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# Interaural Asymmetries Revealed by Dichotic Listening Tests in Normal and Dyslexic Children

Deborah W. Moncrieff*
Frank E. Musiek*

**Abstract**

Normal and dyslexic right-handed children were assessed with three dichotic listening tests, the Dichotic Digits test, the Competing Words subtest of the SCAN, and the Dichotic Consonant-Vowel test. Performance was measured as both number and percentage of correct responses in the right and left ears. Laterality was defined as a simple difference in percentage between the two ears. Differences across the tests were revealed for all children, with the greatest differences occurring for left-ear responses. Only one dichotic listening test, Competing Words from the SCAN, produced a consistent right-ear advantage across all of the children tested. Between groups of children, differences in performance and in laterality were demonstrated. Using a criterion of poorer than 76 percent correct for the left ear, the Competing Words subtest of the SCAN identified 7 of the 10 dyslexic children as abnormal, with no false alarms in the control group.

**Key Words:** Children, dichotic listening, dyslexia, interaural asymmetry

**Abbreviations:** APD = auditory processing disorder; CV = consonant-vowel; REA = right-ear advantage; SCAN = Screening Test for Auditory Processing Disorders

**Sumario**

Niños diestros, normales y disléxicos, fueron evaluados con tres pruebas de audición dicótica, la prueba dicótica de dígitos, la sub-prueba de palabras en competencia del SCAN y la prueba dicótica de consonante/vocal. Los resultados fueron medidos tanto por el número como por el porcentaje de respuestas correctas en el oído derecho y en el izquierdo. La lateralización fue definida como una simple diferencia porcentual entre los dos oídos. Se evidenciaron diferencias a lo largo de las pruebas en todos los niños, apareciendo las mayores diferencias para las respuestas de los oídos izquierdos. Sólo una prueba de audición dicótica, las Frases en competencia del SCAN, produjo una ventaja consistente del oído derecho en todos los niños evaluados. Se demostraron diferencias en rendimiento y en lateralización entre los grupos de niños. Utilizando el criterio de peor del 76% en el oído izquierdo, la sub-prueba de palabras en competencia del SCAN identificó 7 de los 10 niños disléxicos como anormales, sin falsas alarmas en el grupo de control.

**Palabras Clave:** Niños, audición dicótica, dislexia, asimetría interaura

**Abreviaturas:** APD = trastornos de procesamiento auditivo; CV = consonante/vocal; REA = ventaja para el oído derecho; SCAN = Prueba de tamizaje para trastornos del procesamiento auditivo

*(Department of Communication Sciences), University of Connecticut, Storrs, Connecticut
Reprint requests: Deborah W. Moncrieff, University of Florida, P.O. Box 117420, Gainesville, FL 32611

It has been demonstrated that children with dyslexia, a language disorder that leads to reading difficulties (Shaywitz et al, 1994), perform poorly on dichotic listening tasks (Boliek et al, 1988; Hugdahl et al, 1989; Morton and Siegel, 1991; Brunswick and Rippon, 1994). Reliable differences between dyslexic children and control children, however, have proven difficult to establish, and few studies have been able to demonstrate a uniform pattern of laterality results in all of the children tested. Several factors have been thought to contribute to the inconsistencies observed in these dichotic listening studies. The factors that appear to be the most significant are those related to handedness, attentional strategies, and verbal workload of the dichotic material used to test the children (Bryden et al, 1983; Obrzut et al, 1989; Kershner and Micallef, 1992; Lamm and Epstein, 1994).

Laterality during dichotic listening tests is reflected by the overall difference in performance between the two ears. The simple difference score, $d$, is a measure of laterality that reflects the difference between the proportion of correct responses for the two ears, with $d = P_R - P_L$, where $P_R$ represents the percentage of correct responses for the right ear and $P_L$ represents the percentage of correct responses for the left ear. Laterality expressed in this way has been shown to change with age in children. The least amount of change is reflected in scores for Dichotic Consonant-Vowel (CV) tests (Hugdahl and Andersson, 1986). Both Dichotic Digits and Dichotic Words show improvement across development for both ears, with the left ear improving more than the right ear, resulting in a progressive decrease in the magnitude of the right-ear advantage (REA).

