

Assessment and Remediation of an Auditory Processing Disorder Associated with Head Trauma

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Abstract

This case study involves a 41-year-old female who had sustained a mild traumatic brain injury during a horseback riding accident. The patient was seen for medical and neuropsychological testing following this incident and was referred to a speech-language pathologist for rehabilitative services. At 13 months posttrauma, the patient, who was frustrated by a lack of significant progress, requested an audiologic work-up. Results of testing conducted at this time revealed normal peripheral hearing and significant central auditory deficits. Based on these findings, an auditory rehabilitation program was developed and implemented. The components of this patient's rehabilitation program are reviewed, and the posttherapy improvements noted in her auditory functions are detailed. The case is important in that it demonstrates (1) that auditory deficits can be a sequel to minor head injury, (2) that these deficits are often subtle and may not be detected unless central auditory testing is conducted, and (3) that these deficits may be amenable to remediation.

Key Words: Auditory evoked potentials, auditory perceptual disorder, auditory processing disorder, central auditory processing disorder, head injury, traumatic brain injury

Abbreviations: ABR = auditory brainstem response; AME = auditory memory enhancement; DIID = dichotic interaural intensity difference; DPOAE = distortion product otoacoustic emissions; H = high; L = low; MLR = middle latency response; SL = sensation level

Sumario

Este estudio de caso involucra a una mujer de 41 años que había sufrido una lesión cerebral traumática leve en un accidente de equitación. La paciente fue evaluada desde el punto de vista médico y neuro-psicológico después del accidente y se refirió a un terapeuta del lenguaje para recibir servicios rehabilitativos. Trece meses después del trauma, la paciente, frustrada por la falta de progreso significativo, solicitó una evaluación audiológica. Los resultados de las pruebas realizadas en ese momento revelaron audición periférica normal y un déficit auditivo central significativo. Con base en estos hallazgos, se desarrolló e implementó un programa de rehabilitación auditiva. Se revisan aquí los componentes de este programa rehabilitativo, y se detalla la mejoría post-terapia en sus funciones auditivas. El caso es importante en tanto demuestra (1) que pueden existir deficiencias auditivas como secuela de una lesión craneana menor, (2) que estas deficiencias suelen ser sutiles y que podrían no ser detectadas a menos que se conduzcan pruebas auditivas centrales, y (3) que estas deficiencias pueden ser remediadas.

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Palabras Clave: Potenciales evocados auditivos, trastorno auditivo perceptual, trastorno auditivo central, trastorno de procesamiento auditivo central, lesión craneana, lesión cerebral traumática

Abreviaturas: ABR = respuesta auditiva del tallo cerebral; AME = incremento de la memoria auditiva; DID = diferencia dicótica interaural de la intensidad; DPOAE = emisiones otoacústicas por productos de distorsión; H = alto; L = bajo; MLR = respuestas de latencia media; SL = nivel de sensación

The effects of traumatic head injury on the peripheral auditory system are well documented in the literature. Compromise of middle ear structures, the cochlea, and the eighth nerve and associated hearing losses have been reported for patients with fractures of the temporal bone (Griffith, 1979). Both unilateral and bilateral losses have been documented in patients with traumatic head injuries, although unilateral hearing losses ipsilateral to the site of temporal bone fracture tend to occur more frequently than bilateral hearing losses in this population (Bergemalm and Borg, 2001). In addition, the available evidence suggests a correlation between type of fracture and the type of hearing loss with conductive hearing losses being more common in cases of longitudinal fractures and sensorineural hearing losses among patients with transverse fractures (Podoshin and Fradis, 1975; Abd Al-Hady et al, 1990). Finally, in regard to audiometric configuration, the most common pattern of hearing loss following head trauma is a high-frequency hearing loss (Bergemalm and Borg, 2001), but other audiometric patterns have been reported (Scott et al, 1999).

Although many of the early studies of hearing loss in patients with head injury focused on patients with temporal bone fractures, a number of more recent investigations have studied the auditory effects associated with closed head injuries without temporal bone fractures (Rowe and Carleson, 1980; Abd Al-Hady et al, 1990; Kochhar et al, 1990; Musiek et al, 1994). Rowe and Carleson (1980) reported postconcussive symptoms of recurrent headaches, tinnitus, dizziness, instability,

unsteadiness, inattention, and poor memory in up to 60% of patients who sustained minor head injuries without loss of consciousness. Although these symptoms are frequently noted immediately following the traumatic incident, it is not unusual for there to be a delayed onset of some of these symptoms in this particular population. For example, Kochhar et al (1990) have reported that while some patients with minor closed head injuries may experience a pronounced positional vertigo immediately following the injury, other patients may experience an intermittent balance disturbance (dizziness) that is delayed in its onset from days to weeks after injury, which resolves over a time period that may extend anywhere from six to eight months.

Although hearing loss is much more common among patients who have sustained head injuries that are severe enough to cause fractures of the temporal bone, a number of investigations have documented the presence of hearing loss in patients with minor head injuries (Podoshin and Fradis, 1975; Griffith, 1979; Abd Al-Hady et al, 1990; Kochhar et al, 1990; Bergemalm and Borg, 2001). Hearing losses, when noted for patients with minor head injuries, tend to be sensorineural in nature and mild to moderate in severity. Both unilateral and bilateral hearing losses have been reported in these studies, with reports of both recovery of hearing sensitivity and progress of hearing loss occurring over time, as well as the delayed onset of hearing loss in some patients (Bergemalm and Borg, 2001).

