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Original Article

Diagnosis of amblyaudia in children referred for auditory processing assessment

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Abstract

Children ($n = 141$) referred to 5 clinical sites for auditory processing disorder assessment were tested with two dichotic listening tests, one with word pairs and the other with pairs of digits, as part of a comprehensive diagnostic battery. Scores from the Randomized Dichotic Digits Test and the Dichotic Words Test were compared to age-appropriate norms and used to place children into one of four diagnostic categories (normal, dichotic dysaudia, amblyaudia, or amblyaudia plus) or to identify them as undiagnosed. Results from the two dichotic tests led to diagnosis of 56% of the children tested, leaving 44% undiagnosed. When results from a third dichotic listening test were used as a tie-breaker among originally undiagnosed children, a total of 79% of the children's scores were placed into diagnostic categories (13% normal, 19% dichotic dysaudia, 35% amblyaudia, 12% amblyaudia plus). Amblyaudia, a binaural integration deficit evident only from dichotic listening test results, was most prevalent (35% + 12% = 47%) in this population of children suspected of auditory processing weaknesses. Since amblyaudia responds to treatment with Auditory Rehabilitation for Interaural Asymmetry (ARIA), clinicians are guided through the protocol for identifying diagnostic categories so that they can make appropriate referrals for rehabilitation.

Key Words: Auditory processing disorder, binaural integration, dichotic, audiology

Introduction

Amblyaudia is a type of auditory processing disorder (APD) characterized by deficits in the binaural integration of verbal information (Moncrieff, 2011) that is diagnosed by results from dichotic listening (DL) tests. The hallmark pattern of amblyaudia is an abnormally large asymmetry between the two ears during DL tasks with either normal or below normal performance in the dominant ear. The underlying mechanisms of amblyaudia are unknown, but they may be similar to the neural mechanisms of amblyopia or 'lazy eye' in the visual system. In amblyopia, activation in the dominant pathway suppresses information in the non-dominant pathway, leading to an indistinct encoding of visual information at the level of the cortex (Doshi & Rodriguez, 2007). A similar suppression by the dominant ascending pathway may interfere with clear encoding of the auditory signal during routine binaural listening in amblyaudia. Suppression of the ipsilateral signal by the dominant contralateral pathway was evident in early studies with competing digits and served as the basis of the structural model of DL proposed by Doreen Kimura (1961). She noted that individuals identify more verbal material presented to the ear that transmits through more abundant contralateral fibers to their language-dominant hemisphere. Because of its direct contralateral pathway to the left cortical hemisphere, the right ear typically performs better during DL testing in listeners who process language in the left hemisphere. In those who process language in their right hemisphere, the left ear performs better during DL tests (Denes & Caviezel, 1981).

Kimura proposed that because listeners could simultaneously identify information heard at the opposite ear, ipsilateral to their language-dominant hemisphere, information must connect contralaterally to the opposite cortex and then transfer to the language-dominant hemisphere via the corpus callosum. The inter-hemispheric transfer of information aspect of Kimura's structural model was supported by evidence of a near-complete extinction of a listener's ability to identify verbal material presented to the ipsilateral, non-dominant ear following surgical separation of the corpus callosum (Springer & Gazzaniga, 1975; Damasio, 1976; Springer, 1978; Pollmann, 2002). Post-surgical patients later

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Abbreviations:

AMB	Amblyaudia
AMB+	Amblyaudia plus
ANL	Auditory Neurophysiology Laboratory
APD	Auditory processing disorder
ARIA	Auditory Rehabilitation for Interaural Asymmetry
CHP	Children's Hospital of Pittsburgh
DD	Dichotic dysaudia
DL	Dichotic listening
DWT	Dichotic Words Test
HN	Hear Now
LEA	Left-ear advantage
RDDT	Randomized Dichotic Digits Test
REA	Right-ear advantage
SSKL	SoundSkills
UND	Undiagnosed
WNL	Within normal limits

regained some ability to identify material presented to their ipsilateral ears (Musiek & Wilson, 1979), suggesting that dominant pathway suppression was relieved when ipsilateral information could not transfer via the corpus callosum. Contralateral suppression of ipsilateral activation and interhemispheric transfer via the corpus callosum are primary benchmarks of the structural theory of DL listening in normal listeners (Kimura, 2011).

For decades, dichotic tests have been used to investigate hemispheric dominance for language and binaural integration skills in children with listening, learning, and reading disabilities thought to stem from an underlying APD. DL results from children with disabilities were both similar to those obtained in typically developing peers (Lovrich & Stamm, 1983; Prior et al, 1983; Dickstein & Tallal, 1987; Swanson, 1987) and different in three ways as shown in Table 1. Lower scores in both ears (overall) were observed in children with language, reading, or auditory processing when they were tested with consonant-vowels (CVs) (Hynd, 1979; Tobey et al, 1979), digits (Keefe & Swinney, 1979; Pelham, 1979; Grogan, 1986; Pinheiro, 2010), words (Harris et al, 1983; Roush & Tait, 1984), and sentences (Vanniasegaram et al, 2004). Other children performed poorly in their right ears leading to a smaller right-ear advantage (REA) (Thomson, 1976; Harris et al, 1983; Obrzut, 1985; Kershner & Micallef, 1992; Helland & Asbjornsen, 2001), and some produced poorer performance in the left ear leading to a larger REA (Ayres, 1977; Johnson et al, 1981; Dermody et al, 1983a; Aylward, 1984; Berrick, 1984; Moncrieff & Musiek, 2002; Vanniasegaram et al, 2004; Moncrieff & Black, 2008). Researchers proposed several models related to hemispheric dominance for language in children with disabilities, but the heterogeneity of results across different studies ultimately made it impossible to achieve consensus.

A recent survey found that audiologists who assess children for APD use DL most frequently, indicating that it has a high degree of clinical utility (Emanuel et al, 2011). A typical APD test battery often produces heterogeneous results because it assesses a wide array of auditory skills (ASHA, 2005; AAA, 2010). The test battery approach has been criticized for lacking deficit specificity (Cacace & McFarland, 1998), for introducing confounds from supramodal factors such as cognition and attention (Cacace & McFarland, 2013), and for a failure to incorporate non-speech stimuli (Rosen, 2005). Over the years, attempts to characterize results from heterogeneous tests into theoretical models of auditory processing have not been successful (Neijenhuis et al, 2003; Cacace & McFarland, 2005; Jutras, 2007), leading some to conclude that the diagnosis of APD itself is unworkable (Wilson & Arnott, 2013).

Alternatively, clinicians can compare inter-test results within each assessed auditory skill. The clinician uses a battery of tests but evaluates results from one processing skill independently of results from other skills that may or may not be related. Given the variability from DL testing alone, this approach allows the clinician to separately examine binaural integration skills and to characterize different results. As shown in Figure 1, there are four patterns of results that can be obtained from DL tests. Normal scores can be equal in both ears or demonstrate a small interaural asymmetry favoring the dominant ear, defined as the ear with the higher score from the test. This pattern, designated as within normal limits (WNL), is shown in the first set of bars. Scores can be below the cut-off for normal in both ears, again with either no or a small interaural asymmetry (as seen in the second set of bars). We propose to term this pattern dichotic dysaudia (DD) because it represents bilateral symmetrical weakness in a dichotic listening task despite normal monaural listening performance in each ear. A third pattern occurs when the dominant ear score is normal but the non-dominant ear score falls below the normal cut-off as shown in the third set of bars. In this case, interaural asymmetry (either REA or LEA) is abnormally high and the results represent a unilateral weakness during binaural integration of two competing signals. This pattern is termed amblyaudia (AMB) (Moncrieff, 2011). Another pattern that can suggest amblyaudia is a normal non-dominant ear score together with an above-normal score in the dominant ear, yielding a larger than normal interaural asymmetry. When scores in both ears are below normal as in the second pattern, but the value of interaural asymmetry is also abnormally high, a fourth pattern occurs that is a combination of dichotic dysaudia and amblyaudia. This pattern is called amblyaudia plus (AMB+) and children with this pattern of DL scores are likely to demonstrate characteristics of both deficits.

