

The Listening in Spatialized Noise–Sentences Test (LISN-S): Comparison to the Prototype LISN and Results from Children with Either a Suspected (Central) Auditory Processing Disorder or a Confirmed Language Disorder

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Sharon Cameron*†
Harvey Dillon*

Abstract

Background: The Listening in Spatialized Noise—Sentences test (LISN-S®) is a revised version of the Listening in Spatialized Noise (Continuous Discourse) test (LISN®; Cameron et al, 2006a). The software produces a three-dimensional auditory environment under headphones and was developed to assess auditory stream segregation skills in children. A simple repetition response protocol is utilized to determine speech reception thresholds (SRTs) for sentences presented from 0° azimuth in competing speech. The competing speech is manipulated with respect to its location in auditory space (0° vs. + and –90° azimuth) and the vocal quality of the speaker(s) (same as, or different to, the speaker of the target stimulus). Performance is measured as two SRT and three advantage measures. The advantage measures represent the benefit in dB gained when either talker, spatial, or both talker and spatial cues combined are incorporated in the maskers.

Purpose: To document LISN-S performance in a group of nine children with suspected (central) auditory processing disorder ([C]APD), who presented with difficulties hearing in the classroom in the absence of any routine audiological or language, learning or attention deficits to explain such a difficulty (SusCAPD group). The study also aimed to research the effect of higher-order deficits on LISN-S performance in a group of 11 children with a range of documented learning or attention disorders (LD Group). Correlation between performance on the LISN-S and a traditional (C)APD test battery was also compared.

Research Design: In a descriptive design, SusCAPD and LD group performance on the LISN-S was compared to published normative data from 70 age-matched controls. A correlational design was used to compare performance on the various tests in the traditional (C)APD battery to the SRT and advantage measures of the LISN-S.

Results: There were no significant differences between the SusCAPD, LD, or control groups on the conditions of the LISN-S where both the target and maskers emanated from 0° azimuth (low-cue SRT, $p = 0.978$; talker advantage, $p = 0.307$). However, there were significant differences between groups on the performance measures where the maskers were separated from the target by + and –90°. Post hoc tests revealed that there were no significant differences between the LD group and controls on any of these measures. There were, however, significant differences between the SusCAPD group and the controls on all the conditions where the maskers were spatially separated from the target (high-cue SRT, $p = 0.001$; spatial advantage, $p < 0.0001$; total advantage, $p < 0.0001$). The LISN-S did not correlate significantly with any test in the traditional test battery, nor were the nonspatial and spatial performance measures of the LISN-S correlated.

Conclusions: The study supports the hypothesis that a high proportion of children with suspected (C)APD have a deficit in the mechanisms that normally use the spatial distribution of sources to suppress

*National Acoustic Laboratories, 126 Greville Street, Chatswood, NSW 2067, Australia; †Speech Hearing and Language Research Centre, Macquarie University, NSW 2109, Australia

Sharon Cameron, Ph.D., Research Scientist, National Acoustic Laboratories, 126 Greville Street, Chatswood, NSW 2067, Australia; Phone: +61 2 9412 6851; Fax: +61 2 9411 8273; E-mail: Sharon.Cameron@nal.gov.au

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unwanted signals. The LISN-S is a potentially valuable assessment tool for assessing auditory stream segregation deficits, and is sensitive in differentiating various forms of auditory streaming.

