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Auditory rehabilitation for interaural asymmetry: Preliminary evidence of improved dichotic listening performance following intensive training

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Key Words
Dichotic listening
Auditory training
Interaural asymmetry
Left ear deficit
Language disorder

Abbreviations
SCAN-C: Test for auditory processing disorders in children-revised
APD: Auditory processing disorder
REA: Right-ear advantage
LPFS: Low pass filtered speech
FPT: Frequency pattern test
SRT: Speech reception threshold
C-TOPP: Comprehensive test of phonological processing
BLD: Bilateral deficit
LED: Left-ear deficit

Abstract
Children with dichotic left ear deficits received intensive training in phase I and phase II clinical trials designed to establish the efficacy of directly training dichotic listening. Dichotic verbal material was presented in the sound field with intensity adjusted separately for each speaker. Output from the right-sided speaker was initially 20–30 db HL lower than for the left-sided speaker, resulting in excellent performance in the left ear. Intensities were adaptively adjusted throughout training in 1, 2, and 5-dB steps in order to keep performance high across dichotic tasks. In both phase I (n = 8) and phase II (n = 13) trials, children demonstrated significant gains in dichotic left ear performance after training. In phase II, children also demonstrated significant gains in right ear performance. Overall results from the two trials support the feasibility of this training approach for improving a larger than normal interaural asymmetry on dichotic listening tasks. Significant improvements in language comprehension and word recognition in phase II suggest that this type of training may also facilitate language skills in some children.

Sumario
Niños con déficit dicótico del oído izquierdo, recibieron entrenamiento intensivo en pruebas clínicas en fase I y II, diseñadas para establecer la eficacia del entrenamiento directo de la audición dicótica. Se les presentó material verbal dicótico en campo libre, con intensidad separadamente ajustada en cada altoparlante. La salida del altoparlante del lado derecho fue inicialmente de 20–30 dB HL menos que la del izquierdo, resultando en un excelente rendimiento en el oído izquierdo. Las intensidades fueron adaptativamente ajustadas a través del entrenamiento en pasos de 1, 2 y 5 dB con objeto de mantener un alto desempeño durante las tareas dicóticas. Tanto en las pruebas de la fase I (n = 8) como en las de la fase II (n = 13) los niños demostraron ganancias significativas en el desempeño dicótico del oído izquierdo después del entrenamiento. En la fase II los niños también demostraron ganancias significativas en el desempeño con el oído derecho. Los resultados globales de las dos pruebas, apoyan la viabilidad de este enfoque de entrenamiento para mejorar una asimetría interaural mayor de lo normal en tareas de escucha dicótica. La mejoría significativa en la comprensión del lenguaje y en el reconocimiento de palabras en la fase II, sugiere que este tipo de entrenamiento puede también facilitar las habilidades de lenguaje en algunos niños.

For many decades, dichotic listening methods have been used in research related to language and reading disorders (Hugdahl, 2003) and in the clinical diagnosis of auditory processing disorders (Katz & Smith, 1991; Keith, 2000; Bellis, 2003). Deficits in dichotic listening have long been associated with language, learning, and reading difficulties in children (Obrzut et al, 1997; Moncrieff & Musiek, 2000; Jerger et al, 1993), and there is growing evidence that interaural asymmetry during dichotic listening, noted primarily as a left ear deficit, is a common finding among children suspected of language and auditory processing difficulties (Morton & Siegel, 1991; Lamm & Epstein, 1994; Moncrieff & Musiek 2002; Moncrieff, 2006). Under the two primary models of dichotic listening, a small deficit in the left ear is expected in normal right-handed listeners during dichotic listening tasks, resulting in the characteristic right ear advantage (REA). The structural model (Kimura, 1967) predicts this deficit because information presented in competition to the right ear has privileged, direct access via the dominant contralateral pathway to the language-dominant left hemisphere of the brain, whereas information presented to the left ear must be transmitted indirectly to the left hemisphere via the corpus callosum. The attention model (Kinsbourne, 1970) adds that the deficit occurs because priming of the left hemisphere by language facilitates the direction of the listener's attention toward the right auditory space, thereby biasing the listener toward information presented on that side. As supported by both models, children's left ear performance during dichotic listening tasks generally improves with development of cortical interhemispheric pathways, verbal resources within the temporal lobe, and ability to allocate attentional resources to more demanding listening tasks (Harper & Kraft, 1994; Lamm & Epstein, 1997; Neijenhuis et al, 2002; Hugdahl, 2003; Bellis, 2003).

Following simultaneous presentation to the two ears, common features of the stimuli are thought to fuse at the brainstem, leaving features that differ to be separately encoded through ascending auditory pathways (Repp, 1976). Because dichotic listening presents more information than can be easily identified, it can also be sensitive to non-auditory factors such as intelligence, attention, working memory, language, motivation, and fatigue (Studdert-Kennedy & Shankweiler, 1970; Hugdahl, 2003). The divided attention format of dichotic listening which

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instructs the listener to repeat both stimuli each time has been widely and successfully used to derive both the degree and direction (right or left) of interaural asymmetry (Hugdahl & Andersson, 1986; Strouse & Wilson, 1999). It is well known that normal right ear advantage (REA) listeners can enhance performance in their left ear by directing their attention specifically toward it, sometimes resulting in a reversal to a left ear advantage (Kinsbourne, 1970; Hiscock et al, 1999; Obrzut et al, 1993). Recent evidence suggests that dichotic listening tests with instructions to specifically direct attention first to one ear and then the other may produce more reliable ear advantages overall because the listener attends equally to both ears across the entire test (Hiscock & Beckie, 1993; Keith, 2000).

By age five, children can perform clinical dichotic listening tests with digits and words (Harper & Kraft, 1994; Lamm & Epstein, 1997). In both types of dichotic tests, the stimuli are temporally aligned for onset, but because they vary in overall duration and intensity, there is a large amount of differing temporal, intensity, and featural information available to the child. These discrepancies allow for greater identification of both stimuli compared to other tests of dichotic listening that utilize stimuli with more precise temporal alignment and common features such as dichotic listening tests with consonant-vowels (CVs) and rhymes (Asbjornsen & Bryden, 1996; Shinn et al, 2005). Children are also encouraged to guess during tests with digits or words, and the limited number of options involved in the dichotic digits test improves their chances of guessing correctly. The standard double dichotic digits test is administered in a divided attention format with no specific instructions regarding attention (Musiek, 1983). The most commonly used dichotic words test is administered in a directed response format with instructions to repeat the word heard in the right ear first during half of the test and to repeat the word heard in the left ear first during the other half of the test (Keith, 2000). Individual ear scores and measures of interaural asymmetry can be obtained from each test. The child's performance can be compared to normative results to determine whether performance differs from normal for one or both ears.

Historically, there has been considerable controversy over whether poor performance on degraded speech tests represents an auditory-specific deficit or a possible constellation of auditory and non-auditory factors (Cacace & McFarland, 2005; Katz & Tillery, 2005; Musiek et al, 2005; Rosen, 2005). Similarly poor dichotic performance in both ears could be attributable to several factors including intelligence, working memory, language, motivation, fatigue, and vocabulary. Normal performance in one ear together with a significant interaural asymmetry is more difficult to ascribe to these non-auditory factors, however (Jerger & Musiek, 2000; Moncrieff, 2006). A unilateral deficit during dichotic listening has been linked to disorders of interhemispheric pathways through the corpus callosum in patients with known lesions of the auditory system (Musiek et al, 1989; Pollmann et al, 2002; Thomsen et al, 2004), leading many to suggest that a similar pattern in children with no known lesions may be related to deficiencies in the interhemispheric transfer of information from the left ear (Jerger et al, 2002). Because non-auditory factors were sufficient for identifying elements from the dominant ear in these cases, it has been suggested that linguistic priming effects in the left hemisphere may hinder efforts to allocate attentional resources to the non-dominant ear, especially during divided attention dichotic listening tasks (Martin et al, 2007). Larger than normal interaural asymmetries were reported in 84% of the children identified with dichotic listening difficulties in one large study, suggesting a high prevalence of left ear deficits among children at risk for APD (Moncrieff, 2006).