The REA for digits typically shrinks from approximately 15 percent at age 7 to more adult-like levels of 2 percent by age 11 (Bellis, 1996), and the REA for words shifts from around 19 percent at age 3 to 10 percent by age 11 (Keith, 1986). By age 11, it has been thought that most children perform on dichotic listening tests at levels consistent with those achieved by adults. This predicts that a normal, right-handed 11-year-old child would produce levels of performance on a dichotic listening test similar to those produced by adults with an REA of 2 to 10 percent, depending on which stimulus is used in the test. The presence of a larger interaural asymmetry with normal performance in the right ear and significantly poorer performance in the left ear is thought to be indicative of an auditory processing disorder (APD) (Bellis, 1996; Chermak and Musiek, 1999). Any right-handed 11-year-old child whose results demonstrate an REA greater than 10 percent on dichotic listening tests would be suspected of having an APD.

The purpose of this study was to use three different dichotic listening tests to measure the direction and degree of lateralization in two groups of right-handed 11-year-old children, one of which had been diagnosed as dyslexic and a second group of age-matched controls. It was hypothesized that both groups of children would reflect left hemispheric dominance for language and an REA for dichotic listening. It was further hypothesized that control children would demonstrate normal performance on dichotic listening tasks and that dyslexic children would demonstrate reduced performance, with some of the dyslexic children demonstrating an abnormally large REA consistent with a left-ear deficit.

This study was designed to answer the following questions: (1) Does each of the three dichotic listening tests demonstrate a consistent direction and degree of hemispheric lateralization across subjects? (2) Are the direction and degree of lateralization more consistent in control subjects than in dyslexic subjects? (3) Do test results differ between the two groups of subjects tested?

## METHOD

### Subjects

Dyslexic subjects were selected from the outpatient population of the Luke Waites Child Development Center at the Texas Scottish Rite Hospital for Children in Dallas, Texas. Approximately 40 percent of the children seen at Luke Waites Child Development Center are diagnosed with dyslexia. Other diagnoses include developmental language disorder (30%), developmental coordination disorder/dysgraphia (35%), dyscalculia/arithmetic disorder (20%), articulation disorder (20%), slow learner/below-average intelligence (15%), disorder of written expression (15%), and attention-deficit with/without hyperactivity disorder (40%) (Balise, 1996).

To select potential subjects for this study, a chart review was conducted of all age-appropriate children who were evaluated during the previous 2 years at the Luke Waites Child Development Center and who received a dyslexia diagnosis. Dyslexic children were diagnosed on the basis of parent and school history of reading difficulty and on test results that

were consistent with normal intelligence and below-normal results on some or all measures of phonologic awareness and reading skill. From the charts selected, all of those with a diagnosis of hearing loss, attention-deficit disorder with/without hyperactivity, chronic psychological disorder, or neurologic impairment were excluded. All children who were left-handed were excluded. Charts were screened to determine that all children selected demonstrated a Full-Scale IQ score above 85 and a Wechsler Individual Achievement Test (WIAT) basic reading standard score less than or equal to 90. Only monolingual native speakers of English were included in the study.

Control subjects were recruited from a public middle school and from a church in Dallas, Texas. The administration at the school compiled a list of children with normal performance on standardized achievement tests in an age-appropriate grade with no known diagnosis of hearing loss, attention-deficit disorder with or without hyperactivity, psychiatric disorder, or neurologic impairment.

A total of 20 subjects were tested: 10 normal 11 year olds and 10 11 year olds diagnosed as dyslexic. Handedness was assessed by questionnaire (Annett, 1970) for each subject, and all were strongly right-handed. There were 7 male dyslexics, 3 female dyslexics, 7 male controls, and 3 female controls. Participation continued only when hearing thresholds did not exceed 15 dB HL at any test frequency from 500 to 4000 Hz in either ear at initial testing and each subject demonstrated type A tympanograms bilaterally (2 subjects initially demonstrated elevated thresholds with type B tympanograms, and testing was postponed until thresholds improved to below 15 dB HL and tympanograms were type A). All subjects were in excellent general health and all met the above selection criteria.

### Dichotic Listening Tests

Three different tests of dichotic listening were used to assess degree of laterality: (1) the Dichotic Digits test (Musiek, 1986), (2) the Competing Words subtest of the SCAN (Screening Test for Auditory Processing Disorders) (Keith, 1986), and (3) the Dichotic CV test (Berlin et al, 1973). Audiologists routinely use these tests in the assessment and diagnosis of APDs.