Key Words: Auditory stream segregation, (central) auditory processing disorder, learning disorder, spatial stream segregation

Abbreviations: ADHD = attention deficit hyperactivity disorder; ASHA = American Speech-Language-Hearing Association; CANS = central auditory nervous system; (C)APD = (central) auditory processing disorder; CELF = Clinical Evaluation of Language Fundamentals; EEG = electroencephalography; FM = frequency modulation; HRTF = head-related transfer function; IID = interaural intensity difference; ITD = interaural time difference; LD = learning disorder; LISN = Listening in Spatialized Noise test; LISN-S = Listening in Spatialized Noise–Sentences test; LTM = long-term memory; MLD = masking level difference test; NAL = National Acoustic Laboratories; PPS = Pitch Pattern Sequence test; PTA = pure tone average; RGDT = Random Gap Detection Test; rms = root mean square; SD = standard deviation; SNR = signal-to-noise ratio; SPL = sound pressure level; SRT = speech reception threshold; SS = spatial stream segregation; SusCAPD = Suspected CAPD group; VS = vocal stream segregation; WISC = Wechsler Intelligence Scale for Children

Sumario

Antecedentes: La Prueba de Audición en Ruido—Frases Espacializadas (LISN-S[®]) es una versión revisada de las Pruebas de Audición en Ruido Espacializado (Discurso Continuo) (LISN[®], Cameron y col., 2006a). El programa produce un ambiente auditivo tridimensional bajo auriculares y fue desarrollado para evaluar las habilidades de segregación del flujo auditivo en niños. Se utiliza un simple protocolo de repetición de respuestas para determinar los umbrales de recepción del lenguaje (SRT) para frases presentadas a 0° de azimut en lenguaje de competencia. El lenguaje de competencia es manipulado con respecto a su localización en el espacio auditivo (0° vs. + y – 90° azimut) y la calidad vocal del hablante(s) (igual o diferente al hablante del estímulo meta). El desempeño se mide como dos SRT y tres mediciones de ventaja. Las mediciones de ventaja representan el beneficio en dB ganados cuando se incorporan tanto las claves espaciales, del hablante, o ambas combinadas, en los estímulos enmascaradores.

Propósito: Para documentar el desempeño del LISN-S se utilizó un grupo de nueve niños con sospecha de trastorno (central) de procesamiento auditivo ((C)APD), quienes mostraron dificultades auditivas en la clase, en ausencia de cualquier deficiencia auditiva, o de lenguaje, aprendizaje o atención que explicara tal dificultad (Grupo SusCAPD). El estudio también fue orientado a investigar el efecto de deficiencias de alto orden en el desempeño con el LISN-S en un grupo de once niños con un rango de trastornos documentados del aprendizaje o de la atención (Grupo LD). Se realizó la comparación de los desempeños con el LISN-S y la batería de pruebas tradicionales para (C)APD.

Diseño de Investigación: En un diseño descriptivo, se compararon los desempeños de los grupos SusCAPD y LD con el LISN-S para publicar datos normativos de 70 controles agrupados por edad. Se utilizó un diseño de correlación para comparar el desempeño de varias pruebas en la batería tradicional de (C)APD con respecto al SRT y las medidas de ventaja del LISN-S.

Resultados: No existieron diferencias significativas en las condiciones del LISN-S entre los grupos de SusCAPD, LD y control, donde tanto el blanco como el enmascarador emanaron de 0 azimut (SRT de clave baja, $p = 0.978$, ventaja del hablante, $P = 0.307$). Sin embargo, existieron diferencias significativas entre los grupos en las mediciones de desempeño donde los enmascaradores fueron separados del blanco por + y – 90°. Pruebas post-hoc revelaron que no existen diferencias significativas entre el grupo LD y los controles en ninguna de estas mediciones. Existieron, sin embargo, diferencias significativas entre el grupo SusCAPD y los controles en todas las condiciones donde los enmascaradores estaban separados espacialmente del blanco (SRT de clave alta, $p = 0.001$; ventaja espacial, $p < 0.0001$; ventaja total, $p < 0.001$). El LISN-S no correlacionó significativamente con ninguna prueba de la batería tradicional de pruebas, ni tampoco con las medidas de desempeño espacial y no espacial del LISN-S.

Conclusiones: El estudio apoya la hipótesis de que una alta proporción de niños con sospecha de (C)APD tiene una deficiencia en los mecanismos que normalmente usan las fuentes de distribución espacial para suprimir las señales no deseadas. El LISN-S es una valiosa herramienta de evaluación potencial para evaluar deficiencias de segregación en el flujo auditivo, y es sensible en diferencias varias formas de flujo auditivo.