Management of an APD has focused on environmental modifications to clarify the auditory signal for children in classroom settings in order to improve bottom-up auditory processes, together with training in compensatory strategies to enhance cognitive top-down skills in these children (Bellis & Ferre, 1999; Chermak & Musiek, 1997). A recent change in the recommendations for management of APD has been the inclusion of deficit-specific training regimens designed to stimulate neuroplasticity in auditory pathways that may be disordered in children with processing difficulties (Bellis, 2003). Auditory training therapies that are theoretically based and which target an individual auditory processing weakness have been proposed (Musiek et al, 1999), and for children with a unilateral deficit or a significant interaural asymmetry during dichotic listening, training in dichotic listening skills has been strongly recommended (Bellis, 2003).

The theory behind dichotic listening training is similar to the theory underlying constraint-induced therapy in stroke patients. Individuals with unilateral motor weakness have demonstrated benefits when therapy involves inhibiting the stronger side from motor activities and forcing the weaker side to perform functions in an effort to induce cortical reorganization of motor function (Page et al, 2002; Schaecter et al, 2002). These benefits reflect the plasticity of the neural system to adapt following ischemic damage at the cortical level. Several recent studies have demonstrated facilitative effects of auditory training on neural timing in the auditory brainstem (Russo et al, 2005) and cortex (Warrier et al, 2004), and on psychophysical tests of duration judgment (Agnew et al, 2004) and pitch discrimination (Fitzgerald & Wright, 2005), lending support to the notion that training regimens targeted to a particular skill may facilitate performance within an important domain of auditory processing.

The purpose of the present study was to initially test the feasibility of an auditory training paradigm designed to remediate dichotic listening deficits in children in a phase I clinical trial. As described by Robey and Schultz (1998) a phase I trial is a small group experiment designed to explore direct changes in measurement and benefits to daily life following intervention. The goals of this small group experiment were to directly remediate unilateral weaknesses during dichotic listening tests and to observe whether benefits generalized to other listening and learning skills. Despite valid concerns that this type of training might be characterized as 'training to the test', a phase I clinical trial is a critical first step for developing appropriate therapy for children with unilateral deficits. The primary purpose in this initial study was to determine whether dichotic listening itself could be specifically trained in this population. It was proposed that if poor dichotic listening skills are related to listening and language difficulties, that improvements in dichotic listening might facilitate improvements in these other areas as well. To this end, a large amount of dichotic listening material was prepared for presentation through sound field speakers so that children could practice on skills of binaural integration (repeat the stimuli from both sides) and binaural separation (ignore one side and repeat what you hear on the left side). The study was designed to follow the format described by Bellis (2003) which includes an initial determination of the intensity ratio required to enhance left ear performance, followed by systematic adjustments of the intensity for information delivered to one or the other ear in order to maintain the highest levels of performance possible in both ears. It was hypothesized that across time, each child's ability to repeat dichotic material presented to the left ear would remain strong as intensity of material presented out of the right-side speaker systematically increased to a level that was equivalent to the input to the left ear. It was also predicted that practice across multiple training sessions would generally improve the child's dichotic listening performance and that performance differences between the two ears would reach normal values. The purpose in the phase I clinical trial was to pilot this procedure on a variety of children with dichotic listening deficits to determine its feasibility as a training paradigm for children with APD.

Materials and Methods: Phase I Trial

There were eight children involved in the first trial. They ranged in age from 7 to 13 years, with a mean age of 9.7 years. There were two females and six males in the study. Seven children were patients in the multidisciplinary diagnostic training program (MDTP) at Shands Hospital at the University of Florida, where they had been diagnosed with speech and language disorders. The other child had been recruited to participate in research studies of APD at the Auditory Processing Laboratory of the University of Florida, and did not have a prior diagnosis of speech or language disorder. All were in excellent health at the time of the training, and permission to participate was obtained from a parent of each child according to the policies of the Institutional Review Board at the University of Florida in place at the time of the study. All children had achieved a normal level performance on a standardized test of intelligence. One child was on medication for attention deficit disorder (S01). Another child had been previously diagnosed with Arnold Chiari malformation (S07), but all others were free of any known neurologic deficit. One goal of this first feasibility study was to include children with unilateral dichotic deficits together with other co-morbid disorders in order to explore whether intensive training would facilitate dichotic listening similarly in all of the children.

All measures of hearing and auditory processing were performed in a double-walled sound suite. Each child was seated in a comfortable chair and fitted with TDH-49 supra-aural earphones. Hearing thresholds for pure tones at 500, 1000, 2000, and 4000 Hz and speech recognition (SRT) were measured in both ears prior to further testing. Hearing and speech recognition thresholds were better than 25 dB HL in both ears for all children in the study. Because the dichotic digits test was recommended as a screening test for auditory processing disorders in children (Jerger & Musiek, 2000), it was used to initially assess each child's dichotic listening performance. The dichotic digits test (Musiek, 1983) was administered at 50 dB HL relative to the SRT for each child in order to control for threshold differences between the two ears and across children. Throughout the test, two digits were presented to each ear and the child was instructed to repeat both pairs of digits following each presentation, and to guess if not sure of any digit that was heard. The test consisted of 20 pairs of double digits for a total number within each ear of 40 digits. The number of correctly repeated digits for each ear was recorded and converted to percent correct. Each child was also assessed with low pass filtered speech (LPFS) (Wilson et al, 1990), and the frequency pattern test (FPT) (Pinheiro & Ptacek, 1971), both of which were administered binaurally at 50 dB SL re: SRT from the VA CD *Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0* (Department of Veterans Affairs, 1998). For LPFS, children were asked to repeat each of the 30 words that were presented. The total number of words correctly identified was converted to a percent correct score. For FPT, children were asked to listen for a pattern of high and low tones and to identify each pattern (high-high-low, low-high-low, etc.) for a total of 30 patterns. The number of correctly identified patterns was converted to a percent correct score. If the child did not achieve a normal score on the FPT in the verbal response condition, the test was re-administered with the instructions to hum the pattern of tones. Again, 30 patterns were presented and the child's performance was measured in percent correct.

Core phonological processing skills were assessed in each child with the comprehensive test of phonological processing (C-TOPP) (Wagner et al, 1999). Subtests used were phonological awareness, phonemic memory, and rapid naming. Each test was administered in a quiet room according to the directions provided with the test.

Children were selected to participate in the training project if the results from the dichotic digits test indicated a significant interaural asymmetry due to poorer performance in the left ear relative to performance in the right ear. A significant asymmetry was defined as a difference of greater than 20% for children younger than age eight years, 15% for children ages eight to nine years, and greater than 10% for children ages ten years and older. Training consisted of 30-minute sessions, three times per week for a period of four weeks. Training was planned to include a total of 11 sessions because a holiday occurred on one of the training days. Five children completed all 11 sessions and the other three children completed eight to ten sessions due to illness or schedule conflicts. At the beginning of each session, each child was allowed to select an item from an assortment of snacks, stickers, and toys that would be awarded following the training. This was done to keep motivation high throughout the training session and the children seemed to like listening for a prize each time. All training was conducted inside a double-walled sound suite where the child sat in a comfortable chair positioned in the center of the room. Training materials were delivered into the sound suite via speakers that were placed one metre from each side of the child's head. Training materials included several varieties of previously available dichotic listening stimuli, as well as other monaural stimuli that were aligned (CoolEditPro™) into dichotic presentations for the purpose of the training in order to provide a large number of options for each training session. Examples of training materials used throughout the training are listed in Appendix A.