The Dichotic Digits test is composed of the digits from 1 to 10, excluding 7, naturally spoken by a male voice. The test includes 20 double-digit pairs plus 3 practice items. The Competing Words subtest of the SCAN consists of 50 pairs of single-syllable words recorded naturally by a male voice and spoken with simultaneous onset times to the two ears (Keith, 1986). The Dichotic CV test from AUDiTEC is composed of 30 pairs of simultaneously presented pairs of consonant vowels (/p/, /t/, /k/, /b/, /d/, /g/ paired with the vowel /a/). Each possible pair is presented twice so that each token from the pair is presented once to the right ear and once to the left ear. Throughout dichotic listening testing, earphones were reversed, and test order was pseudorandomized across all subjects. Each time test material was changed, the audiometer was recalibrated to the test tone provided.

## PROCEDURE

All dichotic listening material was presented at 50 dB SL relative to the subject's speech reception threshold (SRT) through a Grason Stadler (GSI10) clinical audiometer driving TDH-50 earphones.The subjects were seated in a sound-attenuated room during testing.

For the Dichotic Digits test, subjects were asked to repeat all of the digits they heard each time and were encouraged to guess when they were unsure of a response. Six practice items were presented before actual testing to ensure familiarity with the task. The first report strategy was free recall, during which each participant was asked to repeat all digits heard, and neither digit order nor ear designation was monitored. In a directed response condition, each participant was asked to first report the two digits heard in the right ear followed by the two digits heard in the left ear. During a second presentation of the same double pairs of digits, at a later testing session, each subject was asked to report the two digits heard in the left ear followed by the two digits heard in the right ear. A total score for the right and the left ears was derived in both the free recall and directed response conditions.

During presentation of the first 25 pairs of words in the Competing Words subtest of the SCAN, each participant was instructed to repeat both words, saying the word heard in the right ear first. During presentation of the second 25 pairs of words, each participant was instructed to repeat both words, saying the word heard in the left ear first. Each response was recorded as either correct or incorrect. Correct responses were totaled for each ear in both conditions.

The Dichotic CV test was conducted in a free recall condition with instructions to listen carefully and to report whatever was heard each time. Correct responses were tallied for each ear.

### Statistical Analysis

Right- and left-ear scores were compared across all four dichotic listening tests by mixed-design analysis of variance (ANOVA). There was one between-subjects factor (control vs dyslexic) and two within-subjects factors (test and ear). Statistical significance was evaluated at an alpha error level of .05.

## RESULTS

### Individual and Group Results on Dichotic Listening Tests

Individual results for all subjects in both groups for each of the dichotic listening tests are detailed in Table 1. Total percent correct scores are given for each ear and for each test. Mean percent correct scores and standard deviations are shown for each group and for each ear on each of the dichotic listening tests in Table 2.

### Analysis of Dichotic Listening Test Results

Across all subjects, there were main effects for test, $F = 97.392$, $df = 3, 54$, $p < .001$, and for ear, $F = 16.157$, $df = 1, 18$, $p = .001$, as well as for an interaction between test and ear, $F = 3.040$, $df = 3, 54$, $p = .037$. Between subjects, there was a main effect for group, $F = 8.176$, $df = 1, 18$, $p = .010$. Contrasts for test, ear, and group were all significant, but the contrast for the ear by group interaction was not significant. Analysis for simple effects demonstrated that the Dichotic CV test produced a significant contrast with digits and words and that no other single test produced any significant contrast.

Results of a general linear model (GLM) repeated-measures ANOVA on test and ear scores within each group revealed a main effect for test, $F = 24.117$, $df = 3, 27$, $p < .001$, and for ear, $F = 13.417$, $df = 1, 9$, $p = .005$. Contrasts for test and ear were both significant, with the