The dichotic dysaudia pattern could occur for several reasons, including a cognitive deficit, a language problem, or a failure to maintain attention across the duration of the test. The deficit may stem from poor phonological representations following auditory deprivation, but because it could also be attributed to global factors, it is difficult to attribute this pattern solely to auditory processing. An abnormal interaural asymmetry is difficult to attribute to general deficits in cognition, language, or attention because they are likely to cause weaknesses in both ears. The presence of an interaural asymmetry (amblyaudia and amblyaudia plus) represents a unilateral deficit in the binaural integration of verbal information that is uniquely assessed through DL testing. One mechanism for the large interaural asymmetry is abnormal suppression by contralateral pathways ascending from the listener's dominant ear that hinders selectivity of information ascending from the non-dominant side. This hypothesis has support from a study investigating cortical neural representations following induction of a temporary conductive hearing loss in animals (Polley et al, 2013). This effect was also hypothesized to explain the poor cortical response in children with binaural integration deficits when asked to monitor target stimuli in their weaker ear during competing presentations from their dominant ears (Moncrieff, 2004). Responses were more robust in those children when stimuli was presented to their dominant ear, even when they were supposed to be ignoring that side and attending to presentations on their non-dominant side. Others have proposed that verbal stimuli from the listener's non-dominant ear arrive at the opposite cortical

Table 1. Outcomes from studies of dichotic listening in children with disabilities.

Author/s	*Year*	*Dx category*	*Mean age or range*	*Stimulus*	*Average results*
Lovrich & Stamm	1983	RD	12	CV	No difference
Prior et al	1983	RD	11.6–12.1	Words	No difference
Dickstein & Tallal	1987	RD	12–13	CV	No difference
Swanson	1987	LD	11–12	Words	No difference
Hynd et al	1979	LD	8–10	CV	Lower overall
Keefe & Swinney	1979	RD	10	Digits	Lower overall
Pelham	1979	RD	8–12	Digits	Lower overall
Tobey et al	1979	APD	CV	Lower overall	
Harris et al	1983	Token test groups	6–8	Words	Lower overall
Roush & Tait	1984		9.4	Filtered speech	Lower overall
Grogan	1986	RD	12–13	Digits	Lower overall
Vanniasegram et al	2004	Older SusAPD	6–14	Sentences	Lower overall
Pinheiro et al	2010	LD	8–12	Digits	Lower overall
Thomson	1976	RD	9–12	Digits and words	Lower REA
Harris et al	1983	Token test groups	6–8	CV	Lower REA
Obrzut et al	1985	LD	7–12		
Kershner & Micallef	1992	RD	11.3	CV	Lower REA
Wasserman et al	1999	Substance abusers		CV	Lower REA
Helland & Asbjørnsen	2001	RD		CV	Lower REA
Ayers	1977	LD	6–10	CV	Higher REA
Johnson et al	1981	LD	6–12	Words	Higher REA
Dermody et al	1983	RD		CV	Higher REA
Rovet	1983	Delayed males			Higher REA
Aylward	1984	RD	9.9	Digits	Higher REA
Berrick et al	1984	LD	8–11	Words	Higher REA
Nass et al	1990	Precocious adrenarche	7–14	CV	Higher REA
Asbjørnsen et al	2000	OME	9.0–9.4	CV	Higher REA
Vanniasegram et al	2004	Younger SusAPD	6–14	Sentences	Higher REA

Abbreviations: APD = auditory processing disorder; CV = consonant vowel; LD = language delay; OME = otitis media with effusion; RD = reading disorder; REA = right-ear advantage; Sus = suspected.

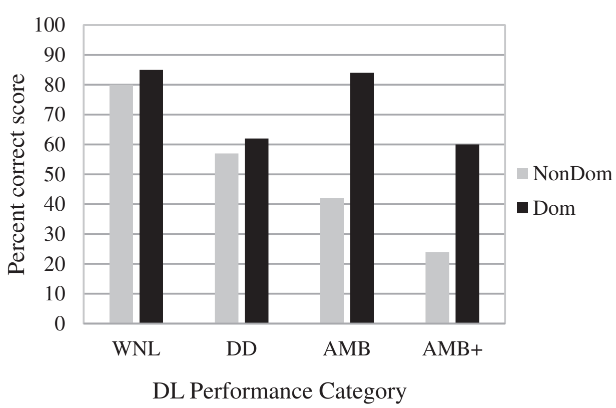

Figure 1. Hypothetical patterns of performance from dichotic listening tests. Gray bars represent performance in the listener's non-dominant ear and black bars represent performance in the listener's dominant ear.

Table 2. Demographic information about children at each site.

Site	*Female*	*Male*	*Total*	*Average age*
ANL	7	8	15	9.27
APC	5	6	11	8.50
CHP	29	27	56	8.61
HN	1	10	11	9.55
SSKL	14	34	48	8.98

Abbreviations: ANL = Auditory neurophysiology laboratory at the University of Pittsburgh; APC = Auditory processing center; CHP = Children's Hospital of Pittsburgh; HN = Hear Now; SSKL = SoundSkills APD clinic.

hemisphere and then fail to properly connect to the language hemisphere because of weak inter-hemispheric transfer through a poorly myelinated corpus callosum (Jerger, 1999; Jerger et al, 2004). Another possibility is that the neural response ascending from the listener's non-dominant ear interferes with normal integration of binaural signals at the level of the cortex.

The purpose of this study was to measure the prevalence of the amblyaudia, amblyaudia plus, and dichotic dysaudia diagnoses at five clinical sites. Scores from two DL tests with normative information for dominant and non-dominant ears were used to identify abnormalities and to group results into diagnostic categories. A diagnostic category was assigned when results from the two tests agreed. When they did not agree, results were characterized as undiagnosed (UND). When children originally characterized UND were evaluated with a third DL test at the same appointment, results from the third test were examined to determine if they matched with results from one of the other two tests. In those cases, two out of three tests were used to categorize results. Further analyses of scores were used to identify the severity of identified deficits and to quantify the prevalence of each category in children referred for assessment.

Methods

A total of 141 children ages 6 to 12 years referred for clinical APD assessment were tested at five different locations in Pittsburgh, Clinton, and Laguna Niguel in the USA, and Auckland, New Zealand. Demographic information regarding the children is included in Table 2. Parents provided consent via Health Insurance Portability and Accountability Act (HIPAA) compliant procedures at the Children's Hospital of Pittsburgh, the Auditory Processing Center, Clinton, Mississippi, and HearNow at Abramson Audiology, Laguna Niguel. Parents provided signed consent forms as approved by the Institutional Review Board of the University of Pittsburgh in the Auditory Neurophysiology Laboratory, and as approved by the University of Auckland Human Participants Ethics Committee at the SoundSkills APD Clinic in New Zealand. Where required, children also provided written assent for participation. All children demonstrated normal hearing thresholds at 25 dB HL or less at all frequencies from 500 to 4000 Hz prior to participation. Auditory processing testing occurred in a sound-treated room or booth with test materials delivered through insert earphones via a two-channel clinical audiometer connected to a CD player or computer. Each child was instructed according to the specific directions for each test, responses were scored on pen and paper forms, and responses were converted to percent correct.