At the onset of training, intensity from the sound field speakers was set to differ by 30 dB HL, with material presented to the right side at either 0 or 10 dB HL, and to the left side at 30 or 40 dB HL respectively. The purpose was to suppress performance in the right ear and to enhance performance in the left ear so that the child could correctly identify 70–100% of the material presented to the left side, with expectations that performance on digits would be higher than performance on words. Each child was instructed to listen to the presented material and to repeat everything that was heard in cases involving single-syllable digits or words. In cases involving CVs, children were instructed to repeat what was most easily heard. With sentence materials, the child was asked to only repeat the sentence heard in the left ear while ignoring the sentence heard in the right ear. In each case, the number of correctly identified items was recorded and the child's percent correct score for each ear was determined. Whenever left ear performance reached 70–100%, the intensity of the material presented to the right side was raised and if left ear performance dropped, either the intensity of the material to the left side was also raised or the intensity of the material to the right side was reduced. Intensity changes were made in 5-dB, 2-dB, or 1-dB steps following this protocol, depending upon the child's relative performance levels in the two ears. Across a session, each child received 5 to 25 presentations of dichotic material under each intensity situation, performance was monitored and a decision was made to adjust relative intensities before the next dichotic material was presented. Fewer presentations (five) were made at an intensity level when the child demonstrated mastery of the task or when the level of performance was equivalent for both ears. More presentations (10 to 25) were used when the child's performance indicated an asymmetry in performance between the two ears so that the child was given more time to practice at the new intensity level. The number of presentations was limited to 25 in order to reduce the likelihood of excessive boredom or fatigue during the training. The training focused more heavily on binaural integration tasks with single-syllable word materials, but by interspersing binaural separation tasks with sentences and fairy-tale segments, children remained focused on the challenging listening tasks. At the end of a session, each child was praised for his or her performance and was rewarded with whatever item had been chosen at the beginning of the session.

Following training, each child returned for a post-training evaluation during which he or she was again tested with the same auditory processing and language assessments that had been used for pre-training assessment. All post-training evaluations were performed in the same manner as during the pre-training evaluations. For example, auditory processing skills were evaluated under earphones in the double-walled sound suite and the language evaluations were conducted in a quite room. All children received their post-training evaluations during the next week following the end of the training period.

Statistical Analysis: Phase I

In Phase I, independent samples t-tests were used to compare pre-training measures between subgroups. Paired samples t-tests were used to compare pre-training measures between ears, and to compare pre-training measures with post-training measures within ears across all subjects. Correlations were obtained with Pearson product moment analysis. Significance was measured, and findings were reported that occurred at alpha levels of $p < .01$ and $p < .05$.

Results: Phase I

Pre-training measures

All pre-training measures of auditory processing and phonological processing for children in the first trial of the training are listed in Table 1. The children were divided into two subgroups on the basis of their right ear performance on the dichotic digits test. Children with normal performance in their right ear and a large asymmetry due to poor performance in their left ear were placed in the left-ear deficit (LED) group. Children with poor performance in their right ear together with a large interaural

Table 1. Pre-training and post-training results for children involved in Phase I clinical trial. Results for auditory processing tests (DDT, LPFS, and FPT) are in percent correct. Results for C-TOPP subtests (PA, PM and RN) are in standard scores.

					DDT			*FPT*				
	Sub-group	*Subject*	*Age*	*Sex*	*LE*	*RE*	*LPFS*	*V*	*H*	*PA*	*PM*	*RN*
Pre-training	BLD	S01	7.9	M	36	60	36	10	91	DNT	DNT	DNT
		S02	10.3	M	38	56	28	CNT	47	79	76	103
		S03	10.3	M	30	52	44	93	DNT	73	55	88
		S04	13.7	M	36	50	40		20	64	73	
	LED	S05	7.10	M	32	78	48	40	20	58	109	85
		S06	8.2	M	52	80	62	52	44	106	97	79
		S07	8.10	F	42	84	62	0	60	88	79	88
		S08	11.0	F	68	94	56	83	DNT	88	100	73
Post-training	BLD	S01	7.9	M	44	58	40	25	65	DNT	DNT	DNT
		S02	10.3	M	36	54	60	0	CNT	79	76	103
		S03	10.3	M	68	76	38	DNT	DNT	73	79	85
		S04	13.7	M	56	70	60	CNT	45	64	70	48
	LED	S05	7.10	M	70	80	60	13	53	73	112	94
		S06	8.2	M	46	68	76	40	90	112	97	85
		S07	8.10	F	48	88	16	40	90	88	82	85
		S08	11.0	F	76	98	76	90	DNT	97	88	76

DDT = Dichotic digits test; LPFS = Low pass filtered speech test; FPT = Frequency pattern test; PA = Phonological awareness; PM = Phonemic memory; RN = Rapid naming; BLD = Bilateral deficit; LED = Left-ear deficit.

asymmetry due to even poorer performance in their left ear were placed in the bilateral deficit (BLD). There were four children in each subgroup. The LED group was comprised of two males and two females with an average age of 9.0 years and the BLD group was comprised of four males with an average age of 10.5 years. An independent samples t-test was performed on age between groups and no significant difference in age was found, presumably because of the small number of children involved and the somewhat wide range of ages.

Pre- and post-training measures of dichotic listening with digits for each child are displayed in Figure 1. The gray bars on the graph represent the pre-training performance score for each child. The black and white bubble bars on the graph represent the post-training performance score for each child. The black bars on the graph represent the minimum value for normal performance for a child of the same age as the subject, taken from published normative information for the test (Bellis, 2003). Children in the BLD group were below normal levels for both ears and children in the LED subgroup were below normal performance in the left ear only. An independent samples t-test on pre-training performance revealed that right-ear scores were significantly smaller in the BLD subgroup than in the LED subgroup on the digits test, $t = 7.035$, $p < .001$, but left-ear scores were not significantly different between the two subgroups. The only other pre-training auditory processing measure that differed significantly between the two subgroups was the low-pass filtered speech test, $t = 3.857$, $p < .01$, with the children in the BLD group producing an average score of 37%, and children in the LED group producing an average score of 54.5%. One child (S01) was not assessed before training with the C-TOPP, but results from the remaining children were significantly different between the two subgroups for the measure of phonological memory, $t = 3.055$, $p < .05$, due to lower standard scores in the BLD group than in the LED group.

Prior to training, left ear scores on the dichotic digits test were significantly lower than right ear scores across all of the children, $t_{(df = 7)} = 6.977$, $p < .001$, as shown in Figure 2.

Training results

Materials chosen to present during each training session depended upon the child's previous performance, age, fatigue, and preference if one was stated. The most commonly used stimuli were dichotic digits, followed by dichotic words. Children received an average of 75 presentations of digits and 41 presentations of single-syllable words in each session, with other materials interspersed as previously described. Relative intensity of the presentations to the two ears varied according to how well each child had performed on the material presented immediately preceding any change. In the beginning, intensity was varied in 5-dB steps, but when performance dropped dramatically in the left ear following 5-dB increases of intensity in the right ear, increments in intensity were reduced to 1 or 2 dB. Average intensities of material presented to both ears and average performance across each session are displayed in Figure 3. As displayed in Figure 3, an average difference in intensity between the two ears of 16.6 dB HL resulted in an average performance of 82% for the left ear and 10% for the right ear in the first session. By the end of session six, average intensities were very similar for the two ears and performance in the two ears was slightly better than 60% with a small left ear advantage. At the end of training, performance remained at better than 60% with a small right ear advantage. The values displayed in Figure 3 represent the average of sound field performance across all types of dichotic listening material (CVs, digits, words, and sentences).