**Table 1 Percentage Correct by Ear for Each Dichotic Listening Test**

| | *DDT-FR R* | *DDT-FR L* | *DDT-DR R* | *DDT-DR L* | *CWS R* | *CWS L* | *CV R* | *CV L* |
|---|---|---|---|---|---|---|---|---|
| Dylexic subjects | | | | | | | | |
| CC | 80 | 75 | 85 | 84 | 94 | 66 | 50 | 37 |
| JH | 90 | 83 | 86 | 89 | 74 | 56 | 50 | 57 |
| VK | 25 | 25 | 60 | 31 | 82 | 60 | 43 | 50 |
| CL | 85 | 70 | 66 | 50 | 86 | 76 | 30 | 33 |
| RL | 93 | 83 | 88 | 80 | 86 | 80 | 53 | 40 |
| ML | 90 | 98 | 93 | 91 | 80 | 76 | 47 | 57 |
| JM | 93 | 88 | 85 | 69 | 94 | 70 | 50 | 37 |
| MP | 98 | 98 | 99 | 96 | 96 | 74 | 83 | 17 |
| SS | 80 | 83 | 85 | 81 | 84 | 70 | 53 | 27 |
| JW | 93 | 95 | 98 | 95 | 86 | 74 | 23 | 43 |
| Control subjects | | | | | | | | |
| AB | 95 | 85 | 99 | 96 | 90 | 82 | 53 | 47 |
| KB | 93 | 93 | 89 | 89 | 76 | 70 | 47 | 53 |
| BC | 88 | 98 | 91 | 100 | 92 | 78 | 60 | 43 |
| BF | 83 | 83 | 91 | 85 | 86 | 80 | 57 | 43 |
| GM | 95 | 98 | 100 | 100 | 96 | 86 | 83 | 40 |
| JM | 100 | 93 | 100 | 98 | 92 | 88 | 53 | 43 |
| BS | 98 | 100 | 95 | 94 | 86 | 84 | 50 | 47 |
| JS | 100 | 100 | 100 | 96 | 90 | 88 | 63 | 50 |
| CS | 85 | 98 | 93 | 95 | 92 | 88 | 60 | 40 |
| HS | 85 | 95 | 81 | 83 | 80 | 76 | 33 | 63 |

DDT-FR = Dichotic Digits test, free recall; DDT-DR = Dichotic Digits test, directed response; CWS = Competing Words subtest; CV = Dichotic Consonant-Vowel test; R = right ear; L = left ear.

**Table 2 Average Percentage Performance by Ear and Between Ears**

| Group | Right Ear | Left Ear | Difference (R-L) |
|---|---|---|---|
| Control | | | |
| Digits: free recall | 92.20 (6.48) | 94.30 (6.00) | −2.10 |
| Digits: directed response | 93.90 (6.21) | 93.60 (5.99) | 0.30 |
| Words | 88.00 (6.11) | 82.00 (6.04) | 6.00 |
| Consonant-vowels | 55.90 (12.80) | 46.90 (7.05) | 9.00 |
| Dyslexic | | | |
| Digits: free recall | 82.70 (21.10) | 79.80 (21.38) | 2.90 |
| Digits: directed response | 84.50 (12.57) | 76.60 (21.10) | 7.90 |
| Words | 86.20 (6.89) | 70.20 (7.57) | 16.00 |
| Consonant-vowels | 48.20 (15.85) | 39.80 (12.70) | 8.40 |

Numbers in parentheses represent standard deviations.

Dichotic CV test producing the significant contrast with digits and words and with a significant difference occurring between the two ears.

In control subjects, there was a main effect for test, $F = 303.450$, $df = 3, 27$, $p < .001$, but no main effect for ear, and, again, contrasts revealed that the Dichotic CV test produced significantly different results from digits and words. Contrasts between the Dichotic CV test and tests with digits and words were much greater in control subjects than in dyslexic subjects.

Between groups of subjects, there was a main effect for both the right ear, $F = 42.311$, $df = 3, 79$, $p = .000$, and for the left ear, $F = 41.762$, $df = 3, 79$, $p < .001$. Post hoc analyses with Tukey and Bonferroni tests yielded significant results in both right and left ears, but only for the Dichotic CV test. When groups were analyzed separately, results for dyslexic subjects were similar to results for all subjects combined. Results for control subjects revealed significant results for the left ear for all tests except between the two conditions of the Dichotic Digits test. So, for control subjects, significant differences occurred between Competing Words and each of the two versions of Dichotic Digits tests. This result was not observed in the dyslexic subjects.

In summary, test results differed significantly across all subjects for both ears. Larger differences among tests occurred in control subjects, and the largest differences in control subjects occurred for left-ear scores between the Dichotic Digits tests in both conditions and the Competing Words test. The Dichotic CV test produced results that varied significantly with digits and words, across both ears for all subjects, separately and combined.