Palabras Clave: Segregación de flujo auditivo, trastorno de procesamiento auditivo (central), trastorno de aprendizaje, segregación de flujo espacial

Abreviaturas: ADHD = trastornos de deficiencia de atención con hiperactividad; ASHA = Asociación Americana de Audición y Habla-Lenguaje; CANS = sistema nervioso auditivo central; (C)APD = trastorno de procesamiento auditivo (central); CELF = Evaluación Clínica de los Fundamentales del

Lenguaje; EEG = electroencefalografía; FM = modulación de frecuencia; HRTF = función de transferencia relacionada con la cabeza; IID = diferencia de intensidad interauricular; ITD = diferencia de tiempo interauricular; LD = trastorno del aprendizaje; LISN = Prueba de Audición en Ruido Espacializado; LISN-S = Prueba de Audición en Ruido-Frases Espacializadas; LTM = memoria a largo plazo; MLD = prueba de diferencia en el nivel de enmascaramiento; NAL = Laboratorios Nacionales de Acústica; PPS = prueba de secuencia de patrón de tono; PTA = promedio tonal puro; RGDT = prueba de detección de brecha aleatoria; rms = raíz media cuadrada; SNR = tasa señal-ruido; SRT = umbral de recepción del lenguaje; SS = segregación de flujo espacial; SusCAPD = Grupo de sospecha de CAPD; VS = segregación del flujo vocal; WISC = Escala Weschler de Inteligencia en Niños

The Listening in Spatialized Noise—Sentences test (LISN-S[®], Version 1.0.0 [Cameron and Dillon, 2006, Sydney, National Acoustic Laboratories]), was developed from the prototype Listening in Spatialized Noise test (LISN[®]) (Cameron et al, 2005, 2006a, 2006b, 2006c). Like its predecessor, the LISN-S has been designed to assess the ability of children with suspected (central) auditory processing disorder ((C)APD) to understand speech when background noise is present. Difficulty processing speech in background noise is a commonly reported symptom of (C)APD (Jerger & Musiek, 2000; Bamiau et al, 2001; Vanniasegaram et al, 2004). (C)APD can be defined as an auditory-specific perceptual deficit in the processing of auditory stimuli that occurs in spite of normal intellectual capacity and normal peripheral hearing thresholds. It is a heterogeneous disorder, incorporating impairment of various aspects of auditory processing, including temporal, spectral, and binaural hearing, as well as the ordering and grouping of sounds (Moore, 2006).

The LISN-S specifically measures the ability of children to segregate a target speech signal from simultaneously presented competing speech signals. This process is referred to as auditory stream segmentation and is the perceptual parsing of acoustic sequences into “streams” composed of sounds arising from a given sound source or group of sound sources. Streams can be selectively attended to and followed as a separate entity amid other sounds (Micheyl et al, 2007). Sound sources may differ in terms of their location in auditory space, their intensity, and their spectral or temporal complexity (Alain, 2007). For example, sounds that have similar onsets, intensities, and harmonically related frequencies are more likely to be perceived as coming from the same source than sounds that begin at different times or differ in intensity and frequency.

Sounds that emanate from the same physical location in auditory space are also likely to be perceived as a discrete stream (Bregman, 1990). The ability to locate a sound in space involves the capacity of the central auditory nervous system (CANS) to detect, perceive, and compare small differences in the arrival time and intensity of signals reaching the two ears. If a sound is located in any plane other than at the median plane of a listener, the sound has to travel a different path length to reach the ears because one ear is nearer and one is farther from the sound source. This gives rise to interaural

time differences (ITDs), which help the listener localize sound (Bamiau, 2007). Further, the head acts as a barrier to high frequency sound waves, resulting in interaural intensity differences (IIDs) between the two ears for sounds that are not directly ahead.