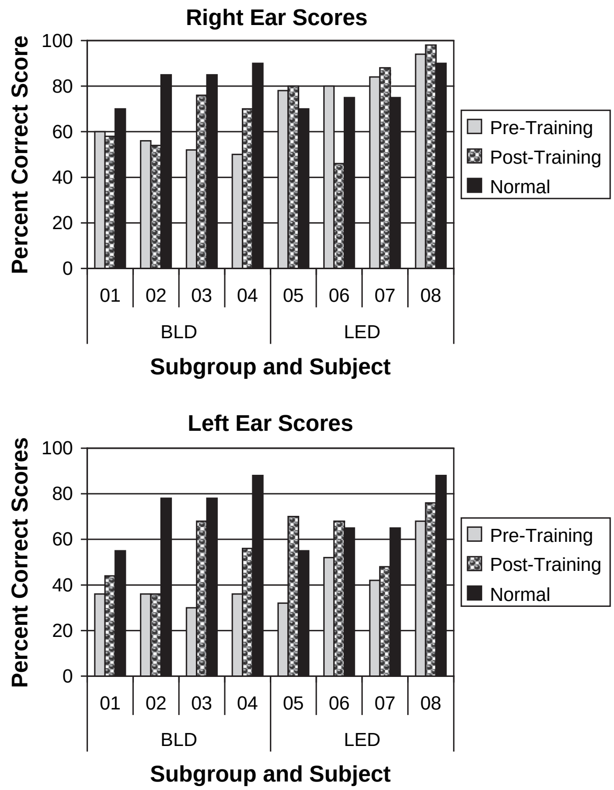

Figure 1. Individual pre-training and post-training scores in percent correct for the right ear (top of figure) and the left ear (bottom of figure) during the dichotic digits test. The minimum value for normal performance on the dichotic digits test is shown by the black bar for each child, based on the child's age at the time of the test. Children with a bilateral deficit on the test are shown on the left (BLD), and children with a left-ear deficit only on the test are shown on the right (LED).

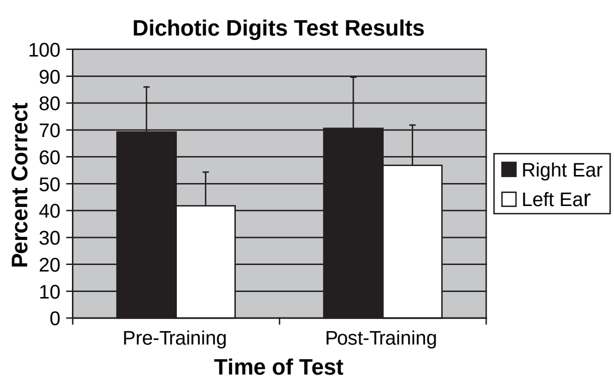

Figure 2. Average pre-training and post-training results in percent correct for the right ear and the left ear from the dichotic digits test for all eight children in phase I clinical trial.

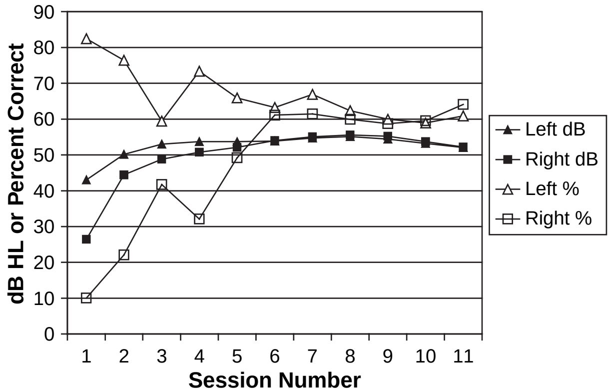

Figure 3. Average changes in intensity in dB HL for all dichotic presentations made to the left and right ears of the children (hollow triangles and squares, respectively), and average performance in percent correct for the left and right ears for all dichotic presentations (filled triangles and squares, respectively) for all eight children across the 11 training sessions in the phase I clinical trial.

Post-training measures

At the end of training, each child was again assessed with the same auditory processing and phonological measures that were used prior to training. The significant differences between the two subgroups found prior to training were no longer present, due primarily to improved performance in the BLD group for LPFS and for the right ear on dichotic digits. Paired samples t-tests comparing pre-training and post-training measures revealed that the left ear scores on dichotic digits were significantly better across all eight children following the training, $t_{(df=7)} = -3.153$, $p < .05$. Pre-training differences between the average right and left ear scores were no longer significant after training, suggesting that performance in the two ears was more symmetrical following the training. A paired samples t-test was performed to compare results obtained during the post-training assessment under earphones with final results obtained in sound field and there were no significant differences, suggesting that children performed similarly when tested under both conditions. As shown by comparing pre-training results displayed by the gray bars to post-training results displayed by the black and white bubble bars in Figure 1, right ear performance remained the same for two children, improved for five children and decreased for one child (S06), whereas left ear performance improved for all but one child (S02) following training. Because the training engaged both ears in a speech-based task, it was not surprising that both ears showed improvements in some of the children. There was concern that inhibition of the right ear during training might potentially reverse the normal right ear advantage, which did seem to occur for one child whose right ear performance dropped substantially (S06). Because this child's digits performance on the last day of training was superior (82% for both ears), this kind of inconsistency in performance less than one week later suggested that factors related to attention might have influenced the post-training measures that are displayed for S06 in Figure 1. The auditory continuous performance test (ACPT) (Keith, 1994) was administered and results were within normal limits for inattention and impulsivity. We retested this child with dichotic digits four months after training and results were again normal in both ears (88% in the right ear and 76% in the left ear). It appears that in this one case, the post-training measure for performance in the right ear was low only for that one particular post-training assessment, for reasons that cannot be explained.

Compared to pre-training results, seven of the children showed improvements in their left ear following training, and one child (S02) performed at the same level in the left ear before and after training. Improvements in left ear performance were modest for three of the children (S01, S07, and S08) and substantial for the other four children.

Effects of co-morbid disorders

The one child who had been previously diagnosed with attention deficit disorder (S01) showed a modest 12% improvement in the dichotic digits left ear score, and a 2% drop in the right ear score after training. The end results were not within normal limits, but they fail to rule out the ability of this training to effect some change in left ear performance in this child with attention difficulties. The child with Arnold Chiari malformation (S07) showed little benefit from the training. Scores for the left ear improved by 6% and in the right ear by 4%, a result that could be due to test-retest variability (Neijenhuis et al, 2001). Similarly, the one child who had not been previously diagnosed with a language disorder (S08) also showed modest gains in both ears (8% in the left, and 4% in the right) that could also be due to test-retest variability. Of the six children who had been diagnosed with a language disorder, two showed no real benefit of the training (S01 and S06) whereas the other four showed more dramatic gains in left ear performance after the training (increases in performance of 20% and 24% for S04 and S06, and 38% for both S03 and S05). Three of these children were from the BLD group. These results suggest that whether a child has a unilateral deficit during dichotic listening or a larger than normal interaural asymmetry together with a bilateral deficit, they may benefit from this type of specific dichotic listening training.

