Twin Study of Central Auditory Processing Disorder

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Abstract
We compared auditory, cognitive, and language test results in a pair of dizygotic twins, one of whom showed symptoms of central auditory processing disorder (CAPD). Results highlight the importance of testing binaural function. In particular, electrophysiologic measures of dichotic listening effectively demonstrated the auditory-specific nature of this child's listening problems. The importance of a thorough and comprehensive evaluation of children suspected of CAPD is stressed.

Key Words: Central auditory processing disorder, dichotic, dizygotic, event-related potential, twins

Abbreviations: ABR = auditory brainstem response, CAPD = central auditory processing disorder, CELF = Clinical Evaluation of Language Functions, ERP = event-related potential, PPST = Pitch Pattern Sequence Test, PST = Phonemic Synthesis Test, RASP = Rapidly Alternating Speech Perception, SCAN = Screening Test for Auditory Processing, SSW = Staggered Spondaic Word Test, TTC = Token Test for Children, WISC-III = Wechsler Intelligence Scale for Children-III

The concept of central auditory processing disorder (CAPD) derives from the notion of specific auditory perceptual deficit (Myklebust, 1954; Sloan, 1986; Cacace and McFarland, 1998). It is supposed that the child or adult frequently encounters listening situations in which a specific deficit in auditory perceptual processing interferes with accurate communication, leading, in a worst-case scenario, to learning disorder and related deficits in academic achievement (Bellis, 1996). The reality of such an auditory-specific deficit has often been questioned (e.g., Rees, 1973; Cacace and McFarland, 1998).

Proponents of the CAPD concept have found it difficult to counter these objections, largely because much of the evidence cited in support of the phenomenon has been derived solely from behavioral tests. Such tests, although extremely useful in illuminating the extent of the CAPD phenomenon, have been criticized on the ground that performance on such tests is potentially influenced by the very disorders one is attempting to rule out (cf., Sloan, 1986; McFarland and Cacace, 1995; Jerger and Allen, 1998). A child's absolute performance on a difficult test of word repetition, for example, may be affected by language disorder, attention deficit disorder, emotional disturbance, or cognitive deficit. Redesigning these behavioral tests to make them less sensitive to such confounds, by incorporating appropriate control observations, has not been widely addressed. As a result, the evidence in support of specific auditory perceptual deficit has not been universally persuasive.

We recently had the opportunity to contribute additional data in support of the CAPD concept. We were able to carry out an extensive testing regimen on a pair of fraternal twins, one of whom had been diagnosed with CAPD. The study of twins, in this context,
the advantage that the unaffected twin provides unique control data for both absolute performance and ear differences on auditory tests. In addition, both home and educational environment, and, to a certain extent, genetic make-up, are better controlled than when an individual is compared to a normative group.

In the following sections, we present case histories, evaluation of cognitive/language status, standard audiometric indices, and electrophysiologic studies of auditory event-related potentials (ERPs).

Case Histories

We identify our two subjects as ET (experimental twin) and CT (control twin). They are 9-year-old dizygotic male twins born 4 weeks prematurely. At birth, ET weighed 5 lbs, 5 oz and CT weighed 4 lbs, 12 oz. One- and 5-minute Apgar scores were 5 and 9, respectively, for ET and 9 and 9, respectively, for CT. Developmental milestones were within normal limits for both twins. They live with their parents, who are both college educated. By questionnaire (Annett, 1970), both twins are right-handed, as are both parents. Medical history is unremarkable for either twin. There have been no hospitalizations or serious illnesses. ET, however, has had 15 known episodes of bilateral and unilateral otitis media between birth and 6 years. All were managed with antibiotics. CT has had 7 such episodes.

Academically, CT is in the third grade and is performing at grade level. ET has attended the same elementary school and is also in the third grade. He received tutorial services in grades 1 through 3 and has received 1 year of private tutoring. He was placed in reading enrichment classes to supplement his reading development in grade 2. ET's teacher in the third grade reports that his primary difficulty is "processing oral and written information and applying it to the task independently." ET was assessed for special education services in the second and third grade but did not qualify for those services.

Initial Auditory Processing Evaluations

Because ET's parents were concerned about his lack of academic progress, they sought comprehensive audiologic, cognitive, and linguistic assessments. Following evaluation by the special education department in his school district, ET was subsequently referred, at the parents' request, to a speech-language pathologist for further assessment. At age 8 years, 6 months, ET was evaluated by the speech-language pathologist using the Screening Test for Auditory Processing (SCAN; Keith, 1986). On this occasion, ET's performance scores on all three subtests and on the composite score of the SCAN were well within the ±2 standard deviation range of the normative group. But both the parents and the classroom teacher were convinced that some form of auditory problem existed. They prevailed on the speech-language pathologist to refer ET to a local university hearing clinic for further evaluation.