## Analysis of Individual Dichotic Listening Tests

Separate GLM repeated-measures ANOVA on percentage scores for both ears in each dichotic listening test revealed main effects for group for Dichotic Digits in the directed response condition, $F = 5.60$, $df = 1, 18$, $p = .029$, and for Dichotic CVs, $F = 7.423$, $df = 1, 18$, $p = .014$. Main effects for ear were revealed for Dichotic Digits in the directed response condition, $F = 6.08$, $df = 1, 18$, $p = .024$, and for Competing Words, $F = 61.18$, $df = 1, 18$, $p < .001$. Interactions between ear and group occurred for Dichotic Digits in the directed response condition, $F = 5.23$, $df = 1, 18$, $p = .035$, and for Competing Words, $F = 12.64$, $df = 1, 18$, $p = .002$.

Follow-up ANOVA on percentage scores obtained by each ear revealed main effects for group during Dichotic Digits testing in the directed response condition for both the right ear, $F = 4.494$, $df = 1, 18$, $p = .048$, and for the left ear, $F = 6.009$, $df = 1, 18$, $p = .025$. A main effect for group during Competing Words testing was revealed only for the left ear, $F = 14.86$, $df = 1, 18$, $p < .001$.

In summary, the free recall condition of the Dichotic Digits test failed to produce significant differences between groups or between ears within either group of subjects. The directed response condition of the Dichotic Digits test produced significant differences both between groups of subjects and between the right and left ears in dyslexic subjects but not in control subjects. The Competing Words test produced significant differences between groups only for left ear performance. The Dichotic CV test produced significant contrasts with other dichotic listen-

ing tests. Between groups of subjects, Dichotic CVs demonstrated significant differences that were similar for both ears.

## Comparison of Results to Normative Data

### *Dichotic Digits test*

Normal scores on the Dichotic Digits test for children age 11 in the free recall condition are 88 percent or better in the left ear and 90 percent or better in the right ear, with the normal REA at 10 percent or less (Musiek, 1983). Normative scores have not been obtained for directed response conditions using the Dichotic Digits test. The directed response format was used in this study to explore the effects of attentional bias in the free recall condition during Dichotic Digits testing and to better compare results on Dichotic Digits testing with results on Competing Words testing during which the directed response format is used.

Separate ear scores during Dichotic Digits testing are shown for both control and dyslexic groups in Figure 1.

As seen in Figure 1, control subjects performed at levels in both ears that were within normal limits for both the free recall and directed response conditions. Unexpectedly, control subjects performed more poorly in the right ear than in the left ear in the free recall condition during Dichotic Digits testing. In the directed response condition, control subjects performed at overall levels that were very similar to those obtained in the free recall condition, with a more typical better performance in the right ear than in the left ear. Dyslexics showed poorer performance overall and more interaural asymmetry than controls. The right ear outperformed the left ear in both listening conditions. Both groups of right-handed subjects demonstrated more rightward laterality in the directed response condition than in the free recall condition.

### *Competing Words Test*

Of the tests used in this study, only the Competing Words test produced an REA in all of the subjects. Normal scores on the Competing Words Subtest of the SCAN for children age 11 were originally calculated as combined scores for the two ears (Keith, 1986). Mean scores for males and females in the normative sample did not differ significantly and were collapsed by Keith for analysis. Because no significant differences were found between average performance by males and females in the normative sample, the scores for the two groups were collapsed into a single average score within each age level. For children age 11, combined scores for both ears of 78 (of 100 possible correct responses) or lower were considered below normal for the test.

To analyze results on the Competing Words test in the same manner as results from other dichotic listening tests used in this study, separate total left- and right-ear scores were converted to percentage scores for each subject. Mean scores for each group by ear are shown in Figure 2.

All subjects in both groups demonstrated better performance in the right ear than in the left ear on Competing Words. The magnitude of the interaural asymmetry was greater in the dyslexic subjects than in the controls. Normative data for laterality based on a simple difference score, *d*, are not directly available from the published report for the SCAN. Results

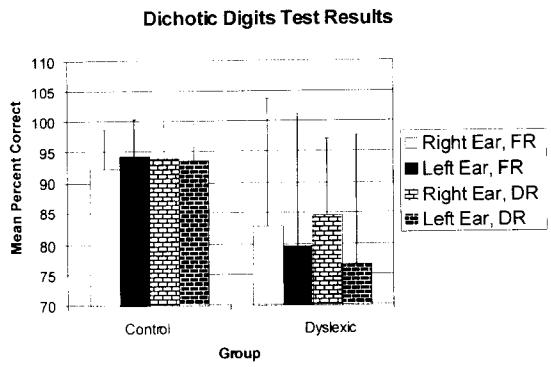


**Figure 1** Right- and left-ear scores from the Dichotic Digits tests in free recall (FR) and directed response (DR) conditions for all subjects.