All children were evaluated for binaural integration skills with the randomized dichotic digits test (RDDT) (Strouse & Wilson, 1999a; Moncrieff & Wilson, 2009) and the dichotic words test (DWT) (Moncrieff, 2011) as part of an APD battery of tests. The RDDT and DWT are appropriate for assessment in children beginning at age 5. Norms based on 95th percentile scores following bootstrapping procedures are available for clinical diagnostic purposes (Moncrieff & Wilson, 2009; Moncrieff, 2015). Both tests were presented dichotically at 50 dB HL. The RDDT is comprised of 18 presentations of randomly occurring single, double, and triple pairs of digits for a total of 54 presentations. The DWT is comprised of 25 pairs of single-syllable words. The child was instructed to listen to each presentation of numbers or words and to repeat all of the numbers or words heard each time, guessing if not sure about what was heard. The mode of presentation was free recall as there were no instructions to present the information in any particular order. Results from both tests were scored as percent correct in left and right ears and converted to percent correct in dominant and non-dominant ears. Ear advantages were calculated as the difference in percent correct between dominant and non-dominant ear scores.

Each child's dominant ear, non-dominant ear, and ear advantage scores were compared to age-specific normative data. The 2-pairs condition of the RDDT was used for normative purposes because it has been shown to be the most sensitive measure from that test for measuring a listener's binaural integration skills (Strouse & Wilson, 1999b). The first free recall list of the DWT was compared to age- and gender-specific normative data (Moncrieff, 2015). The low and high criterion cut-off limits for each test are shown in Table 3. The flow chart shown in Figure 2 was used when the non-dominant ear score fell below the lower bound cut-off score. The flow chart shown in Figure 3 was used when the non-dominant ear score fell within the lower and upper bound cut-off scores. Because the standard for diagnosis of an APD depends upon two below-criterion test scores, results were characterized as WNL, DD, AMB, or AMB+ only when the same pattern occurred in both tests, as shown in the decision matrix in Table 4.

Table 3. Normative cut-off scores for dichotic listening tests.

Randomized dichotic digits test, 2-pairs condition

Ages	Low	High
Non-dominant ear		
5–6	46	55
7–8	63	71
9–10	70	77
11–12	82	87
Dominant ear		
5–6	72	79
7–8	85	89
9–10	87	92
11–12	91	94
Ear advantage		
5–6	20	29
7–8	17	24
9–10	13	18
11–12	7	10

Dichotic words test, free recall condition

Females			Males		
Non-dominant ear			Non-dominant ear		
Ages	Low	High	Ages	Low	High
5	52	69	5	38	60
6–7	65	74	6–7	53	64
8–10	68	75	8–10	65	71
11–12	76	83	11–12	70	79
Dominant ear			Dominant ear		
Ages	Low	High	Ages	Low	High
5	69	84	5	66	77
6–7	79	85	6–7	73	81
8–10	82	86	8–10	81	85
11–12	88	91	11–12	82	88
Ear advantage			Ear advantage		
Ages	Low	High	Ages	Low	High
5	9	25	5	14	32
6–7	9	16	6–7	15	22
8–10	10	15	8–10	13	18
11–12	7	13	11–12	7	14

Low and high scores are the lower and upper cut-offs identified through bootstrapping methods performed on percent correct scores among typically developing children and represent the 95th percentile confidence interval for normal performance. Results for the RDDT did not show any effect of gender.

For many, the category was identical for both tests, but for some, the score on one DL test led to the AMB+ category which represents both DD and AMB. When the second test score led to DD, then the final diagnostic category for that child was DD because the DD deficit is present in the AMB+ category. When the second test score led to AMB, then the final diagnostic category was AMB because amblyaudia is present in the AMB+ result. When results did not lead to the same category, the child's scores were characterized as UND.

A three-way analysis of variance (ANOVA) was performed on dominant and non-dominant ear scores with age, gender, and site as

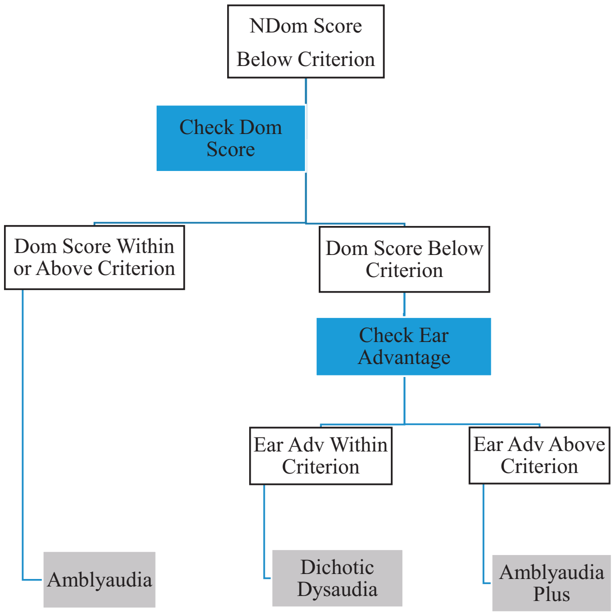

Figure 2. Flow chart to use when the non-dominant ear score falls below the lower bound cut-off score appropriate for a child's age. Results are shown in unshaded boxes. Instructions are shown in darker shaded boxes and interpretations are shown in light shaded boxes.

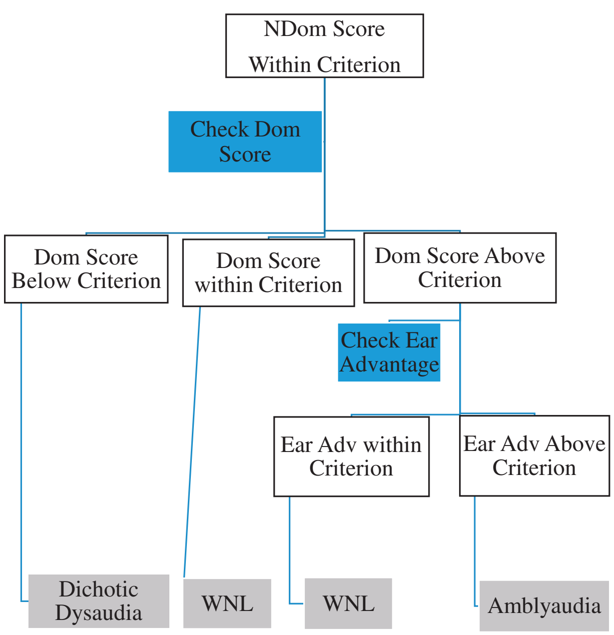

Figure 3. Flow chart to use when the non-dominant ear score falls above the upper bound cut-off score appropriate for a child's age. Results are shown in unshaded boxes. Instructions are shown in darker shaded boxes and interpretations are shown in light shaded boxes.

between-group variables. Similarly, diagnostic category was analysed with univariate analysis of variance (ANOVA) for significant effects of age, gender, and site. The prevalence of each diagnostic category from the two DL tests was measured and further analysed for significant effects of age, gender, and site. The numeric difference between each child's individual ear scores from the cut-off scores for normal was measured for each test and the prevalence of different values indicating mild to severe discrepancies were quantified.

The staggered spondaic words test (SSW), the competing words subtest of the SCAN (CWT), or the dichotic digits test (DDT), (Katz & Smith, 1991; Musiek, 1999; Keith, 2000) was used at some clinical appointments. Those tests were administered according to standard clinical practice at 50 dB HL in both ears. Scores for correctly identified items were tallied and converted to percent correct for each ear. Results were compared to available normative information for left and right ear scores and were then categorized in the same manner as scores for the RDDT and DWT. Results from these tests were used as tie-breakers when results from the RDDT and DWT led to the UND category. The prevalence of diagnostic categories based on results from three DL tests was measured and a separate multivariate ANOVA was used to determine if there were significant effects of age, gender, or site on these secondary results.