This evaluation, carried out at age 8 years, 8 months, included a retest of the SCAN, the Staggered Spondaic Word (SSW) test (Katz et al, 1963), the Rapidly Alternating Speech Perception (RASP) subtest of the Willeford Battery (Willeford, 1977), and the Phonemic Synthesis Test (PST; Katz and Harmon, 1982). On this second SCAN test, ET's composite score and filtered word subtest scores were two standard deviations below the mean. Scores on the Auditory Figure-Ground and Competing-Word subtests of the SCAN were within normal limits. Test results for the RASP were within normal limits. PST and SSW results, however, were said to be abnormal. The conclusion of this audiologic assessment was that ET demonstrated a significant auditory processing disorder in the presence of normal hearing sensitivity.

Three months later, ET was referred back to the school district for further auditory processing evaluation. He was given the SCAN a third time, then tested further with the Dichotic Digits Test (Musiek, 1983) and the Pitch Pattern Sequence Test (PPST; Pinheiro and Ptacek, 1971). On this third occasion, all SCAN results were said to be well within normal limits. Dichotic digit scores were 88 percent for the right ear and 72 percent for the left ear. PPST results were interpreted as demonstrating a weakness in temporal sequencing. The overall conclusion of this evaluation was that ET demonstrated weakness in auditory processing relative to memory and auditory sequencing. Based on these findings, the parents were referred to our facility, the Auditory Research Laboratory, Baylor College of Medicine, Houston, for further evaluation.

Present Laboratory Findings

At the time of our own evaluation the twins were 9 years, 1 month old. The following sections detail the results of cognitive/linguistic
evaluation, basic audiometry, the auditory brainstem response (ABR), behavioral and electrophysiologic studies of dichotic listening, and a comparison of the results of the Token Test for Children (TTC), administered both in quiet and against a background of competing speech.

Cognitive/Linguistic Evaluations

Both twins were evaluated by a licensed diagnostician. The Wechsler Intelligence Scale for Children-III (WISC-III; Wechsler, 1974), an individually administered clinical instrument designed to measure the intellectual abilities of children, was administered. Results were judged to be reliable indices of each twin’s current functional abilities. CT obtained a Verbal IQ score of 107, a Performance IQ score of 98, and a Full Scale IQ score of 103 (mean = 100, SD = 15). ET obtained a Verbal IQ score of 88, a Performance IQ score of 91, and a Full Scale IQ score of 88 (mean = 100, SD = 15). Table 1 summarizes each twin’s specific subtest scores. Noteworthy differences between twins were evident on the information and similarities verbal subtests and on the coding subtest of the performance battery.

Speech-language evaluations were completed for both twins. They were evaluated using the following age-appropriate standardized test instruments: (1) TTC and (2) Clinical Evaluation of Language Functions (CELF). All testing was carried out in a quiet, nondistracting environment. Results of testing were judged to be reliable indices of each subject’s current linguistic skills.

The TTC, a test of comprehension of language, when completed in quiet, yielded an age-scaled score of 500 for CT and 499 for ET (mean = 500, SD = 3). All subtest scores were within the normal range for both subjects (±2 SD). On the CELF, a test of receptive and expressive language function, ET scored at the 70th percentile for total processing (comprehension) and at the 35th percentile for total production (expression). CT scored at the 90th percentile for comprehension and at the 95th percentile for expression. CT was above criterion (i.e., greater than the 20th percentile) on all subtests except word association. Although both subjects tested within the normal range both expressively and receptively, there were striking differences between their performances on two specific expressive subtests. CT was able to name 15.5 words/minute on a confrontation naming task (i.e., name as many animals, foods as you can in 1 minute). In contrast, ET was only able to name 8.5 words/minute. Furthermore, on a second confrontation naming task (naming colors, then forms, and then both together), CT completed this task in 57 seconds with 36 correct. ET took 95 seconds to complete the same task with 36 correct.

Basic Audiometry

Figure 1 shows, for both twins, pure-tone, air-conduction thresholds and performance-intensity functions for words in quiet (PB) and for sentences in competition (SSI). Differences between the twins were not remarkable. ET showed slightly greater sensitivity loss for pure tones but, with the exception of 8000 Hz, all thresholds on both ears were at 20 dB HL or less. PB and SSI scores were slightly poorer for ET at low speech intensity levels, but maximum scores, at 80 dB HL, were comparable. Standard immittance measures were within normal limits for CT. Tympanograms were type A on both ears; both crossed and uncrossed reflexes could be elicited at normal levels at all test frequencies. In the case of ET, however, immittance results were distinctly abnormal. The tympanogram for the left ear was type C with the peak at −100 daPa. Neither the crossed nor the uncrossed acoustic reflex could be demonstrated at any frequency on either ear. These results are consistent with ET’s history of persistent middle-ear disease, which itself may account for the
slight pure-tone sensitivity loss. In view of ET's abnormal immittance results, otoacoustic emission measures are not reported.