The LISN-S was designed to determine not only whether a child has an auditory streaming deficit but also whether that deficit is related to the ability to perceive and attend to sound sources that differ in respect to the frequency-related aspects of a speech signal (vocal stream segregation [VS]) versus the physical location of the source in auditory space (spatial stream segregation [SS]).

PREVIOUS RESEARCH

Earlier research using the prototype LISN (Cameron et al, 2006c) found that the signal-to-noise ratio (SNR) required by a group of 10 children—who presented with difficulties hearing in the classroom (but who tested as having no routine audiological or language, learning, or attention deficits)—to understand a target children’s story in the presence of spatially separated distracter sentences (spatial advantage measure) was significantly higher ($p < 0.000001$) than for a group of 48 normally hearing, age-matched controls. These children were referred to as the APD group, in line with accepted terminology at the time. Of the 10 children in the APD group, 9 were outside normal limits on this task (on average by five standard deviations [SDs]). In contrast, no child in the APD group was outside normal limits on the LISN-S when the maskers were not spatially separated (low-cue SNR measure). The implication and significance of these results are that the inability to adequately combine information at the two ears to directionally suppress noise coming from nontarget directions is a principal element of (C)APD and presumably of listening difficulties in the classroom.

Whereas the prototype LISN showed promise as a tool for identifying auditory streaming deficits in children with suspected (C)APD, the somewhat complex administration procedures limited use of this test to children age 7 and older. The child was required to listen to the target story in background discourse and to indicate whether the story was (a) easy to understand, (b) just understandable, or (c) too hard to understand and then was to point to the appropriate picture on a response



Figure 1. The LISN-S Playback Screen. The graph shows the history of the target level as the range of correct responses from >50% correct to <50% correct is repeatedly traversed. The top horizontal line shows the level of the distracters, and the lower horizontal line shows the average level of the targets during the stable region.

card. The listener’s threshold in any condition was calculated across the final four of seven reversals between “easy to understand” and “too hard to understand.” Once a practice or listening trial was completed, the child was required to provide details of the story that he or she had heard. From a clinical perspective, however, this response procedure could be considered subjective in that story details can vary from child to child. It was decided to produce a more objective version of the LISN with a simplified response procedure that could be used with young children.

Development of the LISN-S

Full details of the LISN-S development, administration, sentence equivalence study, normative data study, and test–retest reliability data have been reported in Cameron and Dillon (2007a, 2007b), and the administration procedure used in the present study is provided in detail in the method section that follows. In summary, a simple repetition response protocol is used to determine speech reception thresholds (SRTs) for sentences presented simultaneously in competing speech (looped children’s stories).

The test is administered under headphones using a personal computer. A three-dimensional auditory environment is created by pre-synthesizing the speech stimuli with head-related transfer functions (HRTFs). Headphone testing offers an alternative to free-field testing, which is limited by factors such as listener head movement, which, in turn, can affect the sound at the eardrum by several dB (Wilber, 2002), as well as affecting replication of loudspeaker and listener placement among clinics and the effects of reverberation among clinics (Koehnke and Besing, 1997). Output

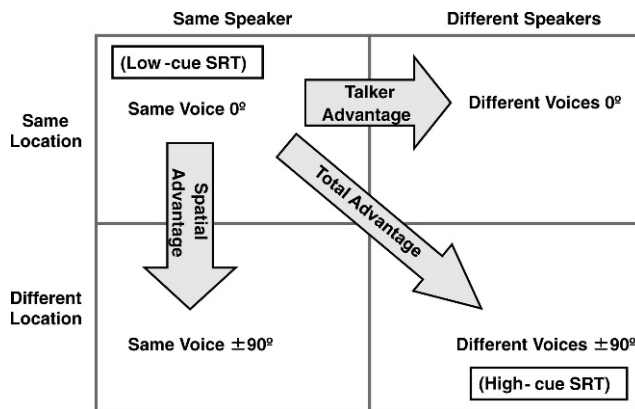


Figure 2. The LISN-S SRT and advantage measures.

levels are directly controlled by the software through an external USB sound card. The screen used in the administration of the LISN-S appears as Figure 1.

