J Am Acad Audiol 17:306–320 (2006)

The Listening in Spatialized Noise Test: An Auditory Processing Disorder Study

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Abstract

The Listening in Spatialized Noise test (LISN)® produces a virtual three-dimensional auditory environment under headphones. Various measures assess the extent to which either spatial, vocal, or spatial and vocal cues combined increase a listener's ability to comprehend a target story in the presence of distracter sentences, without being affected by differences between participants in variables such as linguistic skills. Ten children at risk for auditory processing disorder (APD group) were assessed on the LISN, as well as a traditional APD test battery. The APD group performed significantly more poorly on all LISN measures than 48 age-matched controls. On the spatial advantage measure, the APD group achieved a mean advantage of only 3.7 dB when the distracters were spatially separated from the target by ±90°, compared to 10.0 dB for the controls—the 6.3 dB difference significant at $p < 0.000001$, with nine children scoring outside the normal range. The LISN was considered a promising addition to an APD test battery.

Key Words: Auditory processing disorder, aural figure-ground discrimination, binaural audio engineering, binaural interaction, spatial figure-ground discrimination

Abbreviations: APD = auditory processing disorder; BKB = Bamford-Knowal-Bench sentences; CANS = central auditory nervous system; CHAPS = Children's Auditory Performance Scale; HRTF = head related transfer function; IID = interaural intensity difference; ITD = interaural time difference; LISN = Listening in Spatialized Noise test; MLD = masking level difference test; NAL = National Acoustic Laboratories; PPS = Pitch Pattern Sequence Test; RGDT = Random Gap Detection Test; SNR = signal-to-noise ratio; SSA = spatial separation advantage; WISC = Weschler Intelligence Scale for Children

Sumario

La Prueba de Audición con Distribución Espacial del Ruido (LISN)® produce un ambiente auditivo tridimensional virtual con auriculares. Varias medidas evalúan el grado en el cuál tanto las claves espaciales, las vocales, o las vocales y espaciales combinadas incrementan la capacidad del sujeto para entender una historia en presencia de frases que producen distracción, sin que se vea afectada por diferencias en variables tales como la habilidad lingüística de los participantes. Se evaluó con el LISN a diez niños con riesgo de padecer un trastorno de procesamiento auditivo (grupo APD), al igual que con la batería tradicional de pruebas para APD. El grupo con APD se desempeñó

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Some of the data from this paper were presented at the Inaugural Paediatric Conference of Auditory Processing Disorders in Melbourne, Australia, February 21–23, 2005.

significativamente peor en todas las mediciones del LISN que 48 controles agrupados por edad. En la medida de ventaja espacial, el grupo APD logró una ventaja media de sólo 3.7 dB cuando los distractores estaban separados espacialmente del blanco en ±90°, comparado con 10.0 dB para los controles – la diferencia de 6.3 dB es significativa, con una p < 0.000001, con nueve niños fuera del rango normal. Se consideró el LISN como una adición promisoria en una batería de pruebas para APD.

Palabras Clave: Trastorno de procesamiento auditivo, discriminación auditiva figura-fondo, ingeniería audio-binaural, interacción binaural, discriminación espacial figura-fondo

Abreviaturas: APD = trastorno de procesamiento auditivo; BKB = frases de Bamford-Knowal-Bench; CANS = sistema nervioso auditivo central; CHAPS = Escala de Desempeño Auditivo en Niños; HRTF = función de transferencia relacionada con la cabeza; IID = diferencia de intensidad inter-auricular; ITD = diferencia inter-auricular temporal; LISN = Prueba de Audición con Distribución Espacial del Ruido; MLD = prueba de diferencia en el nivel de enmascaramiento; NAL = Laboratorios Nacionales de Acústica; PPS = Prueba de secuencia de patrones tonales; RGDT = Prueba de Detección de Brechas Aleatorias; SNR = tasa señal-ruido; SSA = ventaja de separación espacial; WISC = Escala de Weschler de Inteligencia en Niños

Auditory processing disorder (APD) is said to affect two to three percent of all children (Chermak and Musiek, 1997). While the biological basis of the disorder has not been established, immaturity or deficiency of the central auditory nervous system (CANS) has been implicated. Regardless of the underlying pathology, APD can lead to academic deficits in areas such as phonics, reading, and spelling, and may also result in mild speech-language impairments (Richard, 2001). According to Jerger and Musiek (2000), despite having normal peripheral hearing thresholds, children with APD display a number of behaviors similar to the symptoms associated with hearing loss—predominantly difficulty listening to speech in the presence of background noise. These behaviors may become apparent in the early school years, or at a later academic stage of the child's life, due to changes in the acoustic environment, or to increased academic demands (Bamiou et al, 2001).

The American Speech-Language-Hearing Association (ASHA, 1996) task force on APD consensus development defined the disorder as a deficit in one or more of six behaviors mediated by the mechanisms and processes of the auditory system, including sound localization and lateralization, and auditory performance decrements with competing acoustic signals. Jerger (1998) noted that APD is most likely a deficit in auditory figure-ground discrimination and/or temporal resolution.

Schow and Chermak (1999) and Domitz and Schow (2000) employed factor analysis to establish the sensitivity and specificity of various assessment tools for the auditory behaviors identified by ASHA as being deviant in children with APD. Schow et al (2000) noted that the complex auditory behaviors of localization, lateralization, and/or binaural interaction were not assessed using the battery of tests administered in the factor analysis studies, and more study would be required to learn how they should be measured. According to Bellis (2003), whereas localization, lateralization, and binaural interaction can be assessed by tasks such as binaural fusion or the masking level difference (MLD) test, there is an apparent need for more efficient tests in this category.

Binaural interaction is defined as auditory processing involving the two ears and their neural connections (Singh and

Kent, 2000). The ability to locate the source of a sound depends on the capacity of the CANS to detect, perceive, and compare small differences in the arrival time and intensity of signals reaching the two ears. The ability to understand speech in a background of noise can be directly related to the ability of the listener to use binaural cues to differentiate the location of the sound source from the location of the noise (Moore, 1997).

Binaural interaction is not, however, the only mechanism available to listeners to help to differentiate a target signal in a noisy environment. Cherry (1953) investigated the various means by which humans recognize what one person is saying when others are speaking at the same time, an ability referred to as the cocktail party effect. Five factors were suggest that could improve discrimination of a target speech signal in the presence of other speech streams. These were (a) the voices were coming from different spatial locations; (b) the listener used lip reading and gesture to focus on the target; (c) the voices differed in pitch, speed, and gender; (d) the voices differed in accent; (e) the subject matter or syntax differed between speech streams. The general term applied to the ability to attend to relevant linguistic information presented with background competing auditory stimuli is "auditory figure-ground discrimination." Richardson (1977) defined factor "a" as spatial figure-ground; factor "c" as aural figure-ground; and factor "e" as statistical figure-ground discrimination.