**Auditory Brainstem Responses**

Figure 2 shows ABR waveforms for both twins for right-ear, left-ear, and binaural stimulation. Stimuli were 2048 rarefaction clicks presented at 70 dB nHL via standard tube-phones (Etymotic, ER3A). All results for both twins are well within normal limits. Wave V is well formed and at normal latency in all six waveforms. Comparison of results for the two twins shows little difference in either amplitude or latency of wave V. Note also in both
Dichotic behavioral and electrophysiologic data were gathered simultaneously using an “oddball paradigm” previously described in detail by Jerger et al (1995). Briefly, pairs of PB words are presented dichotically over a sequence of 300 trials. The subject is instructed to listen for a target speech feature and to press an appropriate button when the target is detected. The target speech feature is presented on 30 percent of trials, 15 percent to the right ear and 15 percent to the left ear. In the remaining 70 percent of trials, no target is presented. Two different speech features, one linguistic, the other non-linguistic, served as targets. Linguistic targets were words that rhymed with “book” (e.g., look, took, cook, etc.). In this paradigm, all words were spoken by a single male talker. Nonlin-

Figure 2 Auditory brainstem responses for right-ear, left-ear, and binaural click stimulation for control twin and experimental twin. Clicks presented at 70 dB nHL.

twins evidence of binaural augmentation of wave V amplitude.

Dichotic Test Results

Evoked electrical activity was recorded from 22 scalp electrodes configured according to the International 10-20 system (Jasper, 1958). All epochs were stored for subsequent offline analysis. Evoked response waveforms reflected the typical “P-300” pattern associated with the oddball paradigm. The waveforms of both twins showed positive peaks at approximately 900 msec, a latency explained in part by the durations of the target words and in part by the young age of the twins. Waveforms were averaged separately for targets to right and left ears. Averaged waveforms were first analyzed to define the peak latencies of the ERPs to targets. Then voltages were interpolated between and among adjacent electrodes. Finally, voltages were assigned colors to generate topographic maps of the evoked activity at the peak positivity of the ERP as defined at the Pz electrode.

Figure 3 shows topographic maps of the distribution of evoked potential activity at the pos-

Figure 3 Topographic distributions of auditory evoked potentials in response to right-ear and left-ear linguistic targets for control twin and experimental twin. Topographic maps computed at positive peak of ERP waveform at midline parietal (Pz) electrode.
itive peak of the ERP waveform for both twins in the dichotic linguistic condition. In the case of CT, activity was distributed symmetrically across the midline parietal and occipital regions and there was little difference between target ears. In the case of ET, however, activity in response to right-ear targets was shifted well to the left of midline. For targets directed to the left ear, little evoked activity can be discerned. In comparison with CT's results, ET's asymmetry is striking.

Figure 4 shows similar results for the dichotic nonlinguistic condition.

**Token Test in Speech Competition**

As noted above, when the Token Test for Children (TTC) was carried out in standard fashion in a quiet environment and with minimal distraction, scores for CT and ET were quite similar, 500 and 499, respectively (mean = 500, SD = 3). All subtest scores were within the normal distribution for both subjects (±2 SD). The examiner noted, however, that during TTC testing, even the slightest background distraction seemed to disturb ET much more than CT. Accordingly, the entire procedure was repeated in the presence of background speech competition (the soundtrack from a popular video cartoon appropriate to this age level). The background competition was presented at a sound pressure level of 75 dB, measured at the

Figure 5 Scores on the Token Test for Children for control twin and experimental twin, both in quiet and in the presence of competing speech.

position of the child's head in the sound field. Figure 5 summarizes serial subtest scores for both twins in both the original quiet condition and in the subsequent experimental background noise condition. CT's performance was completely unaffected by the background competition. On the first subtest administered, however, ET's performance fell more than six standard deviations below the mean, although ET had already performed as well as CT when they took the test previously in a quiet environment. As the test proceeded, ET was able to regain his former performance level by the third subtest. It took him some time, however, to adjust to the presence of the background speech competition.

Table 2 summarizes cognitive, linguistic, and auditory findings for each twin.

**DISCUSSION**

There can be little doubt that twin ET has a specifically auditory perceptual disorder. It is sufficient to note the consistent left-ear deficit in dichotic listening highlighted in Figure 3. If evoked potential amplitude in response to both linguistic and nonlinguistic speech features is poorer when the auditory target is delivered to one ear than to the other, an auditory-specific deficit must be invoked. Neither cognitive, language, nor attentional problems would be expected to favor one ear over the other.