The target sentences are presented from 0° azimuth. In four LISN-S conditions, the maskers are manipulated with respect to their location in auditory space (0° versus ±90° azimuth) and the vocal quality of the speaker(s) (same as, or different from, the speaker of the target stimulus). Performance is measured as two SRT measures and three “advantage” measures. The advantage measures represent the benefit in dB gained when either tonal or spatial cues or both are incorporated in the maskers, compared to a baseline condition in which no cues are present in the maskers (see Figure 2). The use of difference scores to measure performance on the LISN-S minimizes the influence of higher-order language, learning, and communication functions on test performance. For example, because such skills affect both the SRT when the distracters are presented at 0° and the SRT when they are spatially separated at ±90°, these skills will have minimal effect on the difference between the SRTs in these two conditions.

In the development of the LISN-S, experiments were conducted that enabled the sentences to be adjusted in amplitude for equal intelligibility, and normative data were then collected from 82 children from 5 to 11 years of age (Cameron and Dillon, 2006a). Regression analysis showed that there was a strong trend of decreasing SRT and increasing advantage as age increased across all LISN-S performance measures. Because there appeared to be a marked increase in binaural processing skills from age 5 to age 6, it was decided that the LISN-S be used clinically with children from age 6. Cutoff scores, calculated as two SDs below the mean adjusted for age, were calculated for each performance measure for children from age 6 to age 11. These scores represent the level below which performance on the LISN-S is considered to be outside normal limits.

A test–retest reliability study with normally hearing children (Cameron and Dillon, 2007b) showed that reliability (*r*) ranged from 0.3 to 0.8. All correlations

were significant ($p < 0.05$). Across the range of performance measures, critical differences for test score improvements ranged from 2.5 to 4.4 dB.

Aims and Hypotheses

The aims of the following research were to assess a group of children on the LISN-S and on a traditional (C)APD test battery who presented with difficulties hearing in the classroom in the absence of any routine audiological or language, learning, or attention deficits to explain such a difficulty, and to compare the results to those obtained with the original LISN test (Cameron et al, 2006c). The participants in the present study also included a group of children with a range of documented learning or attention disorders, such as auditory memory deficits, dyslexia, specific language impairments, and attention deficit hyperactivity disorder (ADHD), so that the effect of higher-order deficits on the LISN-S could be studied.

It was hypothesized that, in accordance with the results of Cameron et al (2006c), the children in the present study with deficits listening in noise and no other presenting deficits (SusCAPD group) would be likely to show deficits on the conditions of the LISN-S where differentiation of ITD and IID of sounds arriving at the ears were required to distinguish the target from the distracters. It was assumed, however, that the anatomical and physiological processes underpinning spatial and vocal stream segmentation (such as the differentiation of the timing and intensity cues of the various sound sources arriving at the ears) are distinct from the processes involved in higher-order language, learning, and communication functions.

It was, therefore, not expected that the children with a confirmed learning or attention disorder (LD group) would be outside normal limits on the advantage measures of the LISN-S, unless a child presented with a co-morbid condition. It was possible that such a situation could occur because the children in the LD group were referred for assessment to rule out a (C)APD as contributing to their deficit. According to the American Speech-Language-Hearing Association (ASHA, 2005), whereas (C)APD is not due to higher-order language, cognitive, or related factors, (C)APD may lead to or be associated with difficulties in higher-order language, learning, and communication functions. The study, therefore, aimed to determine whether auditory streaming deficits were common in the LD group and, if present, what type of auditory streaming deficit occurred (spatial or vocal or both) and if any characteristics in the participant's presenting profile could explain the co-morbidity.

