range at all frequencies from 250 to 8000 Hz bilaterally. Word discrimination in quiet was 100% bilaterally. Immittance results, shown in Table 1, showed Type C tympanograms bilaterally. Middle ear volumes were normal, but static compliance was somewhat low suggesting some reduced middle ear mobility, consistent with the child’s history.

**Acoustic Reflexes**

Reflex thresholds are shown in the middle rows of table 2. Elevated reflexes are shown in italics. The greatest number of abnormalities were found in the contralateral reflexes. One may assume the large negative pressure (table 1) simply made it difficult to measure the reflexes, but the presence of more normal ipsilateral reflexes suggests this may not be the case. Patterns of absent contralateral reflexes suggest problems in the crossed auditory pathways.

**Auditory Brainstem Responses**

Figure 12 shows ABRs elicited with a slow rate of stimulation (21.7sec). Wave latencies are shown in table 3. Waveform morphology showed good replicability but low amplitude of wave V relative to wave I, 0.25 and 0.29 in left and right ears, respectively. The right ear shows a delay in wave III and V producing an interwave interval between I and III that is significantly increased. The left ear shows a similar pattern in the I–III interval but a longer delay in wave V. With increases in stimulation
rate wave V latency increased 0.32 and 0.24 ms in left and right ears, respectively. The wave V delays and low amplitudes may suggest problems in the region of the SOC, consistent with the crossed reflex abnormalities.

Central Auditory Tests

This child's performance on tests of central auditory function, shown by the squares in figures 10 and 11, were mixed. Scores on the SSW were 2 standard deviations below expectations in the competing conditions. Pitch Pattern Sequence tests results were within normal limits. Performance on the Filtered speech test was within normal limits, as was Words in Ipsilateral Competition for the right ear. Left ear WIC scores were 1 standard deviation below expectations. The AFT-R showed poor performance at all frequencies. Using a criterion of performance on any one test more than 2 standard deviations below expectations, these results would suggest an auditory processing disorder.

Summary

This child presents with evidence of a possible verbal learning disability, consistent with the case history and speech therapy reports. The abnormal findings in the crossed acoustic reflexes and the delayed latencies in the later components of the ABR suggest difficulties at the level of the brainstem. Difficulty with binaural tests of central auditory function, especially in those with competition may reflect some of the problems with the crossed pathways suggested by the acoustic reflex abnormalities.

Case 3 – CACN

CACN is an 8-year, 9-month old male in grade 3. He was referred by his elementary school because he is falling behind academically, particularly in reading and math. He has academic accommodations including one-to-one teaching in the classroom and an Individualized Educational Program. He has had speech therapy for articulation problem and continues with this on an irregular basis at school. His previous hearing tests have been “inconclusive” although he has had two sets of PE tubes for treatment of middle ear problems. He has been taking Ritalin for attentional problems for 6 months. The teachers report some increased attention on his part, although the parents do not. His mother reports that his grandfather and uncles have “terrible hearing” but did not wear hearing aids. The child does not like school, has a tendency to daydream, and shows decreased motivation. He is awkward and clumsy. He reportedly gets “worked up” about doing homework, feeling he can’t do it before he even tries. Test results are shown by the solid diamonds.

Intelligence and Academic Achievement

CACN’s verbal IQ, shown in figure 5, was 90, placing him at the 25th percentile. His performance IQ was 79, placing him much lower, at the eighth percentile. Together his full IQ was 84 placing him at the 14th percentile. Academic achievement was very poor. Although in grade 3, he was reading and spelling at the grade one level with standard scores of 77 and 85, respectively. Arithmetic was much better where he was achieving at the grade 2 level with a standard score of 87. The low IQ scores and low achievement are consistent.

Language and Phonology

This child’s single word vocabulary was age appropriate with a PPVT standard score of 101, placing him at the 53rd percentile. Also within reasonable age expectations were his written expression score on the OWLS shown in figure 6. The standard score of 88 suggested his knowledge of conventions in writing was appropriate. However, both listening comprehension and oral expression were significantly reduced with standard scores of 78 and 77, respectively, placing him at the seventh and sixth percentile. This resulted in an age equivalent that was two years de-
Auditory Brainstem Responses

Figure 13 shows ABRs elicited with a slow rate of stimulation (27.7/sec). Only wave V was present in either ear and its latency was delayed by more than 2 standard deviations (table 3). With an increase from 27.7 to 57.7 clicks/second Wave V latency increased significantly in both ears. These results were highly abnormal and suggestive of eighth nerve and/or low brainstem problems, consistent with the pattern of acoustic reflex thresholds.