A number of studies of patients with closed head injuries have demonstrated auditory brainstem response (ABR) abnormalities, especially in the acute phase of a head injury (Greenberg et al, 1977;

Ozdamar et al, 1982; Hall et al, 1983; Ottaviani et al, 1986; Elwany, 1988; Abd Al-Hady et al, 1990; Jani et al, 1991; Hall, 1992; Musiek et al, 1994; Fligor et al, 2002). Common findings among these investigations were the delay and/or absence of wave V of the ABR, and/or extensions of the III-V or I-V interwave latencies, clearly implicating brainstem compromise in a number of patients with traumatic head injuries. Fewer investigations have examined the performance of patients with head injury on the later auditory evoked responses (Hall et al, 1983; Ottaviani et al, 1986; Hall, 1992) or on behavioral tests of central auditory function (Hall et al, 1983; Abd Al-Hady et al, 1990; Musiek et al, 1994). Results of these investigations have revealed poorly formed or absent middle latency response (MLR) components (Na, Pa), as well as abnormal test performance on monaural low redundancy and dichotic speech tests. These findings would clearly implicate compromise of the central auditory nervous system in at least a subgroup of the patients who sustain closed head injuries. Transient or permanent brainstem and cortical auditory dysfunction seems to be a common consequence of head injury and may occur without cranial fractures (Makishima and Snow, 1975; Greenberg et al, 1977; Abd Al-Hady et al, 1990; Musiek et al, 1994).

Hall et al (1983) found distinct relationship among initial evoked response findings, rate of recovery, and long-term neurological and audiological outcomes in three patients with severe head injury. These authors, as well as others (Ottaviani et al, 1986; Abd Al-Hady et al, 1990), have suggested that auditory evoked responses could be used to estimate rate of recovery and long-term prognosis for recovery, as there was an apparent correlation between electrophysiological auditory results and later behavioral assessment.

In cases of closed head injury, the underlying neuropathology is likely to be related to deformation and acceleration/deceleration of the head, which results in a variety of primary injuries (contusions, concussions, hemorrhage, diffuse axonal injury) and secondary damage (ischemia, hypoxia, edema, increased intracranial pressure and delayed axonal degeneration) (Pearl, 1998). In some cases, these injuries can be readily detected with today's sophisticated

brain imaging techniques, but in many cases the neural compromise eludes detection with current imaging and medical assessment procedures. If these injuries primarily affect the neural substrate that support hearing, then the auditory deficits that are observed are not likely to include significant impairments of threshold sensitivity but, rather, more subtle auditory processing deficits that can be uncovered only through the utilization of electrophysiologic and behavioral tests of central auditory function.

In addition to the auditory deficits discussed above, disorders of attention are common among patients who sustain head injuries, regardless of the severity of the trauma. Biomechanical forces associated with traumatic brain injuries often affect the frontal as well as the temporal lobes within the brain. These forces may cause stretching and shearing of deep white matter tracts, which in turn leads to diffuse axonal injury (Kaipio et al, 2000). Patients with closed head injuries frequently describe situations where their ability to attend to relevant information becomes compromised as a consequence of external distraction, and these patients frequently experience the need to expend extra effort in order to maintain attention and focus in the presence of concurrent stimuli originating from different sources. An increase in the number of errors, the general slowing of performance on cognitive tasks, and fatigue are the most frequent consequences of not being able to inhibit distracting stimuli, which are typically attributed to impaired frontal lobe functioning (Kaipio et al, 2000).

Kaipio et al (2000) demonstrated electrophysiologic evidence of increased shifting of attention and distractibility in patients with closed injury without documented central nervous system compromise and argued that the results are likely related to diffuse axonal injury in the frontal lobes of the patients tested. These investigators have shown that brain imaging techniques often fail to uncover neurologic abnormalities in this population of patients, even in the presence of neurobiological symptoms. Based on these findings, the argument can be made for the need for neuropsychological assessment of patients with minor head injuries even in the absence of negative findings on brain imaging procedures.

Although it is likely that the attention effects may be rooted in a central nervous system compromise involving the frontal lobe, the possibility exists that the attention deficits noted in patients with closed head injury may in fact be secondary to a primary compromise of the neural substrate subserving the auditory system. Given the nature of closed head injuries, the diffuse axonal compromise is not likely to be limited to frontal lobe sites but is equally as likely to affect the auditory areas of the cortex (e.g., the temporal and parietal areas) and the subcortex. If the auditory areas are affected, inefficient processing of auditory stimuli may result. This in turn may affect the patient's ability to attend to relevant auditory stimuli (Chermak and Musiek, 1997).

The case that follows is an interesting case in that it will highlight a number of important clinical characteristics and features associated with minor head injury. These include the following: (1) that a loss of hearing sensitivity is not a consistent audiologic finding in patients with minor head injury; (2) that the auditory deficits that are observed are likely due to biomechanical forces that result in both primary and secondary damage to the neural structures within the central auditory nervous system, and are more likely to involve higher-order auditory processing skills; (3) that comorbid cognitive and vestibular deficits are likely to occur with the auditory processing deficits; (4) that the auditory, vestibular, and cognitive deficits may occur in the absence of any radiological evidence of CANS compromise; (5) that the auditory, cognitive, and vestibular symptoms may not be apparent immediately posttrauma but may show a delayed onset; (6) that symptoms of increased distractibility, inability to sustain attention, and fatigue that are often attributed to cognitive deficits may be potentially related to a primary auditory deficit; (7) that the auditory deficits are not likely to be uncovered if initial assessment of the patients is limited to routine neurological, radiologic, and neuropsychological testing; and (8) that auditory intervention can be used to remediate and/or facilitate recovery of impaired auditory function in patients with significant auditory processing deficits.

CASE REPORT

History

The patient was a 41-year-old female who was seen for an audiological evaluation approximately 13 months after she was thrown from a horse. The patient, a highly intelligent, well-educated, and articulate professional, landed on the top of her head when she was flung from her horse. At the time of the incident she was wearing a helmet, and she lost consciousness only briefly; however, she did become nauseated and vomited immediately following the incident. Additional posttrauma symptoms included disequilibrium, disorientation, and tinnitus that appeared to be more localized in her head than in her ears. She was able to walk and move about without major difficulty, and there were no signs of amnesia immediately following the fall. Given these findings, it was determined that hospital admission was not needed at that time.

A neurologic exam performed a few days after the accident was essentially within the normal range. Based on these findings and the initial posttrauma symptoms, it was the opinion of the attending physician that the patient had sustained a minor concussion in connection with her fall.