It was also hypothesized that the pattern of performance by the children in the SusCAPD group on the various conditions of the LISN-S would be

similar to that found by Cameron et al (2006c) in their group of children with suspected (C)APD. Whereas there were significant differences in mean score between the APD group and control groups in the Cameron et al study on all LISN-S conditions, the children in the APD group performed, on average, much more poorly on the LISN conditions where the maskers were spatialized simultaneously by + and -90° . This result was particularly evident in the spatial advantage measure, where the vocal quality of the speakers is held constant and only the spatial location of the maskers is manipulated. It is, therefore, hypothesized that the SusCAPD group would show marked deficits in spatial stream segregation when compared to both vocal stream segregation (talker advantage) and the low-cue condition where no spatial or vocal cues were available in the maskers.

Finally, McFarland and Cacace (2006) suggest that if a child has a deficit in auditory stream segregation, not only would such a deficit be manifested in a noisy classroom environment, but also a consistent pattern of performance would be expected across tests involving this construct. The authors of this paper propose that dichotic listening be viewed as one of many tests that involve auditory stream segregation. Dichotic listening is a widely used behavioral technique indicating brain laterality, during which participants are presented with two different auditory signals at the same time, one arriving at each ear (Jäncke and Shah, 2002). Dichotic tests can involve (a) binaural separation (also referred to as directed or focused attention), whereby the listener must attend to a signal presented to one ear while at the same time ignoring a competing signal presented to the opposite ear, and (b) binaural integration (also referred to as divided attention), whereby a different signal is presented to each ear simultaneously and the listener must report on each signal (Bellis, 2006).

Dichotic tests differ significantly from diotic tests such as the LISN-S, whereby the same stimuli are delivered simultaneously to each ear. Auditory tests that measure the way that the two ears work together to perceive sound are referred to as binaural interaction tasks. An example of a binaural interaction test that is comparable to the LISN-S is the masking level difference test (MLD). Performance is measured as the difference in dB between (a) the level at which a target signal (tone pips or speech) is detectable when it and a masker are in phase at the two ears and (b) the level when either the target or masking noise is manipulated so that one is out-of-phase at the ears. When either the signal or the noise is out of phase, the waveforms presented to the ears differ with respect to both temporal and amplitude characteristics, resulting in a "release" from masking (Wilson et al, 2003).

According to Bellis (2006), MLD tests exhibit good sensitivity to brainstem dysfunction. As reported,

however, by Cohen and Knudsen (1999) and Middlebrooks et al (2002), spatial cues such as ITD and IID continue to be processed in the auditory cortex and associated pathways. Indeed, Cameron et al (2006c) found no significant correlation between the prototype LISN test and either the dichotic digits test or the MLD, suggesting that these tests are tapping different processes to the LISN. However, so that the issue of correlation raised by McFarland and Cacace (2006) could be further studied, all participants age 7 years or older in the current study were tested on a battery of (C)APD tests, including a dichotic digits test (Musiek, 1983; Wilson and Strouse, 1998), a 500-Hz MLD Test (Wilson et al, 2003), the Pitch Pattern Sequence test (PPS; Pinheiro, 1977), and the Random Gap Detection Test (RGDT; Keith, 2000). It was hypothesized that there would be no correlation between the LISN-S and any other (C)APD test.

METHOD

Participants

Suspected (Central) Auditory Processing Disorder (SusCAPD) Group

The SusCAPD group comprised 9 participants, ranging in age from 6 years and 6 months to 11 years and 2 months (with a mean age of 9 years and 1 month). There were eight males and one female. The SusCAPD group comprised children who had been referred for (C)APD assessment by a primary school teacher, educational psychologist, or pediatrician who had identified the child as exhibiting abnormal auditory behavior relative to his or her peers.