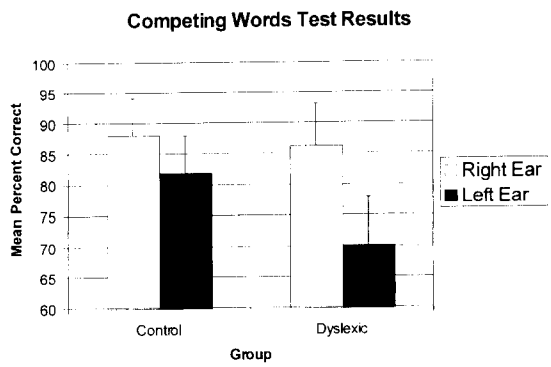


**Figure 2** Right- and left-ear scores from the Competing Words subtest of the SCAN for all subjects.

reported for the ear differences during the right-ear-first and left-ear-first conditions suggest that rightward laterality scores from approximately 11 to 15 percent are mildly abnormal, occurring in 5 to 10 percent of the children tested. Rightward laterality scores from 16 to 20 percent are moderately abnormal and occurred in 2 percent or fewer of the children tested. Scores above 20 percent are severely abnormal. Using a *d* score of greater than 10 as a criterion for abnormal asymmetry on the Competing Words subtest, 7 of 10 dyslexic patients demonstrated abnormal rightward asymmetry with a left-ear deficit. Of those 7 subjects, 2 demonstrated mild asymmetry, 1 demonstrated moderate asymmetry, and 4 demonstrated severe asymmetry. One control also demonstrated mildly abnormal asymmetry with a *d* score of 14.

### *Dichotic CV Test*

Normal scores on Dichotic CV tests tend to be lower than scores on other dichotic listening tests. For 11-year-old children, normal values for the free recall version of the Dichotic CV test used in this study are 39 percent for the right ear and 27 percent for the left ear plus 25 percent for reports from both ears. If the score for both ears is combined with the scores for each ear separately, this results in overall right ear performance of 64 percent and left-ear performance of 52 percent.

Mean scores for the two ears on Dichotic CV testing for both control and dyslexic subjects are shown in Figure 3. Scores were lower than those reported previously for this version of the Dichotic CV test. Standard deviations are not available for this Dichotic CV test, so it was not possible to determine if the results for control subjects differed significantly from published normal values.

As shown in Figure 3, control subjects performed at higher levels in both ears than dyslexic subjects, and both groups demonstrated better performance in the right ear than in the left ear.

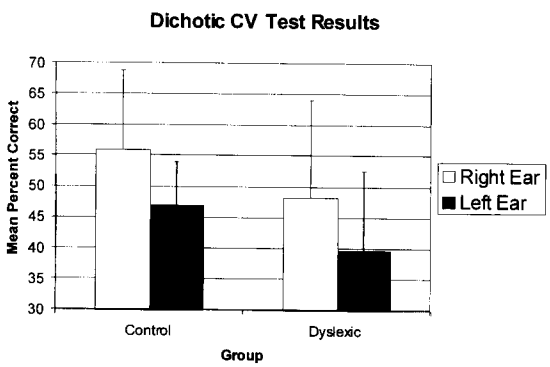


**Figure 3** Right and left ear scores from the Dichotic Consonant-Vowel (CV) test for all subjects.

### Summary of Dichotic Listening Tests

Discrepancies from normal for the dichotic listening tests are displayed in Table 3. Normative data are available for each ear on the Dichotic Digits test (free recall condition), and conversions to standard scores for combined ear scores are available for the Competing Words test. For the Dichotic Digits test (directed response condition) and the Dichotic CV tests, discrepancies of 1 SD or greater from the normal values obtained by control subjects in this study are used.