Effects of age

Given the wide range of ages in this small group of children, we tested whether age may have influenced the increases seen in the some of the children's left ear scores by Pearson product correlation analysis, and there was no correlation between age and improvement in left ear scores.

Post-post measures

After the dichotic training was completed, four children (three of whom had demonstrated substantial gains in left ear performance during our dichotic listening training) were enrolled in an intensive multi-sensory reading program (Phonographics^{TM}). One year after the Phonographics program was completed, the four children were post-post tested with the dichotic digits test. Results from the post-post dichotic assessment are shown in Figure 4. As shown in Figure 4, all of the children demonstrated sustained improvement across the year since the training experience.

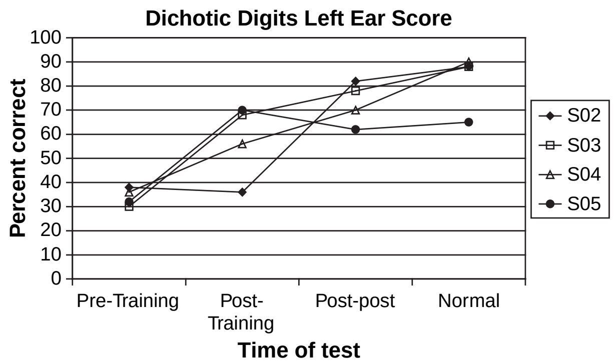

Figure 4. Pre-training, post-training, and post-post-training performance on the dichotic digits test in the left ears of the children who received follow-up language therapy after the dichotic training experience in the phase I clinical trial.

Discussion: Phase I

As hypothesized, seven out of the eight children did demonstrate training-induced benefits in left ear performance. In addition, five children also demonstrated benefits in right ear performance after training. These results support findings from other studies that have reported some benefit in children from intensive training experiences that involve repetitive stimuli and concentrated attention to task (Gillam et al, 2001), especially when tested with the verbal material that was used throughout the training. Improvements may have occurred in both ears for many of the children because even though the goal of the therapy was to preferentially train the left ear, both ears were receiving substantial stimulation of speech material. The ultimate goal of this training regimen is for children to perform at normal levels in both ears on dichotic listening tests. This goal was achieved with two children, one of whom (S05) attained normal performance immediately after training, and another (S06) whose results were normal at a subsequent measure four months later. The failure of the training to result in normal dichotic listening scores in six of the eight children in this first trial raised questions about what factors may have limited their success. The children were all at risk for speech and language disorders, but they had not been matched with respect to factors related to their language difficulties. It was therefore not possible to rule out the influence of language-specific issues on the effects of the training. Some of them may have had more severe receptive language difficulties that interfered with their ability to process the dichotically presented stimuli. Even though the one child who had been previously diagnosed with an attention deficit disorder showed improvement, it was also not possible to rule out the influence of attention factors in this small study. Since none of the children was receiving additional therapy during the training period, it is unlikely that other external factors played a significant role in the enhancement seen in dichotic listening skills in the two children who received the greatest benefit.

The training materials were presented via sound field speakers rather than under earphones in order to make the task more ecologically valid, similar to the listening situations in classrooms where children must focus attention on auditory information of interest that may be arriving from multiple sources (Jerger et al, 2000). Dichotic listening performance for these children was similar in the sound field to their performance under earphones at the end of the training, suggesting that listening dichotically in the sound field may not be significantly more challenging than listening under earphones.

Generalization of training results to improvements in broader language, learning, or reading skills has occurred in some studies on individual bases (Tallal & Merzenich, 1997; Friel-Patti et al, 2001; Valentine et al, 2006). In this study, some of the children did show modest gains in measures other than dichotic listening. Despite the failure of non-dichotic auditory processing or language measures to achieve statistically significant differences following the training, six of the children performed at a higher level on the LPFS test after training, and three performed at a higher level on the test of phonological awareness from the C-TOPP. Since phonological awareness has been linked to language and learning deficits, and with reading disabilities in particular (Catts et al, 2005), the improvement seen in some of the children's scores was mildly encouraging. In the children who received subsequent language therapy, dichotic listening left ear performance continued to improve, suggesting that gains made during the training were maintained across the following year. It is not possible to know whether the continued improvement seen in their left ear scores was due to the dichotic training, to the subsequent language training, or to a combination of both.

Results from the phase I clinical trial suggested that training might enhance dichotic listening performance in children. One unanswered question from the phase I trial was whether a greater number of training experiences would have resulted in more gains in dichotic listening performance or in language skills. Based on the success of phase I, a phase II clinical trial was proposed with children matched for language measures and similarly grouped according to their dichotic listening results. A specific goal of the phase II clinical trial was to increase both the frequency and total number of training sessions in order to evaluate whether more training would produce greater enhancement of dichotic listening performance.

Materials and Methods: Phase II Trial

Thirteen children (eight males, five females) were recruited from the Multidisciplinary Diagnostic Training Program (MDTP) at Shands Hospital at the University of Florida for phase II. All had normal intelligence but were at risk for language disorder. None had been previously diagnosed with attention deficit disorder. Prior to inclusion in the trial, each was assessed for language skills with subtests from the Brigance comprehensive inventory of basic skills-revised (Brigance, 1999), including listening comprehension, word recognition, and oral reading. The Brigance is a criterion-referenced assessment tool that produces grade-equivalency in key skill areas related to educational achievement. All of the children selected for the Phase II clinical trial achieved a first-grade level of performance on the listening comprehension subtest. Pre-training measures of dichotic listening were obtained with the dichotic digits test (Musiek, 1983), and the competing words subtest of the SCAN-C (Keith, 2000). As previously described, the digits test is administered in a divided attention format whereby the child is told to repeat all digits without regard to ear. The words test is administered in a directed response format whereby the child's attention is directed for half of the test toward one ear in order to provide equal bias toward the right and left ears. Following assessment for pure-tone and speech reception thresholds (SRTs) as described for Phase I, both dichotic listening tests were presented to the children at 50 dB SL relative to each child's SRT. As in the first trial, each child's total score for right and left ear were recorded and converted to percent correct. Because the other auditory processing measures used in the first trial were not significantly different following the training, they were not used in the second trial.

Training was conducted in the same manner as in the phase I trial. Each child received the same dichotic listening materials with equivalent proportions of words, digits, and other materials. Intensities were adjusted in the same manner and each child's performance was monitored across the training sessions. Each child was trained four times per week for 30 minutes, an increase of one training session per week. Two children were trained for three weeks for a total of 12 sessions, four children were trained for four weeks for a total of 16 sessions, and seven children were trained for six weeks for a total of 24 sessions. One child was lost to attrition at three weeks (S10). Other children were assessed following training at three weeks ($n = 1$), at four weeks ($n = 4$), or at six weeks ($n = 7$) with dichotic digits. Post-training testing with dichotic words was performed on ten of the children.

Statistical analysis

As in phase I, paired samples t-tests were used to compare pre-training measures between ears, and to compare pre-training measures with post-training measures within ears across all subjects. Correlations were obtained with Pearson product moment analysis. Because the phase II study involved three subgroups, group differences were compared by analysis of variance. Post-hoc differences between subgroups were evaluated with Dunnett's T3. Significance was measured and findings were reported that occurred at alpha levels of $p < .01$ and $p < .05$.

Results: Phase II

Pre-training measures

Pre-training measures of auditory processing and listening comprehension, word recognition, and oral reading are listed in Table 2. Evaluations with the Brigance battery of tests produced grade-equivalent scores for each subtest. All of the children involved in the phase II trial were selected to participate based on a first-grade-equivalent level of performance on the listening comprehension subtest of the Brigance battery. As shown in Table 2, each child's grade equivalent score was converted from a descriptor (lower first grade, upper first grade, etc.) to a numeric score (0.7, 1.3, etc.) in order to compare results.