Traditionally, localization and spatial figure-ground discrimination is assessed in a free-field environment, where sounds are emitted from a number of loudspeakers mounted at various azimuths and elevations around a sound-treated room. However, difficulties inherent in free-field testing may explain why assessment of these processes in APD research has been limited. Test consistency and validity require the listener's head to remain stationary during testing, as slight movements may affect the sound reaching the eardrum by several dB (Wilber, 2002), and many clients, especially young children, will not sit still long enough to complete the test. It is also difficult to replicate speaker and listener placement, as well as reverberation characteristics, between clinics, which is vitally important for test consistency (Koehnke and Besing, 1997). Thus, the ability to perceive speech in noise is typically assessed in the clinic under headphones by presenting a monaural target speech signal and noise through the same earphone at various signal-to-noise ratios (SNRs). This assessment method has been criticized recently, as it does not assess a client's hearing in typical, everyday listening situations, such as is the classroom (Besing et al, 1998; Jerger et al, 2000).

The Listening in Spatialized Noise test (LISN)® was developed to provide an ecologically valid measure of speech understanding in background noise that can also be administered in any audiology clinic, under headphones, using standard audiometric equipment and a personal computer, and is sensitive enough to detect auditory figure-ground discrimination deficits in children with suspected APD who may be having difficulty understanding speech in the classroom.

Finally, Jerger and Allen (1998) state that a lack of clarity about APD probably results from the common use of global behavioral tests without appropriate control conditions and/or manipulated variables. As noted by Wilson et al (2004), children with a supramodal deficit may perform poorly on tests of auditory processing, not because they have auditory-specific perceptual problems but because the test in question is sensitive to other processing demands—such as motivation, attention, memory, cognition, and motor skills—which are necessary to perform any behavioral task. However, by assessing a listener's performance based on difference scores, supramodal variables that may confound results are effectively cancelled out by virtue of the test protocol.

The LISN is an adaptive speech test that was developed using binaural audio engineering techniques in order to simulate a free-field auditory environment under headphones (Cameron et al, 2006a). In the development of the LISN software, distracter sentences (which were looped during playback) were recorded by the first author (Female 1), as well as two other female speakers (Females 2 and 3) and one male speaker (Male 1). Various target children's stories were also recorded by the first author. These prerecorded monaural speech signals were convolved with binaural head related transfer functions (HRTFs). HRTFs are a set of measurements that represent the transformation of a sound wave as it travels from a particular location to the eardrum. The resulting output signal simulates the pinna cues, interaural time difference (ITD), and interaural intensity difference (IID) characteristics of a sound emanating from the designated location. The target stories recorded by Female 1 were all synthesized with HRTFs recorded at 0° azimuth. The distracter sentences recorded by the various speakers were synthesized with the HRTFs recorded at 0°, -90°, and +90° azimuth.

On playback, the distracter sentences therefore differed from the target stories in respect to the vocal quality of the speakers and/or the perceived physical location of the distracters in auditory space. The LISN playback screen, displayed on a PC, is used to retrieve the spatialized target and distracter speech files, and combine and scale these stimuli in dB to produce a binaural output signal. A test protocol was devised to facilitate evaluation of LISN performance on two SNR and three difference scores, or advantage measures. Normative data was collected from 48 children aged seven to nine years, described in Cameron et al (2006b).

The following study was conducted to compare performance on the LISN in a group of children with suspected auditory processing disorder (APD group) to the age-matched normally hearing controls (control group). The study also aimed to compare patterns of performance by the APD group on the child's version of the Pitch Pattern Sequence test (PPS; Pinheiro, 1977); a 500 Hz Masking Level Difference Test (MLD; Wilson et al, 2003); dichotic digits (Wilson and Strouse, 1998); the Random Gap Detection Test (RGDT; Keith, 2000); and Bamford-Knowal-Bench sentences in eight-speaker babble (BKB; Brewer et al, 2000). Listening skills in the classroom were determined using the Children's Auditory Performance Scale questionnaire (CHAPS; Smoski et al, 1998), which was completed by each participant's class teacher. Results on this battery were compared to performance on the LISN to determine whether any correlations existed between assessment tools. It was hypothesized that the children in the APD group may have spatial and aural figure-ground deficits that would not be revealed by the traditional test battery.

METHOD

Participants

There were ten participants in the APD group, ranging in age from 7 years, 0 months to 9 years, 11 months (mean age 8 years, 6 months). There were three females and seven males. The APD group comprised children who had been referred to a participating audiology clinic for APD assessment by a certified primary school teacher, educational psychologist, or pediatrician who had identified the child as exhibiting abnormal auditory behavior relative to their peers. Participants were included in the study if they had Australian English as their first language; no permanent peripheral hearing impairment; pure-tone thresholds of ≤15 dB HL at 500 to 4000 Hz, and ≤20 dB HL at 250 and 8000 Hz; normal Type A tympanograms; and 1000 Hz ipsilateral acoustic reflex present at 95 dB HL. All children in the APD group were assessed by an educational psychologist as having overall intellectual performance within normal limits on the Weschler Intelligence Scale for Children (WISC), as well as no attention deficit or hyperactivity disorder.

Materials

Pure-tone audiometric screening was performed using a Maico MA 53 clinical audiometer with circumaural Sennheiser HDA 200 audiometric headphones. Acoustic immittance data was obtained using an Interacoustics impedance audiometer. Contralateral acoustic reflexes were assessed with a Grason-Stadler middle ear analyser, with 500, 1000, and 2000 Hz probe tones.

The LISN test materials were presented using a Toshiba Tecra S1 laptop computer. The computer was connected to the Maico MA 53 audiometer via an audio cable and presented through the Sennheiser HDA 200 headphones. Participant responses were collected using the LISN playback screen previously described. Before testing commenced, a 1 kHz reference tone activated from the playback screen was used to calibrate the input to the audiometer to 0 VU. The audiometer was set to 50 dB HL during playback. A listener indicated the intelligibility level of a target story using a response card developed from verbal and pictorial speech clarity categories based on Dillon (2001).