Central Auditory Tests

Test results shown in figures 10 and 11 were consistently abnormal, most often by at least 2 standard deviations. SSW showed high error rates in both competing and non-competing conditions and a high number of reversals. AFT-R results showed very poor performance at 250 Hz with better performance at higher frequencies. Filtered Speech perception was 1 standard deviation below expectations in the left ear, which was quite high.

Acoustic reflex thresholds are shown in table 3. No reflexes were elicited in either ear. It was difficult to explain these highly abnormal patterns based upon any of the middle ear measures or peripheral hearing sensitivity.

Summary

This is a child with many problems including a verbal-performance split on IQ testing, poor academic achievement in word reading, but somewhat better in

Attention and Memory

This child showed several significant indicators of attentional problems on the Conners' as can be seen in figure 6. Symptoms for cognitive problems/inattention, hyperactivity were both very significant with anxious/shy descriptors moderately atypical. The ADHD Index was highly significant as was the Global index for restless-impulsive and the Total Global index. On the three DSM-IV symptomology scales including inattentive, hyperactive-impulsive and the total, this child scored extremely high, suggesting significant problems. Results of the TEA-Ch, shown in figure 7, were consistent with these behavioral descriptions and showed that he had difficulty on subtests that involved sustained attention, attentional control/switching, and response inhibition on sustained attention tasks. His overall scores for attentional control switching, selective, and sustained attention were 7.75, 10.0 and 8.8 respectively, suggesting his greatest problems were in attentional control/switching. Thus, both descriptive and performance measures suggest an attentional disorder. Memory tasks, shown in figure 8, showed many deficiencies including verbal tasks for both unrelated strings and stories, for visual tasks involving rote memory and pictures. Memory for designs and verbal learning were age appropriate.

Auditory Processing Disorders: Putting the "Neural" Back into Sensorineural Hearing Loss
spelling and arithmetic, poor listening comprehension and oral expression yet acceptable written expression. Phonologic skills are also mixed with performance very poor for phonologic memory and rapid naming yet phonologic awareness was acceptable. He exhibits many behaviors characteristic of attentional problems, and this is consistent with performance on attention tasks. When we examine his auditory abilities, he shows normal hearing sensitivity but very poor auditory performance on all other measures. His absent reflexes and very poor ABR suggest synchrony problems that may begin very low in the system. He consistently scores poorly on all auditory tasks. His auditory profile may be similar to children suffering from some form of auditory neuropathy/dys-synchrony but with normal pure tone sensitivity.

Conclusions

These case studies are not atypical and suggest that auditory processing problems may often be comorbid with other learning, language, or attentional disorders. The ability to identify integrity problems in the auditory pathways and relate them back to deficits in basic auditory processing may allow us to evaluate the contribution of the auditory system to general cognitive and academic functioning. In many cases, some of which are illustrated here, the problems may begin rather peripherally in the auditory system, perhaps at the level of the auditory nerve and low brainstem.

Case 1 shows a child with very mild abnormalities in low brainstem function as evidenced by elevated acoustic reflex thresholds and somewhat delayed ABR latencies in the presence of very good looking waveforms. Central auditory tests show that when stressed, as in cases of competing messages, the system may break down. This may lead to difficulties in a variety of academic abilities. Case 2 has a somewhat more significant involvement of the auditory system. Problems with acoustic reflexes suggested difficulties in the crossed pathways of the brainstem and abnormal auditory brainstem responses suggested afferent system effects. This may lead to the reduced results on central auditory tests and the reduced scores on tests of listening comprehension and oral expression as well as phonologic processing. Case 3 is the most severely compromised case with striking abnormalities in the acoustic reflexes and auditory brainstem responses. These abnormalities appear to originate very early in the ascending pathway, possibly in the inner hair cell/VIIIIN juncture or the auditory nerve itself. This likely contributes to the very poor performance on all auditory tests and consequently on reduced speech and language performance and poor academic achievement.

These case studies and the high incidence of ABR and acoustic reflex abnormalities noted in the larger group we studied suggest that examination of objective auditory system measures of neural integrity may be a useful part of (Central) Auditory Processing Disorder assessment. Further, the data suggest that for some children the problems experienced may begin very low in the auditory system as is evidenced by a neural hearing impairment that simply leaves audibility (thresholds of detection) intact but compromises other aspects of auditory processing that require more complex signal analysis.

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References