Results

Diagnoses from RDDT and DWT

Based on scores from the RDDT and DWT, a total of 79 children (56%) produced results that could be categorized. As shown in the pie chart at the top of Figure 4, results from 25 children (18%) were categorized DD, from 33 (23%) were categorized AMB, from 14 (10%) were categorized AMB+, and from seven (5%) were categorized WNL. Results from 62 children (44%) were categorized UND because they did not fit into one diagnostic category. The UND category represented results that were WNL plus any other category (DD, AMB or AMB+), or were AMB and DD for the two tests.

Individual results are shown in Table 5. Scores that were below criterion for non-dominant or dominant ear are shown in italics. Scores that were above criterion for dominant ear or ear advantage are shown in bold. The DD category includes those whose scores for both tests fit the DD category and those whose scores fit the DD category for one test and the AMB+ category for the other test (because AMB+ has reduced scores in both ears consistent with DD). The AMB category includes those whose scores fit the AMB category for both tests, or for one test and the AMB+ category for the other test (because AMB+ has the large interaural asymmetry consistent with AMB). The AMB+ category included only those children whose scores were consistent with the AMB+ category for both tests.

There was no significant difference in age across the sites (average age ranged between 8.6 and 9.6 years) and there were no significant effects of age, gender, or site on diagnostic category. There were no significant effects of gender on any ear scores. Age had a significant effect on dominant ear scores from the DWT, $F\ (6,\ 140) = 2.28$, $p = 0.042$, and from the RDDT, $F\ (6,\ 140) = 2.54$, $p = 0.025$. Age also affected the non-dominant ear scores from the DWT, $F\ (6,\ 140) = 2.9$, $p = .012$, and from the RDDT, $F\ (6,\ 140) = 3.60$, $p = .003$. The effects of age were close to significant on ear advantage scores from the DWT, $F\ (6,\ 140) = 2.12$, $p = 0.058$, and the RDDT, $F\ (6,\ 140) = 2.14$, $p = 0.056$. As anticipated, ear scores increased and ear advantages decreased with age; post-hoc tests with Bonferroni correction yielded significant differences only between the extreme age levels. There were significant effects of site on non-dominant ear scores, F (4,

Table 4. Final diagnosis based on two test outcomes.

RDDT TEST OUTCOME	*WNL*	*AMB R dom*	*AMB L dom*	*AMB + R dom*	*AMB + L dom*	*Dichotic dysaudia only*
WNL	WNL	UND	UND	UND	UND	UND
AMB R dom	UND	AMB R dom	UND	AMB R dom + unconf DD	UND	UND
AMB L dom	UND	UND	AMB L dom	UND	AMB L dom + unconf DD	UND
AMB + R dom	UND	AMB R dom + unconf DD	UND	AMB + R dom	Dichotic dysaudia	Dichotic dysaudia
AMB + L dom	UND	UND	AMB L dom + unconf DD	Dichotic dysaudia	AMB + L dom	Dichotic dysaudia
Dichotic dysaudia only	UND	UND	UND	Dichotic dysaudia	Dichotic dysaudia	Dichotic dysaudia

See Table 5 footnotes.

RDDT: Randomized Dichotic Digits Test DWT: Dichotic Words Test WNL: Within normal limits UND: Undiagnosed AMB: Amblyaudia AMB+: Amblyaudia + Dichotic Dysaudia DD: Dichotic Dysaudia R dom: Right dominant L dom: Left dominant unconf: unconfirmed.

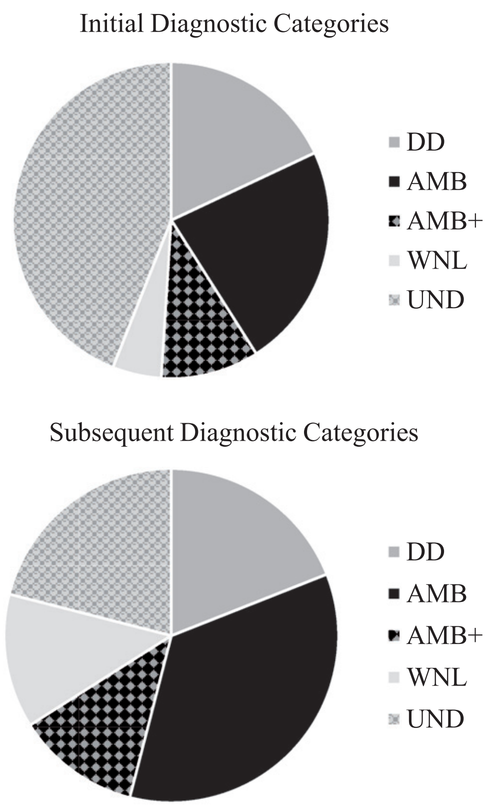

Figure 4. Pie charts showing the proportion of children whose dichotic listening scores resulted in placement into each diagnostic category. The pie chart at the top of the figure represents the category placements following the RDDT and DWT tests only. The pie chart at the bottom of the figure represents the category placements following the RDDT, DWT, and one other dichotic listening test used as a tie-breaker.

140) = 3.90, $p = 0.006$ and dominant ear scores, F (4, 140) = 4.20, $p = 0.004$ from the DWT and on ear advantage scores from the RDDT, F (4, 140) = 4.22, $p = 0.003$. Post-hoc tests with Bonferroni correction indicated that children tested at site HN produced significantly lower dominant ear scores than children tested at all other sites, as shown in Figure 5. Children at site HN also produced significantly lower DWT non-dominant ear scores than children at ANL and CHP, and children at SSKL produced significantly poorer DWT non-dominant ear scores than children at CHP. Children at site HN were not younger than children at other sites, but they may have had greater difficulties with language that interfered with DL performance in both ears. Despite these ear score differences, there was no significant difference in diagnostic category placement across the sites.

Average ear scores from children within each diagnostic category are displayed in Figure 6 for the 2-pairs condition of the RDDT, and in Figure 7 for the DWT. Except for those in the UND category, results within the four diagnostic categories resemble the hypothetical patterns displayed in Figure 1. Average ear advantages for children within each diagnostic category are shown in Figure 8, where it is clear that children placed into AMB and AMB+ produced significantly larger ear advantages than those placed into WNL or DD, who produced more symmetrical ear results. Average ear advantages for children in the UND category were intermediate for the DWT, higher than from children in the WNL category but lower than from children in the AMB or AMB+ categories.

Individual scores from each child were compared to criterion cut-off scores in order to measure how far from normal each score differed. Since a poor dominant ear score determined placement into the DD and AMB+ categories, the average difference from normal of the dominant ear score across the two dichotic tests was calculated for each child in those two diagnostic categories. Because a high ear advantage score determined placement into the AMB and AMB+ categories, the average difference from normal of the ear advantage across the two dichotic tests was calculated for each child placed into those categories. The proportion of children whose average results differed from normal within three numeric ranges for dominant ear scores and five numeric ranges for ear advantages is shown in the pie charts in Figure 9. The pale gray pie slice represents the proportion of average results that differed by less than 10% from the low cut-off criterion for dominant ear scores, or more than 10% above the high cut-off criterion for ear advantage, results that in both cases could be regarded as a borderline or mild deficit. Average dominant ear scores differed from normal by less than 30% as shown by the three sections in the pie chart on the left of the figure. Average ear advantage scores however, differed from 2.5% to 65% as shown by the five sections in the pie chart on the right. There were three average ear advantage results that were 30% to 39% above the cut-off and four that were 41.5%, 47%, 62.5%, and 65% above the cut-off for normal. Each of

Table 5. Individual ear scores, individual test result diagnoses, and final diagnostic category.