The PPS, MLD, dichotic digits, and RGDT tests were presented using a Panasonic portable CD player connected to a Maico MA 53 audiometer with Sennheiser HDA 200 headphones. The 1 kHz reference tone on each CD was used to calibrate the input to the audiometer to 0 VU, and the tests were presented at the recommended levels. Lists 1, 2, 3, and 4 of the BKB sentences in babble were presented via a Hitachi CD player over a loudspeaker. The presentation levels of the sentences and the eight-speaker babble were adjusted using an attenuator.

Design and Procedure

Testing was carried out in an acoustically treated room at the National Acoustic Laboratories (NAL) over one morning session. Testing took approximately three hours per child, including appropriate breaks to avoid fatigue. The children were assessed on the following tasks:

Traditional APD Test Battery

PPS: Various pitch patterns were presented under headphones at 50 dB SL (referring to PTA for 500, 1000, and 2000 Hz tones). Each consisted of three consecutive tone bursts made up of high-pitch and low-pitch tones. The participant was required to verbalize the pattern, for example, high-low-high. The participant was required to hum the pattern only if they were unable to complete the verbal condition. Twenty tone pairs were presented binaurally to ensure the child could distinguish high and low tones. Ten tone triplets were then presented to the right ear as practice. Thirty triplets were scored for each ear.

Dichotic Digits: Two different pairs of sequential digits were presented under headphones to each ear simultaneously at 50 dB SL (re PTA). The participant was required to repeat back all digits heard, regardless of order. Ten single digits and ten double digits were presented dichotically as practice. Forty double digits were then presented and scored for each ear.

RGDT: Pairs of tones ranging from 500 to 4000 Hz were presented binaurally at 55 dB HL. Each of the stimuli were presented in pairs with a silent gap between them, ranging in duration from 0 to 40 msec. One each of the nine gap durations between 0 and 40 msec were tested for each stimulus. The gap detection threshold was defined as the lowest interpulse interval at which two tones were consistently identified. One practice trial of nine tone pairs was provided.

MLD: Stimuli consist of 33 500 Hz tones presented in three-second bursts of 200–800 Hz noise at various fixed SNRs. Stimuli were presented binaurally at 50 dB HL in either a homophasic (SoNo), antiphasic (SπNo), or "no signal" condition. The participant's task was to indicate whether or not he or she heard the tone. MLD was calculated as the score on the SoNo condition minus the score in the SπNo condition.

BKBs: The stimuli were presented in the free-field at 0° azimuth and elevation, with the listener positioned one meter from the loudspeaker. The sentences were presented at a constant level of 65 dB SPL, whereas the babble was initially presented at 55 dB SPL. Speech reception threshold (SRT) was determined using a loose key-word scoring method over a total of 20 reversals of babble level in 1 dB steps, with the first four reversals provided as practice.

CHAPS: The questionnaire was completed by the participant's teacher, who was asked to judge the amount of listening difficulty experienced by the participant, compared to a hypothetical reference population of children of similar age and background, for six listening situations. Degree of difficulty ranged from (+1), where there was less difficulty than in the reference population, to (-5), indicating that the child could not function at all. A child's total overall score could range from +36 to -180. The total overall score was divided by 36 to obtain an average overall score.

LISN

The participants were assessed on two LISN conditions of distracter voice. In each condition the target story was always spoken by Female 1. There were two combinations of speaker for the distracter sentences: Female 1 ("same voice" condition); and Females 2 and 3 ("different voices" condition). For each condition of distracter voice there were two conditions of distracter location: 0° condition (target and both distracters all at 0° azimuth) and ±90° condition (target at 0° azimuth and distracters at + *and* -90° azimuth). A practice trial was also provided, with the distracter sentences spoken by Male 1 and Female 2, for both conditions of distracter location, to familiarize the participants with the test instructions. To ensure that familiarity with a story was not influencing a participant's ability to understand the target discourse, a different target story was used for each LISN condition. The presentation order of test materials was counterbalanced between conditions and tasks.

In a three-alternative, forced-choice adaptive procedure, the participant's task was to indicate the amplitude at which the target story was either easy to understand, just understandable, or too hard to understand in the presence of the distracters, by pointing to the appropriate picture on the response card. The participants were instructed that "easy to understand" meant that almost every word of the target story was understandable; "just understandable" meant that a few words were missed here and there but nearly all the story was understandable; and "too hard to understand" meant that more than just a few words were missed and the story had became hard to follow. Participants were advised to concentrate on the woman telling the story and to ignore the distracters.

The distracter sentences were presented at a fixed level of 40 dB on the competition slider bar. The story was always initially presented at the 50 dB level on the target slider bar. The experimenter decreased the amplitude of the target signal in 4 dB steps until the participant indicated that the story became too hard to understand. At this time the volume was increased in 2 dB steps until the presentation level was again perceived as easy to understand. Adjustments either increasing or decreasing the volume continued in 2 dB steps for a total of seven reversals. The average amplitude—calculated across the final four reversals—was used to determine the "just understandable" level and is referred to as a listener's "threshold" in a particular LISN condition. Once a practice or listening trial was completed, the children were required to provide details of the stories that they had heard. This procedure was implemented to keep the children engaged in the task and to ensure that they did not point to the "just understandable" response card icon unless they could still basically understand the story.

LISN Performance Evaluation Measures

In total the participants' performance was evaluated on two SNR measures and three advantage measures, which were calculated from a participant's thresholds in the "same voice: 0° and ±90°" and "different voices: 0° and ±90°" conditions. Figure 1 illustrates the manner in which the various measures were derived.

- The low-cue SNR was calculated as the threshold in the "same voice: 0°" condition minus 40 dB, and assessed the SNR required to understand the story when only limited cues are available.
- The high-cue SNR was calculated as the threshold in the "different voices: ±90°" condition minus 40 dB, and assessed the SNR required to understand the story when abundant cues are available.
- Tonal advantage was calculated as the difference in thresholds between

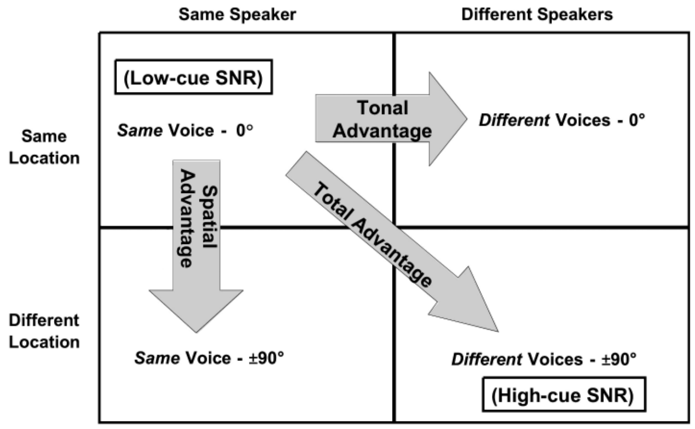


Figure 1. LISN SNR and advantage measures.

the "same voice: 0°" and "different voices: 0°" conditions. The advantage reflected the listener's ability to use differences in the tonal quality of the voices of the speakers to distinguish the target from the distracters.