Within a few days of the accident, the patient began sleeping excessively—as much as 19 hours per day. Dizziness developed and disorientation became more of a problem. The patient became easily fatigued and was having difficulty understanding what people were saying to her. Cognitive problems became increasingly evident as the individual began to experience some mild, but definite, problems in recalling information. At this point in time, the patient was informed by her physician that her postconcussive symptoms would likely resolve over time; however, this did not turn out to be the case.

Over the next year the patient's presenting symptoms either did not improve or improved only slightly, and other symptoms became evident. She was limited by considerable fatigue, generally more as a result of mental rather than physical activity. Listening became a demanding and tiring ordeal. She had trouble attending for long periods of time, and she often needed extended time to "process" information,

particularly when the information she was trying to process was presented auditorily. She also found it difficult to focus attention on more than one task at the same time, especially if the tasks involved auditory information. Additional problems that became apparent during this period of time included difficulties with reading comprehension, mathematical computations, memory, planning, and organizational issues.

The patient continued to experience frequent headaches and dizziness over the first few months following her accident, but these symptoms did improve substantially over the next several months. The tinnitus, which was noted immediately following the accident, resolved after several months and was no longer a problem for this patient at the time she was seen for audiologic testing. However, a number of significant auditory symptoms persisted at one year posttrauma. These included extreme difficulty with the comprehension of complex auditory directives, problems in understanding the speech of people who spoke rapidly, difficulty hearing in the presence of background noise, and problems listening when competing auditory messages were present. In addition, the patient noted that the hearing in her left ear was worse than that in her right ear and that in spite of the fact that her auditory symptoms had improved somewhat over the year, they continued to have a significant negative impact on her life. In fact, the patient would often become somewhat emotional when discussing and/or reflecting on her symptoms.

Communication and Neuropsychological Evaluation

The patient was referred for both neuropsychological and communication evaluations following the onset of the symptoms described above in order to assess the status of her linguistic and cognitive functioning and to provide her with rehabilitative techniques and strategies to help her address any deficits that were identified.

A complete neuropsychological evaluation was administered to the patient seven months following her traumatic brain injury. General areas of difficulty noted during cognitive testing included complex auditory comprehension, processing speed, and mental

endurance, as well as some aspects of new learning. Most notable among the assessment findings was the patient's weaker performance on auditory tasks in comparison to other areas of brain behavior and function. Specifically, the patient struggled with complex auditory information such as following multiple-step instructions and complex continuous speech. Although test results suggested that she was performing within normal limits, the neuropsychologist suggested that the level of performance that the patient was demonstrating at the time of the evaluation was perhaps depressed relative to her pre-trauma levels. It was recommended that the patient be referred to a speech-language pathologist for cognitive therapy to address these apparent relative weaknesses.

The speech and language evaluation included a number of subtests from the Reading Comprehension Battery for Aphasia: Second Edition (LaPointe and Horner, 1998). Overall, the patient presented with difficulty understanding auditory information and reduced processing speed. In addition, reading analysis was considered impaired, and attention and concentration were reported to be significantly impacted. It was noted that with respect to her auditory processing abilities, the patient benefited from reduced speech rates and sentence length, as well as the frequent repetition of information.

The patient was enrolled in speech and language therapy. Although some improvements in her symptoms occurred, the patient was not satisfied with the progress she had made. Approximately one year after her head injury she reviewed her symptoms carefully, and although she had been told that most of her problems were cognitive in nature, she began to entertain the possibility that many of her difficulties may be auditory in nature. Given this conclusion, she sought audiological consultation.

Audiological Test Procedures

The patient's hearing was assessed on two occasions. An initial assessment was conducted at 13 months following her accident. She was then seen for an audiological reevaluation some seven months later following the implementation of an auditory rehabilitation program. All audiological testing was carried out in a

sound-treated booth and included both peripheral and central auditory tests.

Pure-Tone and Speech Audiometry

Pure-tone threshold and speech recognition tests were conducted in the conventional manner. The Northwestern University Test No. 6 (NU-6) was used to assess the patient's speech recognition abilities.

Distortion Product Otoacoustic Emissions

Distortion product otoacoustic emissions (DPOAEs) were derived for both ears using the GSI-60 DPOAE Analyzer at test frequencies ranging from 1000 through 5000 Hz. The intensity levels for the two primary tones were 65 and 55 dB SPL (L1, L2), and three distortion products per octave were obtained with a standard f1:f2 ratio of 1.22. Measurements derived during the assessment procedure included the absolute intensity level (in dB SPL) of each distortion product, the amplitude of the noise floor (in dB SPL) at each distortion product frequency, and the signal-to-noise ratio for each distortion product measured.

Middle Latency Response

Middle latency responses (MLRs) were obtained for each ear using 100 μ sec condensation clicks presented through ER-3A sound insert phones at 70 dB nHL at a rate of 9.8 clicks per second. Electrodes were positioned on the scalp at C3, C4, and Cz with the reference electrode being placed on the earlobe of the ear receiving the acoustic stimulus. Electrode impedances were maintained at less than 5 kohms across the electrode array, and filtering for the MLR was from 20 to 1500 Hz with a 6 dB per octave roll-off. There were a total of 800 accepted trials for each run, and each waveform was replicated. The time period for analysis was 70 msec. Amplitudes and latencies of the Na-Pa responses were measured and then averaged across the original and replicated tracings for each waveform derived for each ear at each electrode site. The MLR procedure outlined above also allows the simultaneous recording

of the auditory brainstem response (ABR) (see Musiek et al, 1999).

Dichotic Digits

The dichotic digits test involves the presentation of digit pairs to the right ear at the same time that different pairs of digits are being presented to the left ear. Stimuli for this test include the numbers from 1 to 10, excluding 7, which are presented to the two ears simultaneously in pairs at 50 dB HL. During each test trial the patient receives two digits in each ear and is asked to repeat all the numbers that are heard. There are a total of 40 digits presented to each ear. The patient is provided as much time as needed to respond to each test item, and a percentage correct identification score for each ear is obtained (for more details on this test, see Musiek, 1983).