Site CHP	Code 8120	Age	Sex M	dnon 33	ddom 61	dea 28	dDx DD	wnon 28	wdom 72	wea 44	wDx AMB+	Final Dx DD
CHP	8118	6	M	61	67	6	DD	64	64	0	DD	DD
CHP	8117	7	F	56	61	5	DD	48	64	16	DD	DD
SSKL	49	7	F	56	61	5	DD	36	64	28	AMB+	DD
SSKL	9	7	M	47	61	14	DD	52	64	12	DD	DD
CHP	8043	7	M	69	78	9	DD	52	64	12	DD	DD
SSKL	27	7	M	75	81	6	DD	44	68	24	AMB+	DD
CHP	8109	7	M	81	83	2	DD	44	52	8	DD	DD
CHP	8137	8	F	56	72	16	DD	60	76	16	AMB+	DD
CHP	8147	8	F	64	69	5	DD	72	76	4	DD	DD
CHP	8161	8	F	64	67	3	DD	60	68	8	DD	DD
CHP	8022	8	F	67	67	0	DD	68	72	4	DD	DD
CHP	8040	8	M	67	81	14	DD	56	72	16	DD	DD
CHP	8126	8	M	72	78	6	DD	76	80	4	DD	DD
SSKL	44	8	M	72	81	9	DD	53	68	15	DD	DD
ANL	2105	8	M	75	78	3	DD	80	80	0	DD	DD
SSKL	4	9	M	72	83	11	DD	24	72	48	AMB+	DD
SSKL	18	10	F	67	72	5	DD	64	80	16	AMB+	DD
ANL	2104	10	M	44	56	12	DD	60	72	12	DD	DD
CHP	8004	10	M	69	83	14	DD	60	68	8	DD	DD
ANL	2103	10	M	72	81	9	DD	76	76	0	DD	DD
CHP	8012	10	M	72	81	9	DD	64	76	12	DD	DD
HN	7141	11	M	69	86	17	AMB+	52	60	8	DD	DD
CHP	8171	12	F	47	50	3	DD	80	84	4	DD	DD
APC	EE9201	12	M	72	72	0	DD	52	76	24	AMB+	DD
ANL	2112	6	F	25	67	42	AMB+	12	80	68	AMB	AMB
CHP	8058	6	F	50	81	31	AMB	64	84	20	AMB	AMB
CHP	8027	7	F	6	83	77	AMB+	68	96	28	AMB	AMB
APC	MBM3157	7	F	47	89	42	AMB	42	66	24	AMB+	AMB
SSKL	46	7	F	56	94	38	AMB	36	84	48	AMB	AMB
SSKL	30	7	F	64	92	28	AMB	36	80	44	AMB	AMB
CHP	8059	7	M	22	78	56	AMB+	60	88	28	AMB	AMB
APC	ES1266	8	F	6	97	91	AMB	0	76	76	AMB	AMB
SSKL	2	8	F	50	86	36	AMB+	48	84	36	AMB	AMB
CHP	8110	8	M	44	83	39	AMB+	52	96	44	AMB	AMB
SSKL	12	8	M	47	78	31	AMB+	64	84	20	AMB	AMB
SSKL	40	8	M	47	86	39	AMB	60	80	20	AMB+	AMB
CHP	8071	8	M	56	86	30	AMB	64	88	24	AMB	AMB
SSKL	28	8	M	64	89	25	AMB	36	80	44	AMB+	AMB
HN	4610	8	M	66	100	34	AMB	28	64	36	AMB+	AMB
SSKL	19	8	M	67	92	25	AMB	32	72	40	AMB+	AMB
CHP	8155	9	F	42	75	33	AMB+	24	84	60	AMB	AMB
APC	AJ31504	9	F	50	100	50	AMB	52	76	24	AMB+	AMB
SSKL	10	9	F	67	94	27	AMB	52	72	20	AMB+	AMB
SSKL	6	9	F	72	97	25	AMB	60	88	28	AMB	AMB
CHP	8035	9	M	6	94	88	AMB	0	76	76	AMB+	AMB
ANL	2128	9	M	42	86	44	AMB	28	92	64	AMB	AMB
CHP	8003	9	M	42	89	47	AMB	28	60	32	AMB+	AMB
HN	7394	9	M	58	86	28	AMB	28	56	28	AMB+	AMB
CHP	8123	9	M	72	100	28	AMB	56	80	24	AMB+	AMB
SSKL	47	10	F	53	94	41	AMB	48	80	32	AMB+	AMB
SSKL	38	10	M	58	89	31	AMB	48	72	24	AMB+	AMB
ANL	2120	10	M	69	97	28	AMB	16	76	60	AMB+	AMB
SSKL	35	10	M	72	94	22	AMB	24	60	36	AMB+	AMB
SSKL	48	11	M	47	97	50	AMB	36	96	60	AMB	AMB
CHP	8146	12	F	28	72	44	AMB+	76	92	16	AMB	AMB
CHP	8048	12	F	78	97	19	AMB	48	88	40	AMB	AMB
HN	7423	12	M	75	97	22	AMB	48	68	20	AMB+	AMB
HN	7428	7	F	19	83	64	AMB+	4	72	68	AMB+	AMB+
ANL	2126	7	F	27	67	40	AMB+	28	68	40	AMB+	AMB+
CHP	8080	7	F	39	67	28	AMB+	20	68	48	AMB+	AMB+
HN	7021	7	M	47	78	31	AMB+	12	44	32	AMB+	AMB+
SSKL	33	7	M	52	75	23	AMB+	40	68	28	AMB+	AMB+

(continued)

Table 5. Continued

Site CHP	*Code 8120*	*Age*	*Sex M*	*dnon* 33	*ddom* 61	*dea 28*	*dDx DD*	*wnon* 28	*wdom* 72	*wea 44*	*wDx AMB+*	*Final Dx DD*
SSKL	51	8	M	*19*	*81*	**62**	AMB+	*36*	*80*	**44**	AMB+	AMB+
HN	4268	8	M	*50*	*80*	**30**	AMB+	*4*	*40*	**36**	AMB+	AMB+
CHP	8175	9	F	*53*	*78*	**25**	AMB+	*36*	*80*	**44**	AMB+	AMB+
SSKL	31	9	F	*56*	*78*	**22**	AMB+	*48*	*68*	**20**	AMB+	AMB+
SSKL	34	9	F	*56*	*83*	**27**	AMB+	*4*	*64*	**60**	AMB+	AMB+
CHP	8060	10	F	*25*	*72*	**47**	AMB+	*48*	*76*	**28**	AMB+	AMB+
CHP	8104	11	F	*61*	*83*	**22**	AMB+	*64*	*80*	**16**	AMB+	AMB+
SSKL	20	11	M	*47*	*69*	**22**	AMB+	*16*	*72*	**56**	AMB+	AMB+
SSKL	13	11	M	*61*	*83*	**22**	AMB+	*24*	*80*	**56**	AMB+	AMB+
CHP	8151	7	M	78	89	11	WNL	72	76	4	WNL	WNL
SSKL	36	8	F	81	**94**	13	WNL	84	**96**	12	WNL	WNL
CHP	8075	9	F	89	**100**	11	WNL	80	84	4	WNL	WNL
CHP	8076	9	F	94	**100**	6	WNL	84	**88**	4	WNL	WNL
CHP	8170	9	M	94	**100**	6	WNL	80	**88**	8	WNL	WNL
ANL	2115	11	F	89	**97**	8	WNL	88	**92**	4	WNL	WNL
ANL	2123	11	F	89	**100**	11	WNL	88	**92**	4	WNL	WNL

Abbreviations: ANL = Auditory neurophysiology laboratory; APC = Auditory processing center; CHP = Children's Hospital of Pittsburgh; HN = HearNow; SSKL = SoundSkills APD clinic; F = Female; M = Male; DD = Dichotic dysaudia; AMB = Amblyaudia; AMB+ =Amblyaudia plus; WNL = Within normal limits; UND = Undiagnosed; dnon = Digits, non-dominant ear; ddom = Digits, dominant ear; dea = Digits, ear advantage; dDx = Digits diagnosis; Wnon = Words, non-dominant ear; wdom = Words, dominant ear; wea = Words, ear advantage; wDx = Words diagnosis

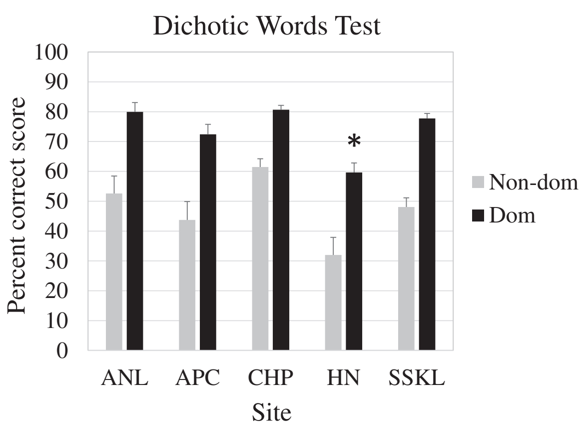

Figure 5. Average DWT scores for children at each of the 5 sites. The asterisk denotes the significantly lower average score among children at the HN site.