This twin comparison illustrates three important aspects of CAPD. First, a specifically auditory problem does not necessarily exist in isolation (Sloan, 1986, 1992). When ET is compared with his normal twin, there is some evi-
Table 2 Summary of Cognitive, Linguistic, and Auditory Findings for Each Twin

<table>
<thead>
<tr>
<th>Measure</th>
<th>CT</th>
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<tr>
<td>Expression (%)</td>
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<th>LE</th>
<th>RE</th>
<th>LE</th>
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<td>8</td>
<td>15</td>
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<tr>
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<td>Normal</td>
<td>Asymmetric</td>
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*With respect to midsagittal plane.
RE = right ear, LE = left ear.

dence of both cognitive and language deficits. Scores on the subtests of the WISC-III (see Table 1) are almost uniformly lower for ET and show substantial differences on the subtests of Similarities and Coding. The twin's Full Scale IQ scores differ by one standard deviation (15 points). There was little difference between the twins on the Token Test (500 for CT vs 499 for ET), but there was substantial difference on the Test of Auditory Comprehension of Language (123 for CT vs 89 for ET) and the Expression component of the CELF (95th percentile for CT vs 35th percentile for ET).

Second, the present data highlight the inherent difficulty in attempting to identify abnormality by comparing a child's absolute performance to a norm. The SCAN test (Keith, 1986), for example, was devised as a screen for CAPD. It yields three subtest scores: (1) Filtered Words, (2) Auditory Figure-Ground, and (3) Competing Words. Each subtest score is compared to a normal range defined by a band ±2 standard deviations around the mean performance of normal children of the same age. SCAN was administered to ET on three separate occasions and by three different examiners over a 5-month period. Of the nine subtest scores yielded by these three administrations, only one, the Filtered Word score on the second test date, was as much as two standard deviations below the norm. The other eight scores were well within the two standard deviation boundary. Note that, on two of the three test occa-
sions, all three subtest scores were normal. Moreover, the score for the Competing Words subtest (a test of dichotic listening) was within normal limits every time the test was given. Yet the most convincing evidence of CAPD in twin ET is the asymmetries in the topographic maps of ERPs in response to dichotic listening (see Figs. 3 and 4). A more successful approach to test development might be to devise measures to quantify ear differences in responses to auditory tasks, to note how speech understanding changes with speech intensity, and to devise visual analogs of such tasks so that the child can serve as his/her own control (cf., McFarland and Cacace, 1995).

Third, the results of the TTC, in both quiet and in the presence of competing speech (Fig. 5), illustrate some fundamental aspects of CAPD. Twin ET was able to accomplish the task successfully when the acoustic environment was favorable. But when distracting speech competition was introduced, his performance, on the same material on which he had already been successfully tested, deteriorated dramatically. Then, after sustained attention to the task, he was able to overcome the effects of the background competition and perform as he had initially. If he had only been tested in the unfavorable acoustic environment, whether he was judged normal or abnormal on this measure, would have depended on the position in the time sequence of testing at which the judgment was made. Especially in children, the manifest effects
performance. The present findings for twin ET are consistent with the expected profile of a child with CAPD. Pure-tone sensitivity was reasonably normal, simple monaural speech audiometry was reasonably normal, and the ABR was normal, but there was a problem in understanding speech stimuli in the presence of speech competition. Not surprisingly, this problem was best demonstrated by structured tests of dichotic listening and best differentiated from cognitive and language disorder by the ear asymmetries revealed by auditory-evoked ERPs.

The extensive testing required to reach this conclusion involved more time than many clinicians are willing to expend on the evaluation of such children. It is instructive, therefore, to ask what conclusions might have been reached in the case of less complete testing. If you had only administered the SCAN and had interpreted the initial results correctly, you would have concluded that there was no evidence for further evaluation. If you had carried out only pure-tone, immittance, and monaural speech audiometry, you would have concluded that auditory test results were all within normal limits. If you had added to this battery the ABR, you would still conclude that there was no evidence of an auditory processing problem. Alternatively, you might conclude, from the slight sensitivity loss and the abnormal immittance results, that the effects of chronic middle-ear disease had left the child with a mild bilateral peripheral hearing loss. If you had added, to this basic battery, tests of cognitive and language function, you might very well conclude that the child's problems derived from mild disorders in these two dimensions. But, by adding a series of tests stressing the binaural processing of auditory stimuli, either by dichotic tests under earphones or by adding background speech competition in the sound field, the asymmetry in performance characterizing a defect in binaural processing was revealed. We believe, therefore, that this case report highlights, among other issues, the importance of thorough and comprehensive evaluation of children suspected of CAPD.

REFERENCES