- Spatial advantage was calculated as the difference in thresholds between the "same voice: 0° and ±90°" conditions. The advantage reflected the listener's ability to use spatial cues (such as interaural time and intensity differences) to comprehend the target.
- Total advantage was calculated as the difference in thresholds between the "same voice: 0°" condition and the "different voices: ±90°" condition. The advantage reflected the listener's ability to use both spatial and tonal cues in combination to detect the target stimulus.

Normative Data

A child was considered to have failed a test if he or she scored more than two standard deviations (SD) below the mean score for his or her age. Normative data for the PPS and dichotic digits tests were taken from Singer et al (1998). Normative data for the BKB sentences in babble was obtained from unpublished data provided by S. Cameron. Normative data for the 500 Hz MLD test was obtained from unpublished data provided by V. Aithal, A. Yonovitz, S. Aithal, and L. Yonovitz.

Normative data on the RGDT was provided by Keith (2000); however, in line with Keith (2000) and Bellis (2003), a participant was only considered to have failed the RGDT if their gap detection threshold exceeded 20 msec. Normative data for each task in the traditional battery is provided in Table 1. Normative data for the CHAPS was taken from Smolski et al (1998), whereby an average overall score of -1.0 or less was considered to put the child "at risk" for APD.

Normative data for the LISN collected from a group of 48 normally hearing 7-, 8-, and 9-year-old children described in Cameron et al (2006b) is provided in Table 2. There were no significant differences found between the 7, 8, or 9 year olds on any LISN SNR or advantage measure. However, as there was a trend of improved performance with age across measures in the normally hearing population, the cut-off scores were adjusted for age using the following formula: cut-off score = intercept + (B-value * mathematical age) - (2 * standard deviations of residuals from the age-corrected trend lines).

RESULTS

LISN SNR and Advantage Measures

In order to investigate differences between the APD and control groups on LISN performance, a Mann-Whitney U test was performed separately on each SNR and

Table 1. Mean Scores and Standard Deviations, Based on Normative Data for the Traditional Central Test Battery, with Cut-Off Scores Calculated as Two Standard Deviations from the Mean, for Either Right Ear and Left Ear, or Bilateral Presentation

		Mean			SD			Cut-Off Score		
Test	Age	RE	LE	Bilateral	RE	LE	Bilateral	RE	LE	Bilateral
PPS	7	78%	76%	-	7%	8%	-	64%	60%	-
	8	87%	76%	-	5%	8%	-	77%	60%	-
	9	91%	91%	-	5%	5%	-	81%	81%	-
Dichotic Digits	7	74%	74%	-	6%	6%	-	62%	62%	-
	8	92%	89%	-	5%	6%	-	82%	77%	-
	9	93%	91%	-	6%	5%	-	81%	81%	
RGDT	7	-	-	7.3 msec	-	-	4.8 msec	-	-	16.9 msec
	8	-	-	6 msec	-	-	2.5 msec	-	-	11 msec
	9	-	-	7.2 msec	-	-	5.3 msec	-	-	17.8 msec
BKBs	All	-	-	0 dB	-	-	1 dB	-	-	2 dB
MLD	All	-	-	11.2 dB	-	-	1.7 dB	-	-	7.8 dB

Table 2. Normative Data Used in Calculation of LISN Cut-Off Scores

Measure	Mean [a] dB	SD (Residuals) dB	Intercept	B-Value
Low-Cue SNR	2.0	1.9	6.93	-0.58
High-Cue SNR	-8.4	2.3	-1.08	0.86
Tonal Advantage	6.7	2.1	5.73	0.50
Spatial Advantage	10.0	1.8	1.62	0.60
Total Advantage	10.4	2.4	8.01	0.28

[a] n = 48

advantage measure. The Mann-Whitney U test was chosen because of unequal group sizes and potential unequal variances between the two groups. The dependent variable was "SNR/advantage," and the independent variable was "group" (control and APD). Figures 2a and 2b show the mean scores for both groups on the SNR and advantage measures respectively. The control group had a significantly more favorable score than the APD group on the low-cue SNR, $p = 0.01$; the high-cue SNR, $p < 0.001$; tonal advantage, $p < 0.001$; spatial advantage, $p < 0.001$; and total advantage, $p = 0.002$.

Scatter plots showing individual results on the various LISN measures for the 10 participants in the APD group, and the 48 participants in the control group, are provided in Figures 3a to 3e. Identification markers (from 1 to 10) on the scatter plots indicate individual participants in the APD group who scored below the cut-off score for a particular LISN measure, and were thus considered to have displayed disordered