Table 2. Pre-training and post-training results for children involved in phase II clinical trial. Results for the dichotic digits test are in percent correct, and results for the Brigance subtests are in grade-equivalency.

						DDT		*Brigance*		
		Subgroup	*Subject*	*Age*	*Sex*	*LE*	*RE*	*LC*	*WR*	*OR*
Pre-training		BLD	S13	8.2	M	48	68	0.7	1	0
		BLD	S14	10.5	F	44	66	0.7	2	0.7
		BLD	S15	11	M	42	78	1.3	1	1.3
		BLD	S16	11	M	44	68	0.7	6	5
		BLD	S17	11.5	M	64	78	1.3	2	2.7
		LED	S18	6.4	F	30	68	0.7	−0.7	
		LED	S19	7.5	F	46	74	1.3	2	1.3
		LED	S20	7.8	M	54	86	0.7	−0.7	−0.7
		LED	S21	8.5	F	44	86	0.7	1	1.7
		LED	S22	9	M	60	80	1.3	3	2.7
		WNL	S23	7.5	M	66	82	0.7	2	1.3
		WNL	S24	8	F	68	72	1.7	3	2.7
		WNL	S25	8.5	M	62	72	0.7		
Post-training	# weeks									
	6	BLD	S13	8.2	M	78	86	0.7	2	1.3
	3	BLD	S14	10.5	F	54	68			
	6	BLD	S15	11	M	74	78	4	1	0.7
	4	BLD	S16	11	M	88	86	5	7	5
	6	BLD	S17	11.5	M	82	86	2.3	3	2.3
	6	LED	S18	6.4	F	64	72	0.7	−0.7	−0.7
	6	LED	S19	7.5	F	76	78	2.7	2	1.7
	3	LED	S20	7.8	M	56	88	0.7	−0.7	−0.7
	4	LED	S21	8.5	F	82	86	2.7	2	1.7
	6	LED	S22	9	M	86	80	2.3	3	3.3
	6	WNL	S23	7.5	M	78	80	1.3	2	1.3
	4	WNL	S24	8	F	78	68	1.3	3	3.3
	4	WNL	S25	8.5	M	82	86	0.7		

DDT = Dichotic digits test; LC = Listening comprehension; WR = Word recognition; OR = Oral reading.

Children were divided into subgroups in the same manner as in the first trial, with children who demonstrated weaknesses in both ears during dichotic listening in one group (BLD), and children who demonstrated weaknesses in the left ear only in another group (LED). In this second trial, a third group of children was identified with right and left ear performance at normal levels (WNL). There were five children in the BLD group, five children in the LED group, and three children whose performance across both ears was close enough to normal to be considered essentially WNL. Subject S16 produced a left ear score on the digits test that was only 1% below normal (54% correct), but was placed in the LED subgroup because that result was 32% poorer than the same child's score for the right ear (86% correct). Because S21 performed slightly below normal for both ears on the digits test with a small difference between the ears and with scores that represented only one digit from normal performance, this subject was placed in the WNL subgroup.

A univariate analysis of variance demonstrated that the average age of children in the three subgroups differed significantly, $F(2,12) = 8.849$, $p < .01$, because children in the BLD group were older (10.4 years) compared to children in the LED group (7.8 years) and WNL (8.0 years). Because children were matched on listening comprehension skills, this result suggests that children with a bilateral deficit for dichotically presented digits may be more delayed in language development than younger children with similar listening comprehension skills who have a unilateral left-ear deficit with dichotic digits. A multivariate analysis of variance was performed on the Brigance subtest measures between groups and no significant differences were found for any of the subtests.

Average pre- and post-training measures of dichotic listening with digits and with words are shown in Figure 5. Before training, there was a significant difference between right and left ear scores with digits, $t_{(df = 12)} = 7.498$, $p < .01$, and with words, $t_{(df = 12)} = 3.879$, $p < .01$. Left ear scores on the digits test were significantly different between the three groups, $F(2, 12) = 4.263$, $p < .05$, with significant differences revealed by post-hoc Dunnett's T3 analysis between children in both the BLD and LED subgroups and those in the WNL subgroup, $p < .05$. Left ear scores on the words test failed to reach significance across the three subgroups, but post-hoc tests did reveal a significant difference between children in the BLD subgroup and those in the WNL subgroup, $p < .05$.

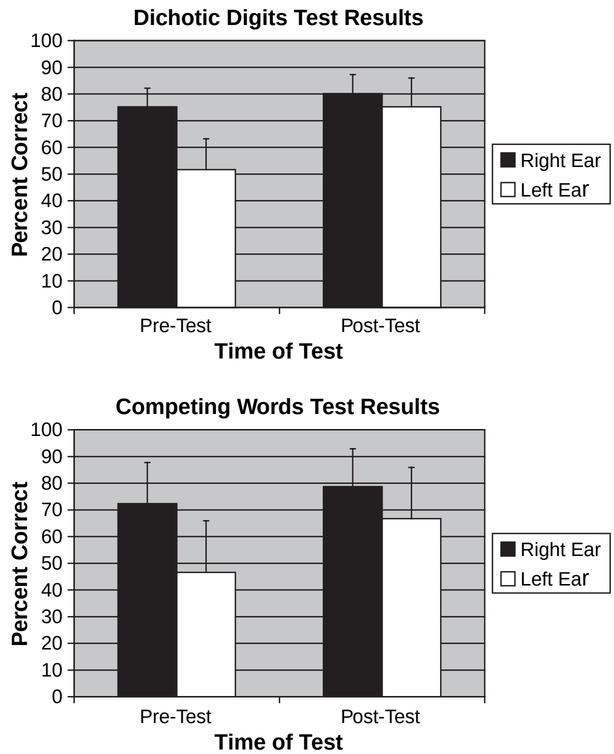

Figure 5. Average pre-training and post-training results in percent correct for the right ear and the left ear from the dichotic digits test (top of figure, n = 13) and the competing words subtest of the SCAN-C (bottom of figure, n = 10) for children in phase II clinical trial.

Post-training measures

Differences across ears

After training, differences between the right and left ears on the digits test were no longer present, but right and left ear results with words were still significantly different, $t_{(df = 10)} = 2.495$, $p < .05$ (n = 10). Three children who all showed left ear improvements on the post-training digits test were not tested with words after training. Also, two of the WNL children produced poorer scores in their left ears on the dichotic words test after training: the left ear score for S19 dropped by one word on the post-training test, and S21 reversed performance, switching from a three-word advantage in the right ear to a three-word advantage in the left ear. S21 was placed in the WNL subgroup because performance was at the borderline of normal on the digits test. This reversal of ear advantage on the subsequent administration of the dichotic words test suggests that this particular child may have had problems with directing attention. Test-retest variability with the dichotic words test is reportedly between 1.17 and 1.78 standard scores for children between the ages of five and eleven years (Keith, 2000). Standard scores are measured for the combined scores obtained by the two ears, and each standard score represents a range of three words. This would suggest that children whose performance remained consistent in terms of which ear performed more strongly than the other would typically demonstrate no greater than a four-to-five words difference between the first test administration and the second test administration for performance in both ears. It is difficult to directly compare these results with the results obtained in this study where percent correct by individual ear was used, but children in this phase II study demonstrated improved performance in the right ear that ranged from no difference to a difference of 4.2 words (mean = 2.79) for all of the children but one (S17) whose right ear performance improved by ten words after training. Left ear improvements following training were greater overall, ranging from no difference to a difference of 15.9 words (mean = 6.03). This average number of words is reduced by the results produced by the two children whose performance in the left ear for dichotic words dropped after training. It would be difficult, therefore, to attribute the improvement seen in the other children for left ear performance on the dichotic words test (mean number of words = 9.0) to test-retest variability.