Frequency and Duration Patterns

These two tests (frequency and duration patterns) are similar in their acoustic composition and test administration procedures. The frequency patterns test is composed of test sequences containing both high (1122 Hz) and low frequency (880 Hz) tone bursts. In each sequence, there are three tone bursts, and the patterns are constructed so that one tone in each sequence is of a different frequency than the other two tones. This allows the generation of six different patterns (HHL, LLH, HLH, LHL, LHH, and HLL). Each tone within the test sequences has a 200 msec duration including a 10 msec rise-fall time, and the interval between tones within a test sequence is 150 msec. The interstimulus interval between successive test sequences is 7 sec.

The duration patterns test is composed of sequences of three tone bursts that vary in terms of their durational features. The frequency of the three tone bursts in each of the test sequences is held constant at 1000 Hz, but two different stimulus durations are used. The tones are either 250 msec (short) or 500 msec (long) in duration, and one of the tones in each sequence is different from the other two, which are of equal duration. Like the frequency patterns test, these requirements for stimulus characteristics result in the generation of six unique sequences. Each individual tone has a 10

msec rise-fall time, and there is a 300 msec interval between successive tones within each sequence. An interstimulus interval of 5 sec is provided between test sequences.

For both tests, a total of 45 test items were presented at 50 dB HL to the patient in the soundfield following the presentation of a number of practice items. The patient was asked to verbally report the patterns heard in each case, and a percentage correct score for each test was derived (for additional information see Musiek, 1994).

Time Compressed Speech

The NU-6 monosyllabic words with 45% compression were presented to the patient. A total of 50 words were presented to each ear at 50 dB HL, and a percentage correct identification score was derived for each ear (see Wilson et al, 1994 for details).

Competing Sentences

The competing sentences test (Willeford, 1977) is composed of a series of sentences. Each sentence contains a total of seven words. The sentences are presented in a dichotic format (one sentence to each ear simultaneously), and the patient is directed to listen to one ear and repeat the sentence heard in that ear (target ear) while ignoring the information presented to the other ear (competing ear). The sentences to the target ear are presented at 35 dB sensation level (SL) (in reference to the spondee or 1000 Hz threshold), and the sentences presented to the

competing ear are presented at 50 dB SL. A percentage correct identification score is derived for each ear. However, the accuracy of the meaning of the sentence and not the individual words is key to the scoring of correct or incorrect responses on this test (see Musiek and Pinheiro, 1985 for details).

Audiological Test Results (Pre-therapy)

Peripheral Auditory Tests

The initial audiological evaluation showed normal pure-tone thresholds and excellent speech recognition scores bilaterally (Figure 1). In addition, normal cochlear function was supported by the results of DPOAE testing (Figure 2). Measures of absolute levels were essentially at or above the 90th percentile bilaterally for the eight frequencies for which distortion products were measured. In addition, the amplitudes of the distortion products compared with the

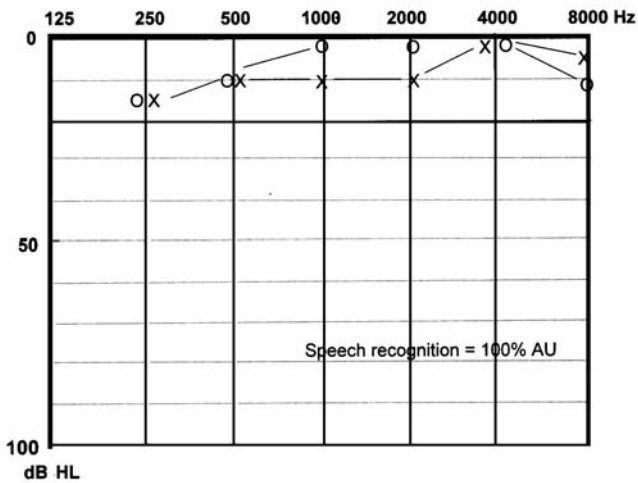


Figure 1. The pure-tone thresholds and speech recognition scores obtained at the time of the patient's initial audiological evaluation (AU = both ears).

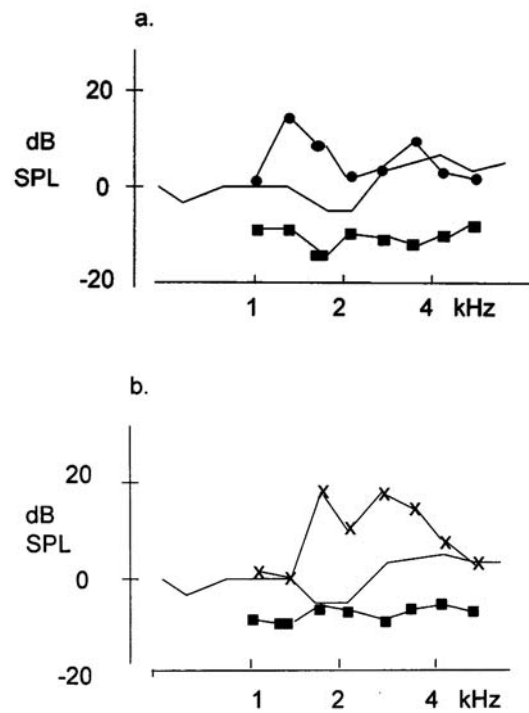


Figure 2. DPOAEs for the right (a) and left (b) ears obtained at the initial audiological evaluation. The squares represent the patient's noise floors, and the filled circles and Xs are the measured distortion product levels for the right and left ears. The line cutting across the figure represents the 90th percentile norms