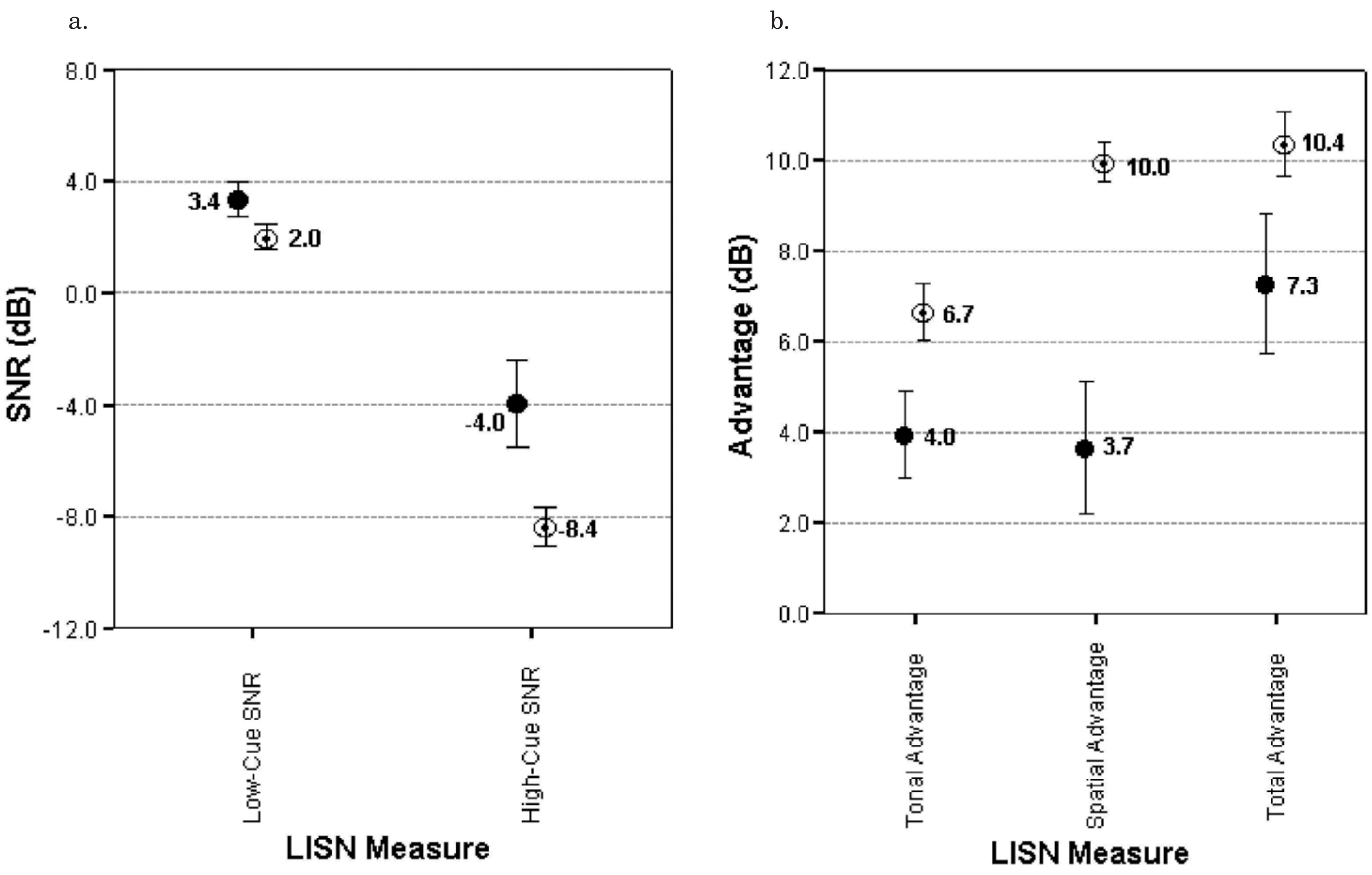
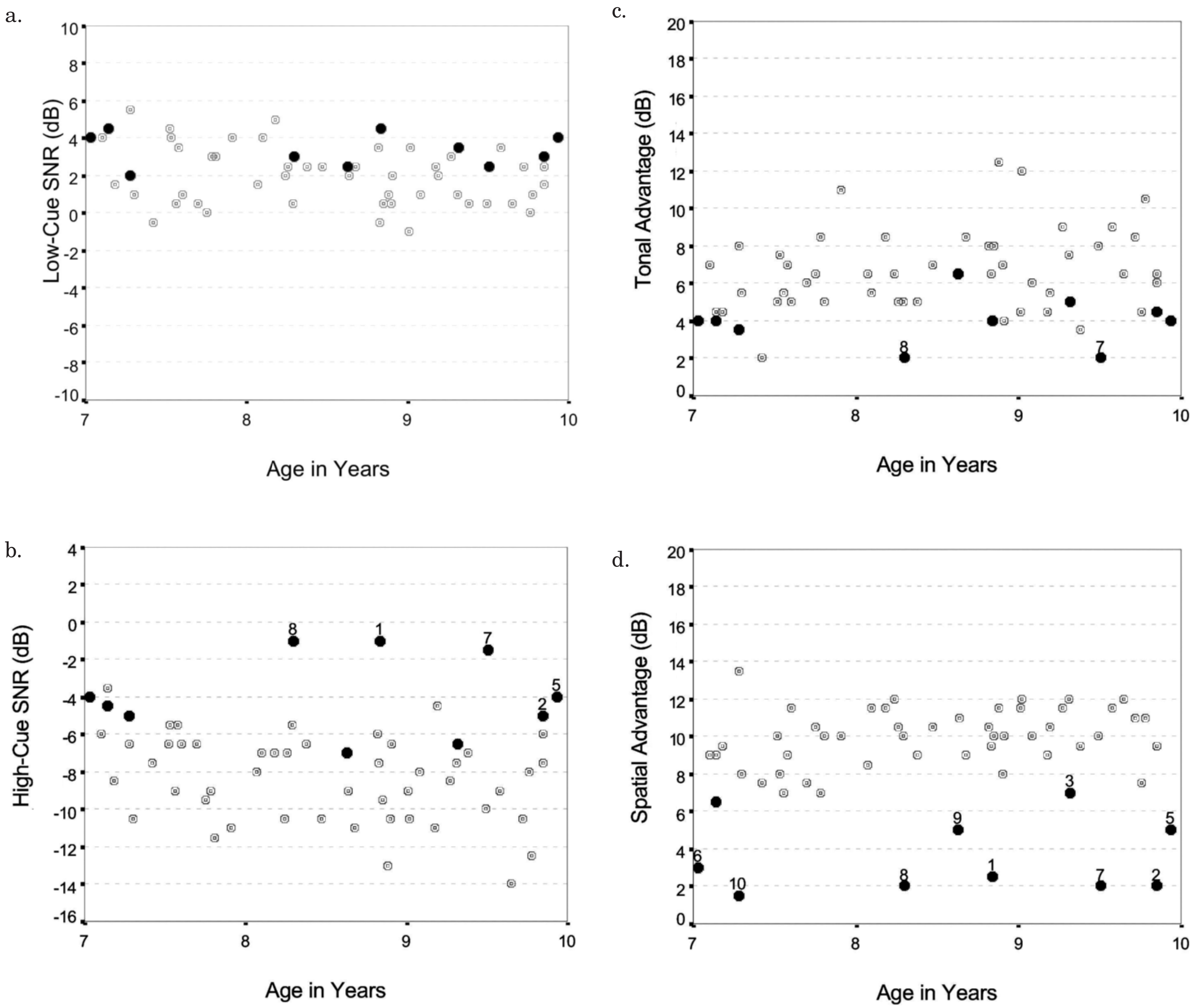


Figure 2. Mean scores on *(a)* LISN SNR measures; *(b)* LISN advantage measures. Filled symbols represent the APD group; open symbols represent the control group. Error bars represent the 95 percent confidence intervals from the mean.