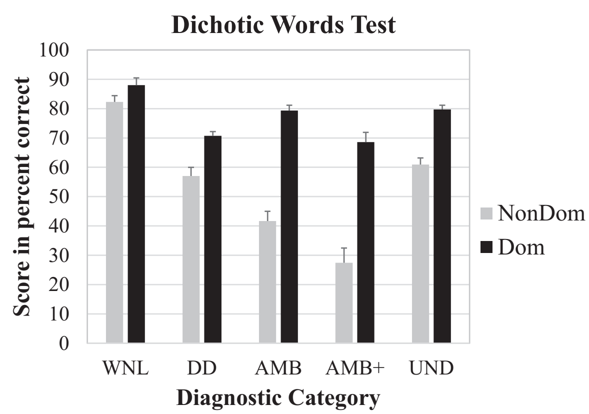

Figure 7. Average non-dominant and dominant ear scores from the Dichotic Words Test across children initially assigned to each diagnostic category.

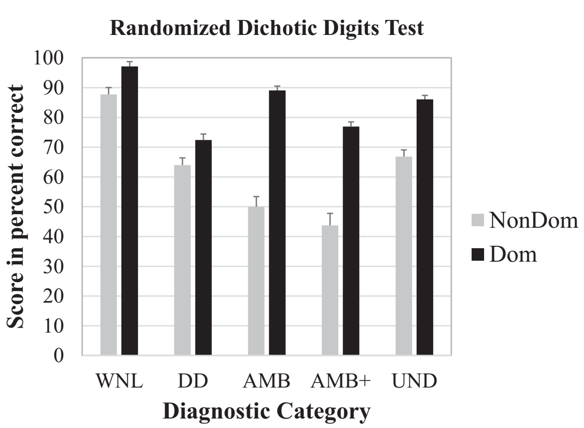

Figure 6. Average non-dominant and dominant ear scores from the Randomized Dichotic Digits Test across children initially assigned to each diagnostic category.

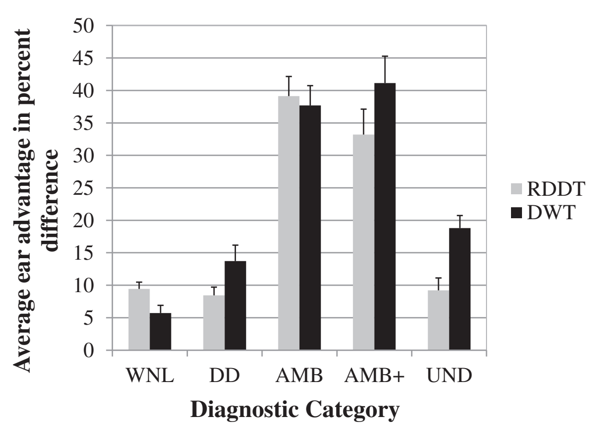

Figure 8. Average ear advantage scores from the RDDT and DWT across children initially assigned to each diagnostic category.

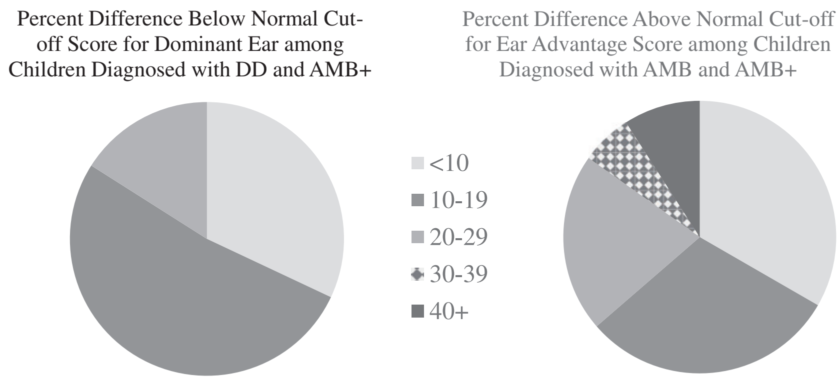

Figure 9. Pie charts showing the proportion of children whose scores fell outside the limits for normal on the DWT. The pie chart on the left shows the proportion of children placed into the diagnostic categories DD and AMB+ whose dominant ear score fell below the normal cut-off. The pie chart on the right shows the proportion of children placed into the diagnostic categories AMB and AMB+ whose ear advantage score fell above the normal cut-off.

Table 6. Individual ear scores for children whose RDDT and DWT scores were not in agreement, placing results into the UND category.