As shown in Table 3, all of the dyslexic subjects demonstrated performance on at least one of the dichotic listening tests that fell below normal or average levels. Several of the dyslexic subjects demonstrated lower performance on more than one dichotic listening test.

More dyslexic subjects were characterized as abnormal on dichotic listening results on the basis of left-ear performance than on the basis of right-ear performance. As shown in the total column for each group of subjects, 6 of 10 dyslexic subjects would be characterized as abnormal when scores for the left ear on the two Dichotic Digits tests are examined for discrepancies from normal. On the Competing Words test, 7 of 10 dyslexic subjects would be diagnosed as abnormal based on a laterality score of greater than 10 percent. Using the criterion that any left-ear score during the Competing Words test below 76 percent is 1 SD or greater below scores obtained by control subjects, the same 7 dyslexic subjects would be diagnosed as abnormal. Two dyslexic subjects, CL and ML, obtained left-ear scores of 76 percent, placing them at the cutoff for normal left-ear performance. A similar criterion of left-ear performance below 1 SD on the Dichotic CV test would be regarded as abnormal for 5 of 10 dyslexic subjects.

In the directions provided for the test, raw scores for the two ears on the Competing Words subtest of the SCAN are to be combined and converted to standard scores for the purpose of identifying disordered behavior. Standard scores below 7 are considered to be indicative of an auditory processing problem, with scores above 4 characterized as borderline and those at 4 or

**Table 3 Discrepancies from Normal Results**

| | *Dyslexic Subjects* | | | | | | | | | | | *Control Subjects* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Test Result* | *CC* | *JH* | *VK* | *CL* | *RL* | *ML* | *JM* | *MP* | *SS* | *JW* | *Total* | *AB* | *KB* | *BC* | *BF* | *GM* | *JM* | *BS* | *JS* | *CS* | *HS* | *Total* |
| DD-FR < 90%-R | * | | * | * | | | | | * | | 4 | | | * | * | | | | | * | * | 4 |
| DD-FR < 88%-L | * | * | * | * | * | | | | * | | 6 | * | | | * | | | | | | | 2 |
| DD-DR < 90%-R | * | * | * | * | * | | * | | * | | 7 | | * | | | | | | | | * | 2 |
| DD-DR < 85%-L | * | | * | * | * | | * | | * | | 6 | | | | | | | | | | * | 1 |
| CW SS < 7 | | * | * | | | | | | | | 2 | | * | | | | | | | | | 1 |
| CW < 76%-L | * | * | * | | | | * | * | * | * | 7 | | | | | | | | | | | 0 |
| CW EAP < 10% | * | * | * | | * | | * | * | | | 6 | | | | | | | | | | | 0 |
| CW REA > 10% | * | * | * | | | | * | * | * | * | 7 | | | * | | | | | | | | 1 |
| DCV < 43%-R | | | * | * | | | | | | * | 3 | | | | | | | | | | * | 1 |
| DCV < 40%-L | * | | | * | | | * | * | * | | 5 | | | | | | | | | | | 0 |
| Total | 8 | 6 | 9 | 6 | 4 | 0 | 6 | 4 | 7 | 3 | | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 4 | |

R = right ear; L = left ear; DD-FR = Dichotic Digits in free recall; DD-DR = Dichotic Digits in directed response; CW = Competing Words; SS = standard score; EAP = ear advantage prevalence; REA = right-ear advantage; DCV = Dichotic Consonant-Vowels.

below characterized as disordered. On the basis of standard score for the results obtained by both ears, only 2 of the dyslexic subjects would be identified as having abnormal performance, and both would have fallen into the borderline category. An alternative method recommended in the test instructions for identifying abnormal behavior on the Competing Words subtest is to compare the raw score difference in performance between the two ears in each of the two listening conditions, right ear first and left ear first. Normative data have been provided to indicate the prevalence of results obtained by this scoring method. On the basis of performance in either of the two listening conditions that fell below the prevalence value of 10 percent, 6 of the dyslexic subjects would be categorized as abnormal. Compared to using a laterality score that measures the simple difference score between the two ears across both conditions combined (REA), this method appears to be producing somewhat different results. Five of the 7 dyslexic subjects categorized with a significant interaural asymmetry based on the REA as a simple difference score across both conditions are also categorized under this method and one dyslexic subject whose REA was not greater than 10 percent (RL) was categorized as abnormal on the basis of low prevalence scores in both conditions, right ear first and left ear first. Because his laterality significantly reversed from rightward in the right-ear-first condition to leftward in the left-ear-first condition, this child's interaural asymmetry also reversed, resulting in an overall low simple difference between the two ears.