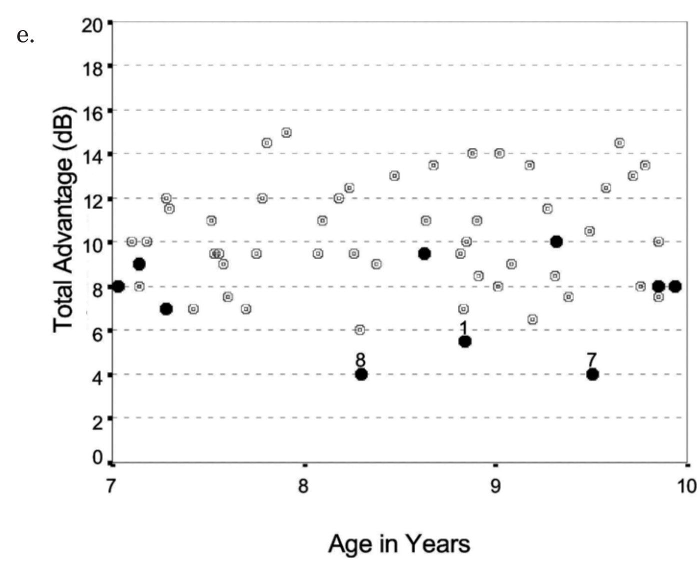


Figure 3. Scatter plots depicting individual results on *(a)* low-cue SNR, *(b)* high-cue SNR, *(c)* tonal advantage, *(d)* spatial advantage, and *(e)* total advantage. Filled symbols represent the APD group; open symbols represent the control group. Filled symbols with identification markers indicate the participant numbers of children in the APD group whose scores were below 2 SDs from the mean, as a function of age.

performance compared to the normally hearing controls. No participant in the APD group was outside normal limits on the low-cue SNR measure. However, five participants (1, 2, 5, 7, and 8) were outside normal limits on the high-cue SNR. Participants 8 and 7 were outside normal limits on the tonal advantage measure. Nine participants were outside normal limits on the spatial advantage measure. Finally, participants 1, 8, and 7 were outside normal limits on the total advantage measure.

Traditional APD Test Battery

To enable comparison of performance by the children in the APD group across age groups, performance on the traditional APD test battery was analyzed using z scores. The z scores were calculated as the participant's score on a particular assessment tool, minus the mean score for the test from the normative data for his or her age group, divided by the SD. Cut-off scores were calculated as 2 SDs below the mean for each age group. Box and whiskers plots illustrating the median and inter quartile range for the 10 children in the APD group on the traditional APD test battery, and the LISN, is provided in Figure 4.

No child in the APD group obtained a result below the cut-off score on either the BKB sentences in babble or the left- or right-ear condition of the dichotic digits test. Only one child (participant 7) performed below normal limits on the verbal task of the PPS. Although participant 7 scored 5 SD below the mean on left ear and 6 SD below the mean on the right ear condition of the verbal task, she obtained a score of 100 percent correct for both ears on the humming condition. Only one child (participant 6) failed the MLD test, although two other children (participants 7 and 9) achieved a borderline pass by only 0.2 dB. Three children

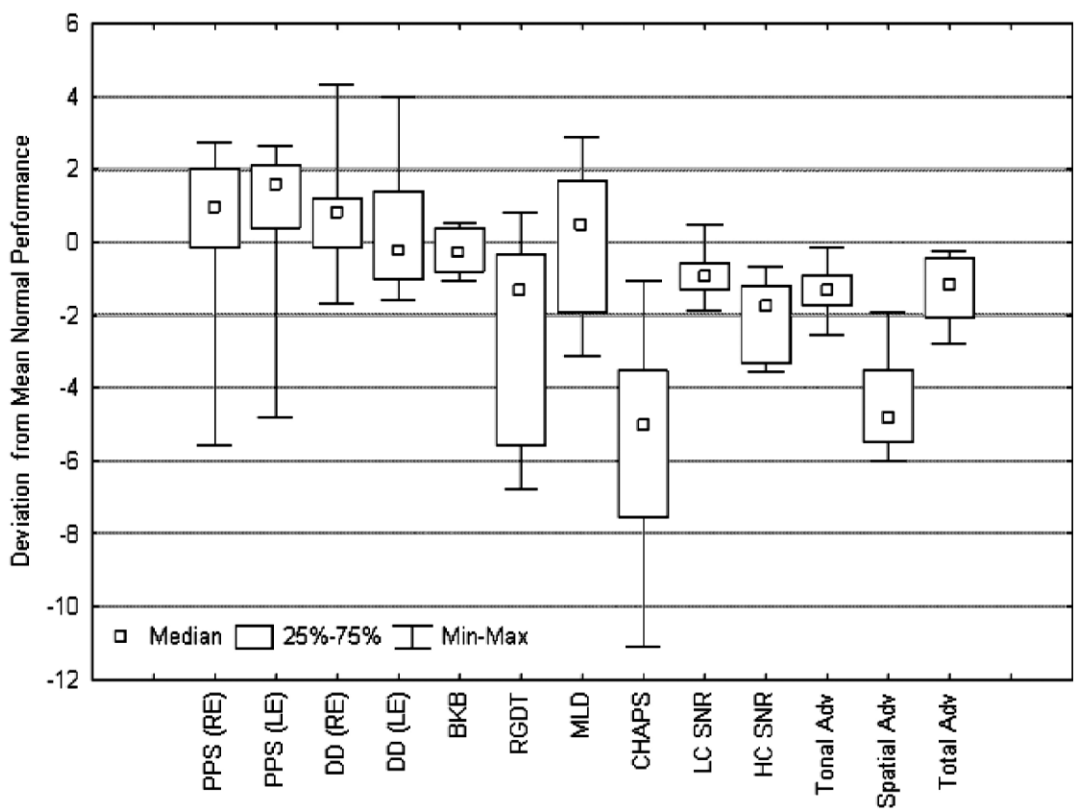


Figure 4. Box and whiskers plots depicting the median and inter quartile range for all APD measures for the ten children in the APD group. The results are expressed as deviations of the scores for the children with APD relative to the mean scores of children with normal hearing, expressed in units of standard deviations of the normative data, that is, z scores.

(participants 1, 7, and 8) were below normal limits of the RGDT. All children, except for participants 6 and 7, were outside normal limits on the CHAPS.