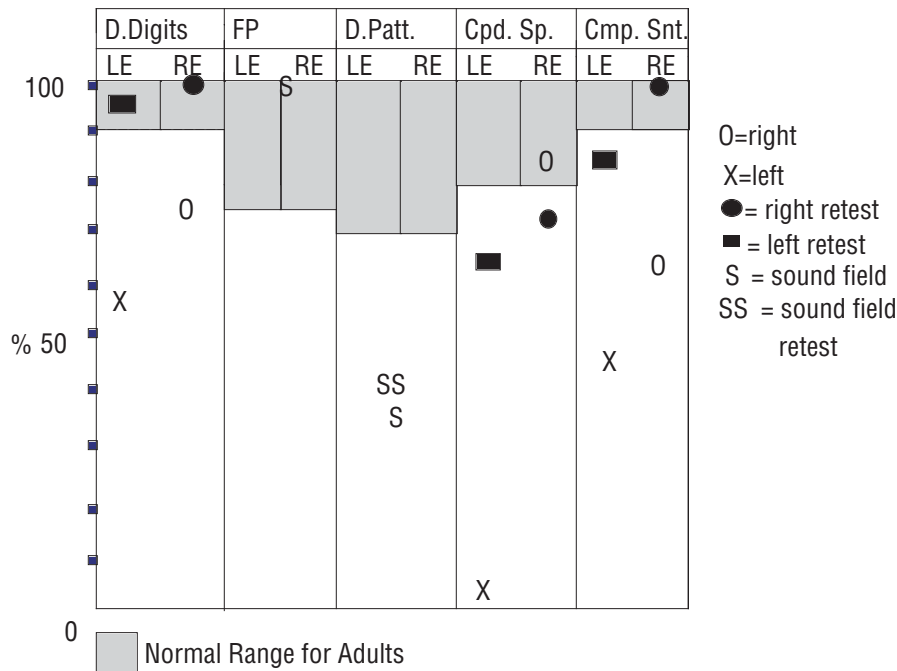


Figure 3. The central auditory test results obtained before the initiation of auditory therapy and then again approximately seven months later. (Key: D.Digits = dichotic digits; F.Patt. = frequency patterns; D.Patt. = duration patterns; Cpd. Sp. = compressed speech; Cmp. Snt. = competing sentences).

amplitudes for the associated noise floors yielded signal-to-noise ratios that were equal to or greater than 10 dB at all eight frequencies for both ears. These measures were well above the established normal criteria for the techniques and equipment utilized (Musiek and Baran, 1997).

Central Auditory Tests

The competing sentences, dichotic digits, and compressed speech tests yielded results that fell outside of the range of normal performance for both ears (Figure 3). Although performance for both ears was abnormal on each of these tests, there was a consistent finding of a greater deficit for the left ear than the right ear on all three tests. This asymmetry in performance was most notable for the compressed speech test where an 80% difference in performance was noted. Both the frequency and duration pattern tests were administered in the soundfield, which yielded a single performance measure on each test. Abnormal performance was noted on the duration patterns test, whereas the patient's performance on the frequency patterns test fell within the normal range of performance.

The pre-therapy MLR demonstrated what appeared to be a more appropriate left ear response than right ear response (Figure 4). There were no clinically significant differences across electrode sites (Cz, C3, C4)

in regard to latency or amplitude measures for either ear when within-ear comparisons were made. However, when results were compared across ears, the amplitudes for the

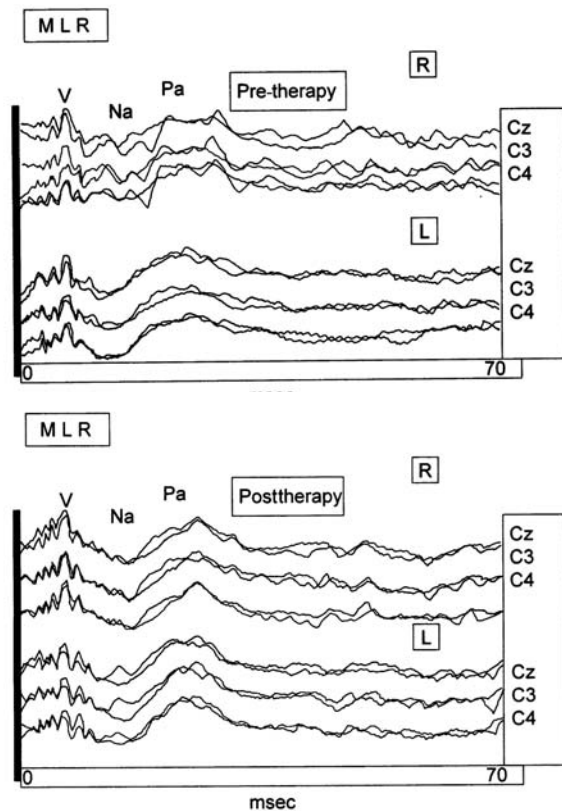


Figure 4. The middle latency response (MLR) for the right and left ears at three electrode sites (Cz, C3, C4) before therapy (a) and after therapy (b). Note: the auditory brainstem response (ABR) recordings appear on the extreme left side of these figures.

Table 1. Pre- and Posttherapy Amplitude Measures for the Na-Pa Component of the Middle Latency Response

Ear	Electrode	Pre-therapy Na-Pa amplitude (μ V)	Posttherapy Na-Pa amplitude (μ V)
Right	Cz	0.95	1.09
Right	C3	0.90	1.11
Right	C4	0.98	1.05
Left	Cz	1.10	1.22
Left	C3	0.98	1.35
Left	C4	1.03	1.19

Na-Pa waves were found to be somewhat larger in the left ear than in the right ear across all electrode sites (Table 1). In addition, the waveform morphologies were better for the MLR tracings derived with left ear stimulation rather than with right ear stimulation (better contours, less noise). These noted differences in the morphologies of the derived waveforms and in the amplitudes of the Na-Pa waves, however, were not considered to be clinically significant (Musiek et al, 1999). The auditory brainstem response (ABR) was simultaneously recorded with the MLR and showed normal results with exceptionally good waveform morphology bilaterally (Figure 4).

Audiological Test Results (Posttherapy)

Peripheral Auditory Tests

The posttherapy evaluation was performed about seven months after the pre-therapy assessment. A screening pure-tone audiogram conducted at this time showed the same findings as those observed during the pre-therapy test assessment (i.e., normal pure-tone thresholds bilaterally). Given this finding, the limited time available for testing, and the fact that the patient's hearing seemed to have improved based on patient report, speech recognition testing and DPOAEs that were normal initially were not repeated in order to devote more time to the previous abnormal test findings.