Site	*Code*	*Age*	*Sex*	*dnon*	*ddom*	*dea*	*dDx*	*wnon*	*wdom*	*wea*	*wDx*	*3rd Test*	*non*	*dom*	*ea*	*Dx*	*FinalDx*
CHP	8052	8	M	*42*	*56*	14	AD	*64*	**88**	**24**	AMB	DDT	*50*	*52.5*	2.5	AD	AD
HN	5737	11	M	86	92	6	WNL	*56*	*72*	**16**	AMB+	DDT	*80*	*82.5*	2.5	AD	AD
SSKL	8	7	M	*42*	*50*	8	AD	*20*	76	**56**	AMB	DDT	*45*	77.5	**32.5**	AMB	AMB
SSKL	14	8	M	81	89	8	WNL	*20*	*64*	**44**	AMB+	DDT	*57.5*	85	**27.5**	AMB	AMB
SSKL	32	8	M	81	89	8	WNL	*48*	*80*	**32**	AMB+	DDT	72.5	92.5	**20**	AMB	AMB
ANL	2114	9	F	*61*	**97**	**36**	AMB	88	**92**	4	WNL	CWT	73	93	**20**	AMB	AMB
CHP	8049	9	M	*39*	*58*	19	AD	*36*	**92**	**56**	AMB	DDT	37	77	**40**	AMB	AMB
SSKL	29	9	M	78	86	8	WNL	68	**88**	**20**	AMB	DDT	75	97.5	**17.5**	AMB	AMB
SSKL	50	9	M	72	89	17	WNL	68	**92**	**24**	AMB	DDT	77.5	95	**22.5**	AMB	AMB
HN	6805	10	M	*63*	**94**	**31**	AMB	72	*76*	4	AD	DDT	*70*	97.5	**27.5**	AMB	AMB
SSKL	3	10	M	*61*	*81*	20	AD	*60*	84	**24**	AMB	DDT	*67.5*	85	**17.5**	AMB	AMB
SSKL	21	10	M	69	*81*	12	AD	*56*	**88**	**32**	AMB	DDT	*75*	90	**15**	AMB	AMB
SSKL	43	10	M	92	**94**	2	WNL	*48*	*72*	**24**	AMB+	DDT	80	95	**15**	AMB	AMB
CHP	8167	11	M	81	89	8	WNL	*48*	88	**40**	AMB	DDT	*80*	95	**15**	AMB	AMB
SSKL	17	11	M	83	92	9	WNL	*56*	*72*	**16**	AMB+	DDT	*80*	95	**15**	AMB	AMB
SSKL	25	11	M	*64*	92	**28**	AMB	72	*80*	8	AD	DDT	*50*	*82.5*	**32.5**	AMB	AMB
CHP	8017	12	M	83	**97**	14	WNL	*52*	*72*	**20**	AMB+	CWT	*37*	80	**43**	AMB	AMB
SSKL	15	12	M	81	92	11	WNL	*52*	88	**36**	AMB	DDT	*67.5*	90	**22.5**	AMB	AMB
CHP	8093	6	M	*28*	72	**44**	AMB	56	*64*	8	AD	CWT	*33*	*57*	**24**	AMB+	AMB+
CHP	8053	8	M	*58*	*72*	14	AD	*48*	**88**	**40**	AMB	DDT	*25*	*55*	**30**	AMB+	AMB+
CHP	8178	8	F	*53*	89	**36**	AMB	68	*76*	8	AD	SSW	*55*	*70*	**15**	AMB+	AMB+
CHP	8094	6	F	*44*	**83**	**39**	AMB	76	84	8	WNL	CWT	60	63	3	WNL	WNL
CHP	8065	8	F	*44*	89	**45**	AMB	76	**88**	12	WNL	DDT	60	65	5	WNL	WNL
SSKL	42	9	M	72	**94**	**22**	AMB	76	**88**	12	WNL	DDT	90	100	10	WNL	WNL
ANL	2118	10	M	78	*81*	3	AD	92	**100**	8	WNL	CWT	70	70	0	WNL	WNL
CHP	8062	10	F	78	**94**	16	WNL	72	*80*	8	AD	CWT	63	67	4	WNL	WNL
HN	6603	10	M	100	**100**	0	WNL	*40*	*52*	12	AD	DDT	92.5	92.5	0	WNL	WNL
SSKL	39	10	M	80	*83*	3	AD	76	**88**	12	WNL	DDT	90	92.5	2.5	WNL	WNL
ANL	2130	11	F	88	92	4	WNL	76	*80*	4	AD	CWT	77	87	10	WNL	WNL
CHP	8019	11	M	*72*	*83*	11	AD	76	88	12	WNL	CWT	70	87	17	WNL	WNL
CHP	8115	12	F	94	97	3	WNL	80	**96**	**16**	AMB	DDT	95	97.5	2.5	WNL	WNL
HN	4395	12	M	94	100	6	WNL	*12*	*56*	**44**	AMB+	DDT	90	95	5	WNL	WNL
SSKL	23	12	M	92	92	0	WNL	*48*	*80*	**32**	AMB+	DDT	95	97.5	2.5	WNL	WNL
CHP	8032	7	F	*61*	*83*	22	AD	*48*	84	**36**	AMB	DDT	70	80	10	WNL	UND
CHP	8098	7	F	*53*	*69*	16	AD	*60*	**88**	**28**	AMB	CWT	47	53	6	WNL	UND
SSKL	37	7	M	86	86	0	WNL	*52*	*72*	20	AD	DDT	75	97.5	**22.5**	AMB	UND
SSKL	1	8	F	81	**94**	13	WNL	*60*	*72*	12	AD	DDT	*57.5*	*75*	**17.5**	AMB	UND
SSKL	16	8	M	69	86	17	WNL	*60*	*76*	16	AD	DDT	67.5	90	**22.5**	AMB	UND
SSKL	24	8	M	72	89	17	WNL	*64*	*68*	4	AD	DDT	75	97.5	**22.5**	AMB	UND
ANL	2124	9	F	*61*	92	**31**	AMB	72	*76*	4	AD	CWT	60	77	17	WNL	UND
SSKL	7	9	F	83	*83*	0	AD	*56*	*76*	**20**	AMB+	DDT	80	95	15	WNL	UND

(continued)

Table 6. Continued

Site	*Code*	*Age*	*Sex*	*dnon*	*ddom*	*dea*	*dDx*	*wnon*	*wdom*	*wea*	*wDx*	*3rd Test*	*non*	*dom*	*ea*	*Dx*	*FinalDx*
SSKL	41	9	F	*56*	*75*	19	AD	*20*	**92**	**72**	AMB	DDT	77.5	92.5	15	WNL	UND
SSKL	11	10	M	67	*75*	8	AD	68	84	16	WNL	DDT	*67.5*	92.5	**25**	AMB	UND
CHP	8025	11	F	*83*	*89*	6	AD	80	88	8	WNL	CWT	63	87	**24**	AMB	UND
SSKL	22	12	M	86	89	3	WNL	*64*	*68*	4	AD	DDT	*77.5*	*90*	**12.5**	AMB	UND
APC	AJ103007	6	F	56	**83**	27	WNL	*38*	*78*	**40**	AMB+						UND
CHP	8130	6	M	61	**83**	22	WNL	*48*	*64*	16	AD						UND
APC	AH121106	7	M	*56*	**97**	**41**	AMB	76	**84**	8	WNL						UND
APC	JP6296	7	M	*53*	89	**36**	AMB	54	74	20	WNL						UND
CHP	8176	7	F	*56*	**97**	**41**	AMB	88	**92**	4	WNL						UND
ANL	2101	8	M	83	**94**	11	WNL	*56*	*72*	16	AD						UND
CHP	8127	8	M	*61*	**97**	**36**	AMB	88	**96**	8	WNL						UND
APC	GS5164	9	M	67	**95**	**28**	AMB	*44*	*48*	4	AD						UND
CHP	8011	9	M	79	*81*	2	AD	88	**92**	4	WNL						UND
CHP	8034	9	F	67	*78*	11	AD	80	**88**	8	WNL						UND
CHP	8136	9	F	*44*	*83*	**39**	AMB+	88	**92**	4	WNL						UND
ANL	2129	10	M	*56*	*81*	**25**	AMB+	76	**88**	12	WNL						UND
APC	RM3313	10	F	*36*	89	**53**	AMB	*58*	*60*	2	AD						UND
APC	CT5183	10	M	*64*	**100**	**36**	AMB	*64*	*80*	16	AD						UND
CHP	8169	10	M	*44*	*64*	20	AD	*52*	84	**32**	AMB						UND
CHP	8185	10	F	*28*	92	**64**	AMB	76	**88**	12	WNL						UND
APC	BM10101	12	M	*69*	92	**23**	AMB	*64*	*72*	8	AD						UND

Abbreviations: RDDT = Randomized dichotic digits test; DWT = Dichotic words test; ANL = Auditory neurophysiology laboratory; APC = Auditory processing center; CHP = Children's Hospital of Pittsburgh; CWT = Competing words subtest; HN = HearNow; SSKL = SoundSkills APD clinic; F = female; M = male; DD = Dichotic dysaudia; AMB = Amblyaudia; AMB+ = Amblyaudia plus; WNL = Within normal limits; SSW = Staggered spondaic words test; UND = Undiagnosed; dnon = Digits, non-dominant ear; ddom = Digits, dominant ear; dea = Digits, ear advantage; dDx = Digits diagnosis; wnon = Words, non-dominant ear; wdom = Words, dominant ear; wea = Words, ear advantage; wDx = Words diagnosis.

these seven average ear advantage score differences represents a significantly larger interaural asymmetry than normal and indicates a severe deficit in binaural integration skills.

Diagnoses from RDDT, DWT, and a third DL test

Among the 62 children characterized as UND on the basis of results from the RDDT and DWT, there were 43 who were tested with another DL test at the same appointment. Scores shown in Table 6 under the column headed 3rd Test confirmed a result from either the RDDT or the DWT in 33 of those children and failed to confirm previous results in 10 others who then remained in the UND category. When results from these 33 children were added to those given a diagnostic category from the RDDT and DWT scores alone, the number of children placed into a diagnostic category increased to 112 (79%). As shown in the pie chart at the bottom of Figure 4, there were 27 children (19%) categorized as DD, 49 (35%) categorized as AMB, 17 (12%) categorized as AMB+, 19 (13%) categorized as WNL, with a remaining 29 (21%) still categorized as UND.