Correlations

A Spearman rank order correlation matrix was plotted using the z scores for the ten participants in the APD group for the various tests in the traditional APD battery, and the SNR and advantage measures of the LISN. Z scores for the APD group on the thresholds obtained by the participants on the "same voice: ±90°" condition, and the "different voices: 0°" condition were also included in the analysis to determine whether performance on these thresholds correlated with any other assessment tool. Results are shown in Table 3. Statistically, it could be expected that within a correlation matrix, 1 in 20 correlations may be significant by chance alone if an alpha level of 0.05 were to be used. As the current analysis utilized 105 comparisons, five correlations may be erroneously found to be significant. In order to reduce the chance of finding an erroneously significant correlation, only correlations significant at a level of $p < 0.01$ are highlighted in the table.

The LISN high-cue SNR measure correlated significantly with the tonal advantage measure ($r = 0.82$, $p = 0.004$), the "same voice: ±90°" condition ($r = 0.80$, $p = 0.005$), and the "different voices: 0°" condition ($r = 0.79$, $p = 0.007$). The LISN total advantage measure correlated significantly with the high-cue SNR ($r = 0.84$, $p < 0.002$), tonal advantage ($r = 0.93$, $p < 0.001$), and spatial advantage ($r = 0.77$, p = 009) measures. Spatial advantage also correlated significantly with the "same voice: ±90°" condition ($r = 0.86$, $p < 0.001$). Some correlation would be anticipated between the total, tonal and spatial advantage measures, and between the spatial advantage measure and the "same voice: ±90°" condition, due to the fact that each of these pairs of measurements share a common element and are thus intrinsically related. These correlation coefficients are higher, however, than would be expected were the correlation to be due to variance in the common element alone.

The LISN low-cue SNR measure was not significantly correlated with performance on any other LISN measure or assessment tool. The LISN spatial and tonal advantage measures were also not significantly correlated ($r = 0.52$, $p = 0.13$).

The left- and right-ear scores on the PPS were also significantly correlated ($r = 0.79$, $p = 0.006$).

Table 3. Spearman Rank Order Correlation Matrix of z Scores from the APD Group on the Traditional APD Test Battery, the LISN Measures, and the LISN "Same Voice: ±90°" and "Different Voices: 0°" Condition Thresholds

	PPS -RE	PPS -LE	DD -RE	DD -LE	BKB	RGDT	MLD	CHAPS	LC SNR	HC SNR	Tonal Adv	Spatial Adv	Total Adv	SV ±90°
PPS-LE	*.79													
DD-RE	-.06	-.06												
DD-LE	.32	.31	.09											
BKB	.76	.58	.23	.28										
RGDT	-.22	-.33	.10	.09	-.34									
MLD	.30	-.02	-.43	.09	.07	-.01								
CHAPS	-.71	-.31	.32	-.28	-.35	-.35	-.38							
LC SNR	.22	.13	.60	-.01	.55	-.37	-.45	.09						
HC SNR	.32	.09	.20	.44	.38	.55	-.23	-.64	.31					
Tonal Adv	.25	.20	-.06	.62	.28	.56	-.01	-.54	-.11	*.82				
Spatial Adv	.20	.06	-.06	.43	-.14	.71	-.07	-.62	-.27	.61	.52			
Total Adv	.32	.25	-.07	.61	.22	.64	-.09	-.66	-.17	*.84	*.93	*.77		
SV ±90°	.26	-.02	.22	.42	.19	.61	-.19	-.60	.16	*.80	.52	*.86	.72	
DV 0°	.34	.25	.42	.48	.35	.35	-.16	-.43	.45	*.79	.68	.31	.59	.46

* $p < 0.01$

DISCUSSION

LISN Performance

This study has revealed that, as a group, the children at risk for APD performed significantly more poorly on all the LISN SNR and advantage measures than the normally hearing controls. Whereas the performance of the APD group on the low-cue SNR measure was significantly poorer at an SNR of 3.4 dB than the controls at 2.0 dB, an inspection of individual results revealed that no child in the APD group scored outside normal limits on this task, and six of the ten children performed within one standard deviation of the mean, based on the normative data for their age. These results suggest that a child with APD can perform the low-cue SNR measure of the LISN at an SNR comparable to age-matched normally hearing controls.

According to Richardson (1977), the low-cue SNR is a statistical figure-ground task, whereby contextual information provides the dominant cue for differentiating, and thus understanding, the target stimulus in the presence of the distracters. As the children in the APD group had intellectual function within normal limits, it would not be surprising if they were able to use contextual cues to a similar advantage as the controls. The fact that the APD group as a whole achieved a significantly poorer SNR on this task than the control group suggests that other unknown deficits, such as temporal resolution dysfunction, exist in the APD group that affect performance on this task.

In contrast, the disparity between the APD and controls groups was particularly evident for the spatial advantage measure—the mean score for the APD group being 3.7 dB, compared with 10.0 dB for the controls. This difference of 6.3 dB is an extremely strong effect, significant at $p < 0.000001$. Nine of the ten children in the APD group performed below the cut-off score for their age group on the spatial advantage measure. Five of the nine children who performed below cut-off scores on spatial advantage (participants 1, 2, 5, 7, and 8) were also outside normal limits on the high-cue SNR measure. It is likely that children with profiles such as this will require a higher SNR in the classroom than normally hearing peers. As demonstrated by the inferential statistics, the APD group needed a significantly greater signal-to-noise ratio at -4.0 dB in the high-cue SNR measure of the LISN (where all cues are present) than the normally hearing controls who recorded a mean SNR of -8.4. As Crandell and Smaldino (2004) note that even normally hearing children experience greater speech recognition difficulties in noise than adults, children with such profiles may be particularly vulnerable in noisy classroom situations.

Four children in the APD group (participants 3, 6, 9, and 10) were outside normal limits on the spatial advantage measure of the LISN only, suggesting that these children may be compensating for their apparent reduced ability to take advantage of spatial cues by relying more heavily on other cues—such as tonal differences between speakers—in order to distinguish the target from the distracter voices. In support of this assumption, only two children, participants 7 and 8, performed below cut-off scores on the tonal advantage measure of the LISN. Reliance on a limited number of cues may, however, expend a child's mental resources, resulting in fatigue. It is speculated that children with deficits only in binaural processing may benefit from improving the SNR in some classroom situations in order to distinguish their teacher's voice from those of classmates or chatter from nearby classrooms—most probably at the end of the day when they may become mentally fatigued from reliance on limited cues.