Differences within ears

Paired samples t-tests comparing pre- and post-training scores revealed significantly improved performance for the right ear, $t_{(df=12)} = -2.406$, $p < .05$, and for the left ear, $t_{(df=12)} = -6.735$, $p < .001$ for dichotic digits; and for the right ear, $t_{(df=9)} = -2.954$, $p < .05$, and for the left ear, $t_{(df=9)} = -2.407$, $p < .05$ for words, despite the reversals described above. As shown in Figure 6, greater gains were made for left ear performance across the training as expected, but similar to the results obtained during phase I, many children also made gains in their right ears.

Differences on language skills

Paired-samples t-tests demonstrated improvements in listening comprehension, $t_{(df=11)} = -2.631$, $p < .05$, and in word recognition, $t_{(df=10)} = -2.390$, $p < .05$. Results for oral reading did not demonstrate significant improvements. As shown in Figure 7, children in the BLD subgroup demonstrated the largest gains for listening comprehension and oral reading.

Correlation effects

Left ear improvements on dichotic tests and improvements on language measures were significant in the phase II training trial. In order to evaluate whether these changes may have been related to either a child's age or the number of sessions that each child received, dichotic listening results, listening comprehension results, age, and number of sessions were analysed for significant correlations. Children's improvements in listening comprehension were significantly correlated with both age, $R = .675$, $p < .05$, and with improvements in left ear scores with digits, $R = .686$, $p < .05$ (n = 12), but they were not correlated with improvements in left ear scores with words, $R = .278$, $p > .05$, or with the number of sessions each child received, $R = -.014$, $p > .05$. Older children produced greater improvements in listening comprehension following training, but this could be due to the fact that the older children were poorer at listening comprehension at the beginning of training. They were selected on the basis of first grade level performance on that one score and then matched to younger children with similar results. As shown in Figure 8, the significant correlation with left ear scores on the digits tests suggests that children who improved the most with the dichotic digits test also improved the most on listening comprehension.

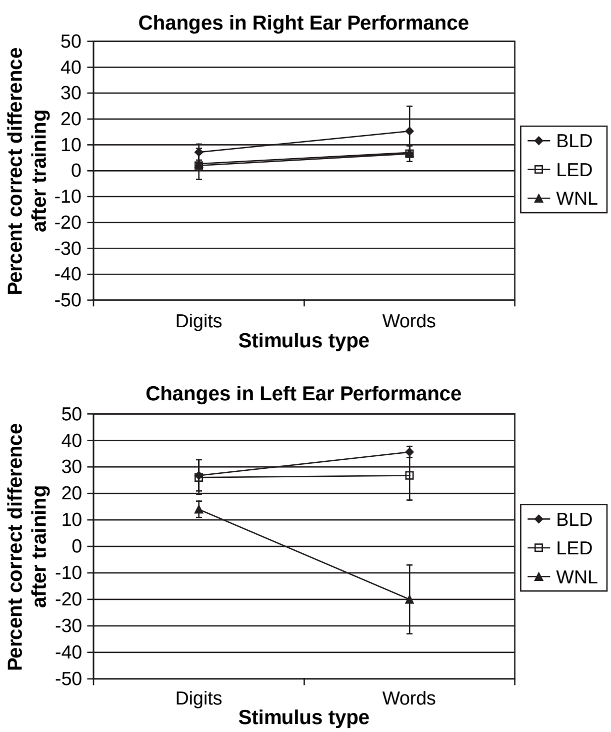

Figure 6. Comparison of the changes in performance by the right ear (top of figure) and the left ear (bottom of figure) on the dichotic digits test and the competing words subtest of the SCAN-C for children within the three subgroups (BLD = bilateral deficit, LED = left-ear deficit, and WNL = within normal limits on DD test) involved in the phase II clinical trial.

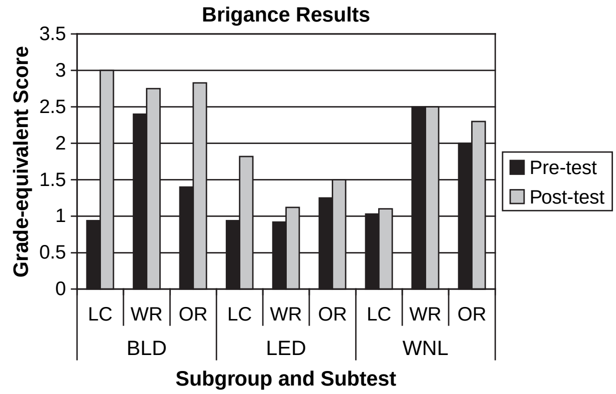

Figure 7. Average pre-training and post-training results from the Brigance comprehensive inventory of basic skills: Revised, depicted in grade-equivalent scores, for children within each of the three subgroups involved in the phase II clinical trial.

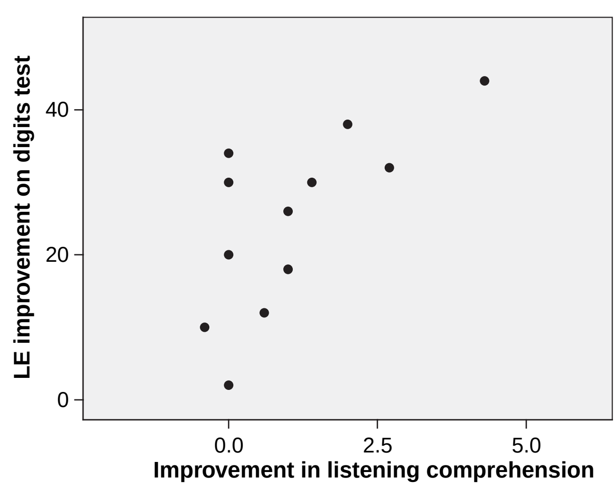

Figure 8. Scatterplot of the individual scores for improvement in the left ear on the dichotic digits test and improvement in the listening comprehension subtest from the Brigance battery for children involved in the phase II clinical trial.

Discussion: Phase II

In the phase II trial, children benefited from the training experience with significant improvements in dichotic listening. All of the children in the phase II trial received more training than the children in the phase I trial, from 12 to 24 sessions in total. After training, two of the BLD children and all five of the LED children achieved normal left ear performance on post-training testing with digits. The higher incidence of improvement in children with the unilateral deficit suggests that children with bilateral dichotic listening deficits may not derive the same level of benefit from the dichotic training, a result that is compatible with the results obtained during phase I. Whether the children with bilateral deficits were hindered by extra-auditory factors such as attention, motivation, or more severe language deficits beyond what we evaluated is unknown. Neither age nor number of sessions was linked to success, suggesting that some children may achieve optimum results in fewer sessions whereas others who are trained for a full six weeks may still fall short of normal left ear performance. Periodic evaluations throughout the training regimen were used to gauge progress and identify when a child had reached a plateau in performance. S17 is an example of a child whose performance had improved significantly after four weeks and training was stopped. Other children showed modest gains at two and four weeks, and demonstrated continued improvement across the entire six weeks of training.