Central Auditory Tests

There were a number of positive changes in the patient's performance on several of the central tests administered. The changes

were particularly evident in the left ear when pre- and posttherapy results were compared (Figure 3). Posttherapy performance on the competing sentences test improved from moderately depressed to within the normal range for the right ear and from severely depressed to close to normal performance for the left ear. Test scores on the compressed speech test dropped slightly in the right ear (10%) but improved dramatically (+ 58%) in the left ear, whereas bilateral improvements were noted for the dichotic digits tests, with posttherapy scores rising to within the normal limits for both ears. As was noted for the competing sentences and compressed speech tests, the post therapy improvement found for the left ear was greater than that observed for the right ear. The duration patterns test revealed little change when pre- and posttherapy comparisons were made. The MLR showed increased amplitudes for the Na-Pa wave and better waveform morphology across all electrode sites and for both ears after therapy (Table 1). The ABR waveform was essentially identical to the pre-therapy tracings for both ears and all electrode sites.

Rehabilitation Plan

The therapy plan developed for this patient was one based on a consideration of the patient's presenting auditory symptoms and the results of her audiological assessment (i.e., significant performance deficits on a number of central auditory tests). Although the focus of the rehabilitation plan was on the remediation of auditory deficits, the presence of co-morbid cognitive deficits was acknowledged. Certainly some of these cognitive deficits were associated with central auditory dysfunction and vice versa. However, it was our belief that it was important to provide this patient with consistent auditory

therapy that involved highly repetitive auditory tasks that would require a great deal of effort from the patient without creating excessive frustration. The patient had been receiving speech and language therapy for a number of months prior to her involvement in the current rehabilitation program, and she was interested in trying some new approaches. She was informed that the demands of her auditory therapy program would be considerable both in terms of effort and time. The patient was to initiate the program with the help of her family. She was to work daily on the procedures suggested with the amount of time per day depending on how she felt.

One clear advantage that we had in the development of a rehabilitation program for this case was that the patient was highly motivated and was genuinely interested in improving her auditory skills. She vowed that she would commit the necessary time and effort to achieve the desired outcomes, and perhaps more importantly, she had confidence in the therapy plan. Moreover, because of her education and training, she had great insight into her problems and had some good ideas of her own for therapy approaches. Since consistency was high on our list of priorities and the patient lived a considerable distance from our clinic, the decision was made to teach her various therapy approaches and have her work on them daily on her own. The patient agreed to a rather demanding therapy regimen.

Clear Speech (Modified)

One of the first strategies introduced to the patient was a modification of the clear speech approach developed by Picheny and his colleagues (1985). The patient was instructed to ask people that communicated with her on a daily basis to speak about 10% slower and 10% louder (by their own estimates) when speaking to her. It was emphasized to her that encouraging her communication partners to speak either too slowly or too loudly or deliberately would distort their speech and make matters worse but that slight changes in rate and loudness would help. This strategy was selected primarily because the patient complained often about difficulty understanding people who spoke rapidly. She also demonstrated considerable performance deficits for the

compressed speech test, which will be discussed in greater detail later.

Reauditorization

Reading aloud (or silently) can be helpful as a form of auditory training and reauditorization (Musiek, 1999). Reading engages the auditory cortex and association areas of the auditory cortex (Price, 1997) and creates important interactions between vision, cognition, and audition for which this patient needed practice. Reading aloud also provided this patient with practice in listening at a given pace and synthesizing a continuous stream of words, which challenges attention. After the accident, the patient noticed reading to be more difficult; hence, this allowed practice on reading for reading improvement. The patient was encouraged to read as much as possible and did so—often reading at length daily. The patient also listened to others reading aloud, and she additionally rehearsed messages by repeating them aloud and practiced answering questions spontaneously.

Dichotic Interaural Intensity Difference Training (Modified)

Since the patient demonstrated a left ear deficit on dichotic listening in the absence of any significant peripheral auditory or ABR findings, a problem with binaural integration/separation at the cortical or subcortical level was entertained. Therefore, the use of dichotic interaural intensity difference (DIID) training was the therapy procedure of choice to address this deficit area (see Musiek and Schochat, 1998; Musiek et al, 2002). The rehabilitation procedure requires the presentation of dichotic materials to the patient while the intensity of the signal delivered to the good ear (or the ear with the better performance) is adjusted (i.e., lowered) until the poorer ear's performance on one or a variety of dichotic listening tasks improves to a level that is essentially equal to or better than that of the good ear. With an intensity advantage to the poorer ear, dichotic training is initiated using an adaptive approach designed to gradually increase the presentation level for the better ear while maintaining high performance for the poorer ear. As the intensity is increased in the good ear, its performance increases. Eventually,

both ears demonstrate improved performance on various dichotic listening tasks when the intensity levels at both ears are equal. In order to maximize the benefits of this approach, it is important to use a wide variety of dichotic speech materials and a wide variety of dichotic tasks. This training can be done in a soundfield with speakers positioned on either side of the patient and/or under earphones.

Since the patient could not make the trip to our clinic to perform this procedure under formal conditions, an informal DIID therapy program was developed for the patient to implement at home. This was accomplished by using a stereo system with a balance dial for intensity control at the two ears. Increased intensity was provided to the left ear to stimulate that pathway more than the right in a dichotic or diotic condition (the dichotic condition was created by using a different sound source presented to the right ear). The patient controlled the intensity of the stimuli. A variety of listening materials and dichotic tasks (binaural integration and separation tasks) were utilized for training, and the therapy technique was utilized several times per week.

Auditory Memory Enhancement (Modified)

Since it was clear that the patient was experiencing both cognitive and auditory problems, it was considered necessary to implement a procedure that would require a variety of cognitive manipulations. In order to achieve this goal, the auditory memory enhancement (AME) procedure was implemented as part of the patient's rehabilitation program (Musiek, 1999). The AME procedure is designed to assist with the encoding of incoming stimuli to facilitate auditory memory and retrieval. The procedure is delineated in detail elsewhere (Musiek, 1999), but its application in the rehabilitation program for this patient will be outlined briefly here.