### Summary of Results

Differences between the two groups of subjects were found for all three dichotic listening tests. Results from the Dichotic Digits test in the directed response condition and the Competing Words test produced the greatest differences between groups for scores obtained in the left ear.

The Competing Words test produced scores in control subjects that most closely fit the idealized normal results for a verbal dichotic listening task, and among all of the tests used in the study, it was the only test that produced a significant difference between the right and left ears when results were obtained as a simple difference score across the two listening conditions. Under the same scoring criteria of a simple difference score, the Competing Words test identified the largest number of subjects as abnormal. When performance was evaluated under the recommended standard scoring conditions that combine performance in the two ears, important information about the left ear's reduced performance relative to the performance in the right ear was lost, and overall results appeared normal for several children.

## DISCUSSION

This study proposed to answer four basic questions about dichotic listening tests. In response to the first question of whether all such tests would produce a consistent direction and degree of hemispheric lateralization, the answer is negative. Results from the Dichotic

Digits test in the free recall condition and the Dichotic CV test are consistent with previous evidence that free recall listening conditions produce a high amount of variability with lateralization measures that may be reversed from what is expected or different from results obtained through other measures (Zatorre, 1989; Hugdahl et al, 1997). As recommended, efforts to control for attentional strategies with the directed response condition for Dichotic Digits and with the Competing Words test produced different results that may have been more reflective of hemispheric lateralization for language (Bryden et al, 1983; Asbjørnsen and Hugdahl, 1990). Uncontrolled attentional strategies may bias a listener's responses toward either the easier right ear or toward the more difficult left ear. The effect of attentional strategies during Dichotic Digits testing is strongly suggested in the results obtained for dyslexic subject VK, whose performance fell dramatically below that of all other subjects on the free recall Dichotic Digits test. Under the directed response condition, performance for VK improved significantly, especially for the right ear, and on Competing Words, performance for VK was similar to that of other dyslexic subjects.

Similar effects of attentional bias during the free recall condition may have been ameliorated during the directed response condition of the Dichotic Digits test. Some of the children who failed to show the expected REA during free recall testing did demonstrate an REA during directed response. This suggests that biasing attention by directing the response during a dichotic listening test may produce more reliable laterality indices at the cost of losing information about attentional strategies used by the listener. Since laterality is such an important measure for diagnosing an auditory processing disorder, test conditions that will produce the most valid measure of both direction and degree of lateralization are essential (Jerger and Musick, 2000). The presence of several reversed laterality results during the free recall condition suggests that compared to directed response, free recall may reflect laterality more poorly.

Inconsistencies in lateralization results occurred for both groups of children, suggesting that in addition to attentional factors, they may be related to stimulus characteristics of the test. The Dichotic Digits test may be too easy for use in 11-year-old children. Scores in both groups of subjects were at or near maximum performance, and several of the right-handed subjects who produced an REA with the Competing Words test failed to produce the anticipated REA for one or both versions of the Dichotic Digits test. A reversal in laterality results observed in the children is not likely to have occurred as a result of variability in hemispheric dominance for language. Because it is composed of a closed set of 9 highly familiar numbers (the numbers from 1 to 10, excluding 7), the Dichotic Digits test has a relatively low verbal workload that may have produced a ceiling effect in children of this age. Each trial was composed of four digits, two presented to each ear simultaneously, and the children were encouraged to guess when unsure of a response. When listening to double digits, the chance of guessing a correct response is enhanced by both the limited number of choices to make for each trial and the lighter demands on memory when the maximum number of stimuli per ear is consistently limited to two. Dichotic Digits testing with a higher verbal workload test can be achieved by the use of three or four digit pairs or by randomly presenting single, double, and triple pairs of digits to the listener so that stimulus length is uncertain (Strouse and Wilson, 1999).

In response to the third question posed, test results did demonstrate differences between the two groups of children with respect to interaural asymmetry. Reference to Table 3 shows that a simple criterion of left ear score below 76 percent on the Competing Words test identified, as abnormal, 7 of the 10 dyslexic children and 0 of the 10 control children. No other test or combination of tests achieved this degree of separation between the groups.

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