As in other intervention studies (Tallal et al, 1998; Tallal, 2000; Gillam et al, 2001b), results were not limited to benefits in the area of auditory performance that were specifically targeted. Many of the children also showed improvements in language skills following this dichotic listening training. On the listening comprehension subtest, some children gained from one year to 4.5 years in performance following training. Three of the children who made substantial gains were in the BLD subgroup and three of them were in the LED subgroup, suggesting that dichotic listening category did not affect gains made in listening skills. Since other intensive intervention programs have also demonstrated language benefits (Gillam et al, 2001a), it seems plausible that any systematic training paradigm might additionally facilitate language just by nature of presenting speech-based material to actively engaged children over several weeks' duration.

Discussion

The most important goal of the two clinical trials was to evaluate the efficacy of intensive training on performance in a child's weaker ear during dichotic listening tasks. Results from both the first and second phases were encouraging. It appears that for some children, the unilateral deficit measured during dichotic listening tests can be eliminated following intensive training and that for others, left ear performance can improve. The fact that children with bilateral deficits during dichotic listening failed to make the same gains during training as children with unilateral deficits suggests that non-auditory factors related to attention, motivation, or language may inhibit success in some of these children, or that some deficits may require additional intervention beyond what was given here. The gains that these children with bilateral deficits did make, however, suggest that despite the presence of co-morbid factors, these children might still benefit from participating in a dichotic listening training experience. The continued improvement in dichotic listening observed in the children who received follow-up language therapy following the phase I trial suggests that a combination of dichotic training and language therapy may be facilitative, especially for children with bilateral deficits together with an interaural asymmetry. The large gains made in phase II by the children in the BLD subgroup on the listening comprehension test from the Brigance battery suggests that for these children, participating in the training may have had a positive impact on their ability to understand auditory information in general.

Attention enhances the right ear advantage after priming of the left hemisphere with a linguistic stimulus (Kinsbourne, 1970) and can facilitate left ear performance when a listener allocates resources preferentially toward that side (Asbjornsen & Hugdahl, 1995). An attention deficit disorder in children results in poor self-regulation and executive control (Barkley, 1997) that may interfere with the normal function of attention, especially during challenging listening tests (Pillsbury et al, 1995). Whether problems with attention may also contribute to inconsistent results across different tests of dichotic listening is still a matter of debate (Chermak et al, 1999; Hiscock et al, 2000). In the phase II trial, one child displayed inconsistent results that could not be fully explained. As recommended by the Consensus Conference on Auditory Processing Disorders in Children, this child (S21) was placed in the WNL subgroup because of borderline performance on the dichotic digits test (Jerger & Musiek, 2000). Pre-training performance by this child on the words test (Keith, 2000) was low in both ears and would have resulted in a disordered standard score. Furthermore, the child's performance was better in the left ear than in the right ear, reflecting a left ear advantage. A left ear advantage can occur in as many as 20% of right-handed listeners (Bryden, 1988), but it should occur across both dichotic tests if it is reflective of right hemispheric specialization for language. The reversal to a LEA and drop in performance observed during the words task suggest that S21 may have had greater difficulty allocating attention effectively when the task was more challenging, as it is with words (an open set dichotic task), than with digits (a closed set dichotic task). Following training, S21 had better scores for digits (up 10% in the left ear and up 14% in the right ear), but left ear performance fell by five words on the competing words subtest. Overall performance with words remained in the disordered category and the laterality reversed to a REA. During some clinical evaluations for auditory processing, problems with attention are suggested by these kinds of inconsistencies in performance across different tests that assess the same auditory task. Because an undiagnosed problem with attention deficits may interfere with training, it may be advisable to assess children for attention difficulties with a continuous performance task before they are enrolled in a dichotic listening training program.

In addition to the possibility that undiagnosed attention difficulties may have contributed to the instability seen in ear advantages for S21, these results also highlight the potential difficulty of using the double dichotic digits test as a primary screening tool for APD. It has been shown that double digits may have ceiling effects in older children (Moncrieff & Musiek, 2000; Neijenhuis et al, 2002) and it appears that results from the test falsely suggested normal performance in this even younger eight-year-old child. In this case, the competing words subtest would have more properly identified this child as below normal for dichotic listening and together with the results from digits testing, revealed the inconsistencies suggestive of difficulties with attention.

Another important finding from these clinical trials was that each child progressed similarly across the training experience, but that there were benefits to tracking each one individually in a flexible manner. In both phases I and II, the number of dichotic presentations and the order in which they were delivered were varied in an attempt to remain attentive to the progress each child was making. Varying the material helped to keep motivation high by engaging the child in the selection process from a limited set of dichotic materials so that the child maintained a sense of ownership in the therapy process. Digits and words were used most often because they were the simplest type of materials to process and to score, but the children enjoyed the variety provided by intermittently listening to sentence-length material and environmental sounds as well. Switching between presentations of single-syllable words (digits, words, and rhymes) and sentences gave the children an opportunity to engage in binaural integration activities (repeat both stimuli) and binaural separation activities (ignore the right ear and tell me what's being said toward the left ear, etc.). Whether this facilitated the overall training directly is not known, but it did appear to minimize fatigue and boredom and keep the children actively engaged throughout the training process. This information will be helpful in determining a standardized procedure to be used in future studies investigating the efficacy of this training regimen.

On many occasions during the training paradigm, the intensity of the right-side speaker was increased by 1 dB HL when a child was performing at a very high level in the left ear. Surprisingly, increments of 1 dB HL for material presented toward the right ear resulted in an initial drop in the child's left ear performance until the child was able to readjust his or her listening to accommodate this small change in the listening environment. The smaller incremental steps of 1 or 2 dB HL enabled the children to keep performance levels higher than were possible with the 5 dB HL steps that were utilized in the beginning of the training. Interaural intensity differences for mid-frequency pure tones at 90 degrees azimuth are approximately 10 dB, and at 270 degrees azimuth are approximately half as much (Kuhn, 1987), suggesting that for pure tones, a 5-dB step would have been appropriate. There is very little information available regarding interaural intensity differences for speech, but in one study of dichotically presented phonemes under earphones, a difference of 3 dB was needed to produce the characteristic right ear advantage in normal listeners (Graves et al, 1987). In another study, a patient with an auditory processing disorder exhibited greater sensitivity to interaural intensity differences with clicks than normal (Jerger et al, 1991), suggesting that interaural sensitivities may differ in individuals with auditory processing difficulties. The children in these clinical trials demonstrated greater sensitivity to interaural intensity differences than were originally expected. As a result, smaller increments in intensity for material delivered toward the right ear were used in order to keep each child on track.

These two clinical trials were designed as small group experiments to test the efficacy of this new dichotic training paradigm with children (Robey & Schultz, 1998). Because the number of children enrolled in both phases was small, results must be interpreted cautiously. The changes in dichotic listening performance and in some cases, in listening and language skills, suggest that this type of training may facilitate auditory processing in children with a binaural integration deficit. The results also suggest that improvements in dichotic listening may facilitate listening in general and ultimately may help children with language and learning tasks. A next step is to replicate these findings in a controlled experimental research study with standardized procedures according to the guidelines of a phase III clinical trial.

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Appendix. Dichotic materials used during training

Name of material	*Source*
Single dichotic digits	Auditec VA Tonal & Speech Materials
Double dichotic digits	Auditec VA Tonal & Speech Materials Musiek, 1983
Triple dichotic digits	VA Tonal & Speech Materials
Randomized dichotic digits	Strouse & Wilson, 1999
Competing words	SCAN-C (Keith, 2000) SSW (Katz & Smith, 1991)
Dichotic words	Deborah Moncrieff NU-6 CID W-22
Competing environmental sounds	Katz
Dichotic spondees	VA Tonal & Speech Materials
Competing sentences	VA Tonal & Speech Materials
Cinderella segments	Jerger & Moncrieff
Dichotic synthetic sentences	VA Tonal & Speech Materials