The procedure was originally developed for use with children, but it has been modified for adult use in this case. The patient was asked to read materials (e.g., an article in a magazine) and to identify the key concepts or ideas that are being conveyed in the materials she is reading. When a key concept is identified, the patient is expected to sketch an illustration in 45 seconds that captures the essence of that concept. The patient then

continues reading and searching for the next important idea in the article, and the same process is repeated until the end of the article is reached. At the completion of the article, the patient is asked to review the sketches developed and then to attempt to reconstruct the article and tell it to someone who is willing to listen. The AME procedure was followed approximately two to three times per week by this patient.

Auditory Speech Discrimination Training

In this component of the rehabilitation program, the patient was asked to isolate words and word combinations that she confused and to work on the identification and discrimination of these words. Practice on discrimination of similar sounding words was also included in this aspect of the auditory training.

Temporal Sequence Training

Training to enhance the patient's ability to sequence various auditory events was another important aspect of the patient's program. This was accomplished in large part through the utilization of a commercially available game ("Simon Game"). This game requires the sequencing of four different tones that are coordinated with four different colored lights. Simple to complex patterns of flashing lights and brief tones are presented by the game, and the player must replicate the sequence. If the sequence is replicated correctly, another element is added and so on (adaptive). The patient trained on this game several times a week, often playing with her son. She played the game both with and without visual cues. This game provided training on an auditory task that requires a number of important skills, including temporal processing, pattern recognition, and working memory.

Metacognitive Strategies

There were several strategies that the patient had developed on her own over time to help facilitate her communication and cognitive abilities. Several of these were integrated into her auditory rehabilitation plan as these helped the patient in her

Table 2. Metacognitive and Communication Strategies Developed and Utilized by This Individual with a Minor Head Injury

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- Use of a conversation notebook to keep notes on discussions in an organized manner
 - Use of deduction puzzles to assist with the identification of the central issues in messages
 - Use of telephone call ID and answering machine options to record and review messages
 - Use of a notebook to prepare for meetings/conversations in advance
 - Use of self-quizzing techniques to facilitate understanding and memory of important information
 - Use of tape recorders to record important information and increase conversational confidence
 - Use of e-mail as opposed to other communication mediums (telephone) for more complex communications
 - Use of preplanning strategies to assist in the timely identification of problematic situations and the ability to plan effective coping strategies.
-

everyday activities. A list of these strategies is provided in Table 2.

DISCUSSION

Auditory Processing and Concussion

This case presents several concepts of importance to the application of tests for central auditory processing dysfunction and associated therapy procedures. First, it is important for clinicians to realize that concussion and other types of head trauma can result in an auditory processing disorder. This case, as well as others that have been reported in the literature (Jerger and Jerger, 1981; Abd Al-Hady et al, 1990; Bergemalm and Borg, 2001), demonstrates this well. Head trauma may or may not involve the auditory system; however, when it is involved it is critical to make this determination. Often multiple sensory and cognitive systems are compromised in concussion or head trauma. However, if the auditory system is one of many central nervous system functions involved, it should be assessed. Neuropsychologists are often the professionals who evaluate postconcussive effects. They use procedures and tests to evaluate various cognitive functions, including auditory perception. However, the neuropsychologists' tests for auditory function are usually cursory, at best, and in some cases provide little valid audiologic information. Given the limitations inherent in these test batteries and the possibility of

significant compromise of the central auditory nervous system in patients who have sustained head injuries, the audiologist should be called upon to evaluate many of these patients posttrauma. In these types of cases, it is important for the audiologist to carefully assess both the peripheral and central auditory systems. Speech-language pathologists are often asked to provide therapy to patients with closed head injuries. It is important for these and other professionals to be aware that there can be compromises of the central auditory nervous system, and in these cases the audiologist (neuroaudiologist) may have a lot to offer both in diagnosis and therapy. There is no question that postconcussive patients are a clinical population that is underevaluated and underreferred to audiologists.

Test Interpretation

The audiogram and speech recognition scores that were normal, combined with normal DPOAEs, support an interpretation of a normal peripheral auditory system in this case. These normal findings and the marked hearing symptoms related by the patient would argue for central auditory involvement and further diagnostic testing, which was completed in this case. The central auditory tests revealed abnormal performance for all tests except frequency patterns, with the left ear performance being noticeably poorer than the right ear on all three tests where the performance of the two ears was individually assessed (competing sentences, compressed

speech, dichotic digits). The normal performance on the frequency patterns test, but not on the duration patterns test, is an interesting finding since both tests measure temporal processing abilities, at least in part. However, it has been shown by Musiek et al (1990) that although these tests are quite similar in terms of their test constructions, they measure slightly different auditory processing skills. Therefore, the differences noted in the patient's performance on these two tests could be related to the locus and extent of the neural compromise sustained. This damage may have spared the neural substrate needed for the accurate processing of frequency patterns but compromised that required for normal processing of the duration patterns. Another possible explanation for the difference in scores on the two pattern tests is that perhaps the patient was able to optimally use the pitch differences in the frequency patterns test to strategically offset a temporal sequencing deficit. Since the duration patterns do not provide any cues other than those that are temporal, the patient's true deficits became evident.

The finding of a difference in the performance of the two ears on the compressed speech test as well as both dichotic speech tests (digits and competing sentences) could be interpreted as an indicator of possible asymmetric involvement of the central auditory system. Since the ABR is normal bilaterally, this asymmetric involvement of the central auditory system is likely to be at the cortical or subcortical level. Three of the behavioral central tests yielded left ear deficits that were considerably greater than right deficits, suggesting that the right hemisphere may have sustained greater neural compromise (Musiek et al, 1984; Musiek and Baran, 1987). The observation of a depressed left ear score on one of these tests (i.e., compressed speech) in particular significantly increases the probability that the right hemisphere was involved to a greater degree than the left. This particular finding supports the hypothesis that the left ear deficit noted during behavioral testing is associated with dysfunction in the right hemisphere and not the callosal connections. It has been well established that callosal involvement affects dichotic listening but not performance on monaural low redundancy speech tests (Milner et al, 1968; Musiek et al, 1984). It should be noted, however, that there

were bilateral deficits on the compressed speech and dichotic speech tests, which would argue for at least some (though less) involvement of auditory structures other than those in the right hemisphere.