Discussion

At five different clinical sites, children suspected of having APD were clinically assessed with a battery of auditory processing tests that included two DL tests, one with pairs of single syllable words and another with randomly presented pairs of single, double, or triple digits. Scores from the two DL tasks resulted in the placement of more than half of the children into one of four different diagnostic categories. For the remaining children, test scores from the two DL tests were not in sufficient agreement to result in placement into one of the diagnostic categories. In cases where a third DL test had been administered, the scores from the third test were evaluated and when scores from the third test were in agreement with one of the first two DL tests used, the child was then placed into the appropriate diagnostic category. In all, a diagnosis of Amblyaudia, characterized as an abnormally large interaural asymmetry during DL tests with or without poor DL performance in both ears, was made in 66 of the 141 children referred for testing (47%). The high prevalence of DL score results that lead to a diagnosis of amblyaudia in this population of children suggests that many children suspected of APD suffer from this binaural integration deficit. Because amblyaudia can be remediated through auditory rehabilitation for interaural asymmetry (ARIA) (Moncrieff & Wertz, 2008), proper identification of children with amblyaudia can potentially lead to an effective therapy that could improve their binaural listening skills.

The primary evidence of amblyaudia is a larger than normal difference in performance between the two ears during DL tests. This can occur in three different ways. In the first, performance in the dominant ear is normal and performance in the non-dominant ear is significantly below normal. In the second, performance in the dominant ear is supra-normal and while performance in the non-dominant ear reaches or exceeds the low end cut-off for normal, there is an abnormally large difference between the two ears. In the third pattern, performance in both ears is below the normal cut-off but the difference in score between the two ears is larger than the normal high-end cut-off score. In each case, the DL task has yielded significantly better performance in the listener's dominant ear than in the non-dominant ear. The presence of a large interaural difference has been described in a variety of clinical patients, including those with previously identified lesions in the corpus callosum (Springer & Gazzaniga, 1975; Damasio, 1976; Springer, 1978; Musiek & Wilson, 1979; Pollmann, 2002) and in children with listening, language, and reading difficulties (Ayres, 1977; Johnson et al, 1981; Dermody et al, 1983a,b; Aylward, 1984; Berrick, 1984; Moncrieff & Musiek, 2002; Vanniasegaram et al, 2004; Moncrieff & Black, 2008).

Amblyaudia is not the only deficit that can be characterized through DL tests, however. The pattern of performance that leads to similarly poor performance in both ears does not represent amblyaudia, but instead suggests either a bilateral problem with dichotically-presented verbal material or a possible global difficulty with language, cognition, or attention. The term dichotic dysaudia has been chosen to represent this pattern of performance because it is important to distinguish it separately from auditory receptive language difficulties that are more typically diagnosed through monaural or diotic presentations of verbal information. A child with dichotic dysaudia may or may not demonstrate binaural auditory receptive language weaknesses if tested with diotic presentations under earphones, but that skill is not typically assessed during standard clinical procedures. Since this pattern does occur when children are tested with DL tests, the term used to identify it is meant to specify a deficit that is represented exclusively by poorer than normal performance in both ears during DL testing. In all, 31% of the children tested at these five sites demonstrated the dichotic dysaudia pattern (19% with DD and 12% with AMB+).

A full battery for assessing APD should begin with a comprehensive audiological evaluation that examines pure-tone hearing sensitivity, immittance, speech recognition, otoacoustic emissions, and acoustic reflexes to rule out a retrocochlear pathology before beginning with auditory processing tests. In addition to DL tests, an APD battery can include recognition of frequency patterns, speech-in-noise, monaural low-redundancy speech, detection of gaps, and binaural release from masking. Amblyaudia can occur either with or without weaknesses in any of these other auditory processing skills, so each clinical report should address findings from all tests that have been performed. The current standard suggests that a child should be diagnosed with APD if results fall below normal on any two processing assessments. Under this standard, the diagnostician is not required to either characterize the nature of the auditory deficit or confirm it by administering another test that challenges the same skill. As proposed in the results from this study, the diagnosis of amblyaudia on the basis of results taken from two or more DL tests allows the clinician to differentially identify a binaural integration deficit and recommend a deficit-specific treatment for it. Test results from the battery can also be used to identify weaknesses in other auditory skills included under current standards, such as speech perception with background noise or filtered speech, pattern recognition with interhemispheric transfer, temporal resolution, or binaural release from masking.

This is an alternative approach in the diagnosis of APD that is consistent with the current standard that the individual must demonstrate below normal performance on two or more tests, but it more stringently requires that the performance deficit be recorded within one auditory processing skill. The high prevalence of amblyaudia identified in this population of clinically-referred children, with or without the co-morbid diagnosis of dichotic dysaudia, indicates that identification and potential treatment of amblyaudia is important when assessing children for APD. Amblyaudia is regarded as a bottom-up deficit in the processing of binaural signals that if left untreated, is likely to interfere with any other remediation technique that is provided. For example, the use of an assistive listening device is often recommended for children with APD, but its use may accentuate the underlying interaural asymmetry and potentially lead to rejection of, or poor compliance with the device. Effective treatment with ARIA has been shown to yield more symmetrical processing and enhanced binaural integration (Strouse & Wilson, 1999b). Achievement of normal binaural integration performance on DL tests indicates more effective neural encoding of the binaural signal in these children which is likely to then facilitate listening, learning, and rehabilitation through other therapy techniques, including the use of assistive devices.

Despite evidence of poor performance on one DL test, more than 20% of the children were placed in the UND category. Based on findings from other assessments in the battery, some of these children may have been diagnosed with an APD that did not include amblyaudia and others may have had normal or ambiguous results on other tests as well. In those cases, the clinician must examine the entire battery of tests for a pattern of concordant results that can be used to identify an auditory processing weakness. When no deficit is apparent in initial testing, the best recommendation may be to retest the child in 3–6 months if parents and teachers are still concerned to see if a consistent pattern of performance can be identified through follow-up testing. When a child referred for APD assessment demonstrates inconsistencies across the battery of tests, the clinician can also assess the child's attention skills with a continuous performance test if one is available. If an attention deficit is suspected or confirmed with a continuous performance test, it may be best to recommend follow-up testing for attention issues and possible pharmaceutical intervention before subsequent re-evaluation of the child for APD.

Age and gender affect individual ear scores and values of interaural asymmetry (Hiscock, 1994; Moncrieff, 2011; Voyer, 2011), so any DL test used to diagnose amblyaudia should provide normative information that considers both age and gender. Both of the tests used in this study have appropriate normative information for children between the ages of 5 and 12 years. Other DL tests provide normative information by age and those can be used to supplement results from the RDDT and DWT, as shown in the follow-up testing used in this study to resolve initially discordant results. In all cases, clinicians must use their discretion when evaluating results from a variety of tests to reach the best diagnostic decisions, but the purpose of this study is to provide audiologists with guidelines they can use to diagnose a relatively common auditory processing weakness revealed by results from DL tests.

Greater discrepancies from the cut-off score for normal suggest a more severe deficit in binaural integration performance. Children in this study demonstrated varying degrees of deficit and no pattern was specifically related to age or gender. Age and gender had no effect on category of diagnosis either. Each of the sites that participated in this study produced similar results, indicating that valid categorization of amblyaudia can be made in any clinical setting that follows these procedures. The identification of amblyaudia in the children involved in this study led to the recommendation that they participate in ARIA to remediate their binaural integration deficit.

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