The correlation matrix corroborates the conclusions drawn from the individual data and the inferential statistics on the various LISN measures. Performance by the APD group on the high-cue SNR was significantly correlated to the "different voices: 0°" condition. This is an understandable result as cues arising from different voice characteristics were available to the listeners under both these conditions. Similarly, performance by the APD group on the high-cue SNR was significantly correlated to the "same voice: ±90°" condition of the LISN. In this case, cues arising from spatial separation are available in both conditions.

For the same reasons, we might have also expected to see correlations between the high-cue SNR and both the tonal and spatial advantage measures. These correlations should be weaker, however, as the two advantage measures are also affected by the low-cue SNR scores. As Table 3 shows, a significant correlation was found between the high-cue SNR and tonal advantage measures ($r = 0.82$, $p = 0.004$). The correlation between the high-cue SNR and spatial advantage measures was 0.61, which, with only ten participants, was not significant ($p = 0.06$). These relationships suggests that performance on the high-cue SNR measure, which represents the actual signal-to-noise ratio required to understand a target story in the presence of the distracters when all cues are present, can be related to spatial and aural figure-ground discrimination.

When specifically examining relationships between the difference scores, tonal and spatial advantage were not highly correlated ($r = 0.52$, $p = 0.125$). Most of the apparent correlation is due to the fact that the two measures have a common baseline condition in the low-cue SNR measure, as random measurement error in the low-cue SNR measure will cause the spatial and tonal advantage measures to be partially correlated. These results suggest that spatial and tonal advantage operate as separate cues in differentiating speech streams.

Finally, the low-cue SNR did not correlate highly with any other LISN measure, with all correlations having a strength of $r = 0.45$ or less. This suggests that the ability to predominantly use contextual cues to differentiate speech streams was not related to the overall SNR ratio required to understand speech when all cues were present, or to the advantage scores achieved by utilizing tonal or spatial differences between speech streams.

Traditional APD Test Battery and Correlations with the LISN

No child in the APD group scored below the cut-off score for their age group on the BKB sentences in babble or the left- or right-ear conditions of the dichotic digits test. Only one child scored less than two standard deviations from the mean on the 500 Hz MLD test, although two children were only just within normal limits on this task. All three children were also outside normal limits on the LISN spatial advantage measure. No child in the APD group failed the MLD test and passed the LISN spatial advantage measure. Five children, however, failed the spatial advantage measure and passed the MLD test. It is suggested that hierarchical binaural processing within the CANS may explain these results, with the MLD limited to measuring performance at the lower structures of the brainstem, as reported by Bellis (2003), while the more complex LISN stimuli may measure binaural processing involving higher structures, including the auditory-spatial maps in the cortex.

Only one child performed below normal limits on the left- and right-ear conditions of the PPS. It was of interest that this child also failed the tonal advantage measure of the LISN, although no conclusions can be drawn from this result due to the small sample size of children in the present study who failed both tests.

In contrast, three children in the APD group (participants 1, 7, and 8) were unable to detect interstimulus gaps of 20 msec or greater on the RGDT. Interestingly, these participants were also outside normal limits on the spatial advantage measure of the LISN, as well as the high-cue SNR, and the total advantage measure. However, the RGDT did not correlate significantly with any LISN measure.

Finally, six children scored -1.0 or less on the CHAPS; however, no significant positive correlation was found between performance on the CHAPS and any APD assessment tool. It is therefore suggested that while the CHAPS may provide valuable information in assessing overall auditory function, it is not, in itself, a valid indicator of APD. In particular, the magnitude of the difficulties evidence by the CHAPS score is not related to the magnitude of the deficit evidence by any of the tests used in the experiment. Rather, all aspects of the child's performance must be analyzed in determining their suitability for diagnostic testing, or in categorizing a child with auditory processing disorder.

Detecting the Presence of APD

The validation of any test for APD inevitably involves consideration of what results the new test results should be compared to. The essential problem is that there is no gold standard for determining which children have APD. In the absence of a gold standard, what criterion should be used to judge that a test is more capable than other tests of detecting the presence of an APD? In this study, we have randomly sampled the population of children whose teachers or counsellors have considered that the child is performing in a manner consistent with the presence of an APD. Each child in the present study was referred for assessment based on abnormal academic performance at school that was not related to intellectual dysfunction or an attentional deficit. If the criteria for a child being at risk for APD is persistent listening and learning difficulties in the absence of intellectual, behavioral, or standard audiological deficits, one could argue that the LISN spatial advantage measure was the most sensitive tool in the test battery utilized in this study for diagnosing an auditory processing disorder. Certainly, the results show that more of these children were outside the range of normal performance on the LISN spatial advantage measure than was the case for any of the other tests included in the battery. These conclusions are, of course, subject to the caveat that there were only ten children in the study.

Unlike most other tests of APD, the LISN advantage measures are difference scores so that the effect of many other variables on the measure is minimized, if not eliminated. These variables include knowledge of language, attention, auditory closure skills, frequency resolution ability, and doubtless many others. Negating the effects of these factors may have contributed to the high sensitivity of the LISN spatial advantage measure. In future work, such additional factors may even include peripheral hearing loss.

Implications of Results

Regardless of the fact that four of the nine participants in the APD study who failed the spatial advantage measure presented only with a binaural processing problem, it should not be forgotten that these children were still recommended for assessment due to difficulties they were facing at school. Even if children with this profile are compensating for the disorder by using other auditory cues, the fact that they are reported to be facing listening and learning problems at school suggests that further action, such as providing specific spatial figure-ground remediation, or providing an improved SNR, may need to be taken, and the benefits or otherwise of such remediation is certainly an area for further study.

CONCLUSION

Based on the criteria that a child is at risk for APD if the child presents with persistent listening and learning difficulties in the presence of no intellectual, behavioral, or standard audiological deficits to otherwise explain his or her dysfunction, the LISN appears to be a sensitive and worthwhile assessment tool for diagnosing this disorder. The LISN test of auditory figure-ground discrimination has substantial real-world validity, and the component scores can offer some insight into the nature of any APD present. Results on the LISN indicate that of those children with APD, there may be a high proportion who have deficits in the binaural processing mechanisms that normally use the spatial distribution of sources to suppress unwanted signals. Based on the encouraging results of this study, performance on the LISN for children at risk for APD deserves further investigation.

Acknowledgments. The authors would like to thank the Jim Patrick Audiology Centre at the Royal Institute for Deaf and Blind Children, in Sydney, Australia, for their cooperation in referring children for this study. We would also like to thank the Macquarie University Psychology Clinic for their timely assistance in providing educational psychology assessments for children in this study who did not already have such testing completed.

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