A key aspect of this case was the correlation between the patient's well-delineated symptoms and the findings on the central auditory test battery. One of the patient's main complaints was difficulty understanding people who speak at a fast rate. This symptom correlated well with the severely depressed scores on the compressed speech test, which is a test that speeds up the rate of speech in a controlled manner. To further interpret this symptom, it is likely that the patient had some temporal processing difficulties (i.e., reduced scores on the duration pattern perception test), which may have been the basis for this particular auditory complaint.

Another interesting symptom that can be associated with the greater left than right ear deficit on the central behavioral tests is that the patient felt that she could hear better in her right ear than her left ear. When she was directed to begin using the right ear on the phone rather than the left (which she had always previously used), she reported that she heard remarkably better. This improvement was noted in spite of the fact that her pure-tone audiogram was normal and symmetrical. This kind of reliable subjective auditory finding in individuals with damage to one hemisphere has been reported before (Musiek et al, 1994). The difference between ears for hearing on the phone can be explained by the patient's performance on the compressed speech test in that the telephone, which has a spectrum that is limited at both the low and high frequencies, serves as a low redundancy speech test—like compressed speech.

Listening to multiple speakers, such as in group situations, was another challenge for this patient. This difficulty was reflected in deficits on two types of dichotic listening tests. The dichotic digits test requires the binaural integration of speech signals from both ears, and the competing sentences test requires the separation of the signals presented to the two ears and the suppression of the stimuli being presented to one ear while attending to those being delivered to the other ear (see Musiek and Pinheiro, 1985). On both tests, abnormal performance was noted

during pre-therapy assessment, with significant asymmetric test scores favoring the right ear being noted.

The MLR also demonstrated some asymmetry with the left ear showing smaller amplitude measures across recording conditions; however, in our view this may not represent clinically significant differences in and of itself (Musiek et al, 1999). However, it does show a similar trend as the behavioral test findings discussed above.

Effects of Auditory Processing Therapy

The auditory processing therapy that was recommended and used with this patient is therapy that has been primarily used with children and adults with auditory processing disorders associated with learning difficulties. This report marks an expansion of this type of therapy. This case, although representing a new application of these therapies, was ideal in that the patient was highly motivated and knowledgeable about her problem. In our view, this was a key facet to the success of the rehabilitation program.

The improvements in auditory and cognitive function both objectively and subjectively were compelling. The dichotic digit scores after therapy improved to within the normal range while compressed speech and competing sentence scores showed marked improvements to near normal performance levels. The MLR also showed a trend toward improvement after intervention in that both amplitude measures and waveform morphology changed posttherapy. While it is difficult to determine if these findings constituted a significant change in the MLR, it does appear that the changes noted were greater than one would have expected without some intervening reason (Ozdamar et al, 1982).

Subjectively, the patient reported improvements along several fronts that she attributes to the success of her auditory rehabilitation program. The patient can now talk on the phone using her left ear as she did prior to the accident. She can follow and engage in most conversations; however, some people who talk at an extremely fast rate remain difficult to follow, but she asks them to slow down. She is also able to “tune out” auditory distractions more effectively while focusing on other tasks. Quoting from the

patient’s own words, “I can talk, listen (and think) while the radio is on and people are talking around me. This was impossible after my accident and has greatly improved, though not recovered 100%.”

Other improvements, which perhaps were more cognitive than auditory in nature, were additionally noted by the patient. The patient noted an enhanced ability to recall conversations and share information about these conversations. She also reported an increased confidence in her overall memory—both short-term and working memory. Finally, improvements in organizational skills, concentration, and speed of thinking were also noted by this patient after therapy.

These objective and subjective improvements are especially important to consider since the patient had lived for more than a year following the accident with no significant improvements, despite professional intervention, in what she termed her auditory (and some cases, cognitive) difficulties. During this year’s time the patient had formulated many strategies to help herself cope with challenging listening situations. These successful communication enhancement and metacognitive strategies, which had served her well in the year that intervened between her accident and her enrollment in the auditory rehabilitation program outlined above, were integrated into her overall auditory rehabilitation program. It was interesting that this patient stated that she needed blocks of silence to rest the auditory system together with ample sleep to allow her to function optimally day in and day out. She also has learned that her ability to follow conversations is facilitated if she does not try to integrate every detail in the conversation but, rather, focuses on the big picture or Gestalt representation (such as in the AME procedure).

It is also important to understand that although the patient’s symptoms have improved markedly over the course of her rehabilitation program, some deficits still remain. Processing speed remains a problem and she still experiences some difficulty attending to multiple talkers at once. In addition, full comprehension of messages poses a challenge to this patient. These real-world deficits are still there—although not to the degree they once were. It is likely that these residual auditory and cognitive effects will persist and that the patient will continue

to experience some auditory and cognitive deficits in the future. Within the auditory domain, the central auditory test battery shows a residual deficit on the duration patterns test, which is primarily a temporal processing test. Some of the lingering difficulties experienced by this patient are likely to be related to this finding. The patient's rehabilitation program included activities that attempted to address the deficits uncovered by the auditory duration test. However, temporal processing is likely to be a multifaceted process with many subcomponents that may not be adequately assessed by current test procedures. Perhaps there is need for more tests of temporal processing to guide us to the most optimal therapies related to temporal processing deficits.

It is difficult to determine with the limitations of one case study whether or not these therapies could be advantageous to others with mild head injury and auditory problems. It is also difficult to rule out some degree of latent spontaneous recovery in this patient. However, this case does argue for considering diagnostic audiology and related therapies as a possibility for individuals with mild head injury and auditory symptoms. This report also argues for the need for more research in this area.

SUMMARY

Concussion and other types of minor head trauma can result in significant central auditory deficits in the absence of any obvious deficits within the peripheral auditory system. The presence of these types of auditory deficits can be documented through the use of appropriately selected behavioral and electrophysiologic measures. Once identified, a comprehensive therapy plan can be developed in an effort to manage these deficits. In this case, auditory training, as well as listening and cognitive strategies, were applied with good results to this patient with central auditory deficits secondary to head trauma.

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