An educational psychologist assessed all children in the SusCAPD group as having overall and subtest-specific intellectual performance within normal limits on the Weschler Intelligence Scale for Children (WISC) or an equivalent IQ test. That norm was defined as having a scaled score of eight or above, a standard score of 90 or above, or the equivalent percentile rank of 25 or above (Baron, 2004), as well as their having no ADHD. Percentile ranks reflect one person's performance relative to the normative population. For example, a percentile rank of 71 indicates that the student scored as well as or better than 71% of students of the same age in the normative population (Martin and Brownell, 2005). The full-scale IQ scores for the SusCAPD group ranged from 73% to 99% (with an average of 90%).

Participants were included in the study if they had (a) no permanent peripheral hearing impairment, (b) pure tone thresholds of ≤ 15 dB HL at 500 to 4,000 Hz and of ≤ 20 dB HL at 250 to 8,000 Hz, (c) normal type A tympanograms, and (d) 1,000-Hz ipsilateral acoustic reflex present at 95 dB HL. All participants had Australian

English as their first language, except for participant #77, who was born in Australia but spoke the Filipino dialect of Cebuano at home until he started preschool at age 2.

Learning or Attention Disorder (LD) Group

The LD group comprised 11 participants, ranging in age from 7 years and 2 months to 11 years and 8 months (with a mean of age 9 years and 4 months). There were seven males and four females. The LD group comprised children with a confirmed learning disorder who had been referred for (C)APD assessment by a primary school teacher, educational psychologist, or pediatrician to rule out (C)APD as attributing to academic deficits in the classroom.

All children in the LD group had audiometric profiles within normal limits as documented for the SusCAPD group, and all had Australian English as their first language. The participants in the LD group had overall intellectual performance within normal limits on the WISC or equivalent IQ test, although they had borderline or low results on specific WISC subtests related to their learning disorder or on other assessment tools used to diagnose their condition. (It was not possible, however, to interpret the full-scale IQ score for participants #80 and #83 because of the wide variation in their subtest scores).

Table 1 lists the specific deficits for each participant on the various assessment tools, as well as his or her overall IQ score, where interpretable. Most results are reported in percentile ranks. In the case of participants #87 and #90, however, only scales scores were provided by the educational psychologist for the subtests that fell below the normal range. Scaled score descriptive range names used in Table 1 are provided by Baron (2004).

Materials

Pure tone audiometric screening was performed using a Maico MA 53 clinical audiometer with circumaural Sennheiser HDA 200 audiometric headphones. Acoustic immittance data were obtained using a GN Otometrics OTOflex 100 impedance audiometer. Contralateral acoustic reflexes were assessed using 500-, 1,000-, and 2,000-Hz probe tones.

The LISN-S test materials were presented using an Optima Pentium D desktop computer (with the central processing unit isolated from the test room to reduce noise) and Sennheiser HD 215 circumaural headphones. The headphones were connected to the headphone socket of the PC through a Miglia Harmony Express USB Sound Card. The sensitivity of the sound card was automatically set by the LISN-S software. At this preset level, the combined distracters at 0° have a long-term root mean square (rms) level of 55 sound pressure level (SPL) as measured in a Brüel and Kjær type 4153 artificial ear. Calibration was performed by

Table 1. Deficits of the 11 Children in the LD Group

Participant ID	Main Deficit	Result	Assessment Tool	Full-Scale IQ (Percentile Rank)
80	Working memory; Visual processing speed	13th percentile (borderline); 2nd percentile (low)	WISC-IV	†NA
81	Spelling; ADHD and anxiety	19 (critically low); Positive	South Australian Spelling Test; ADHD screener	27th
82	Visual Dyslexia (scotopic sensitivity)	<12 months below chronological age	NARA	53rd
83	Verbal comprehension Working memory	8th percentile (borderline) 2nd percentile (low)	WISC-IV	†NA
84	Auditory memory (recalling sentences)	2nd percentile (low)	CELF-3	73rd
85	Behavioural and attention problems	Positive	* School counselor report	90th
86	Literacy	<12 months below chronological age	NARA	79th
87	Working memory Information (e.g., LTM)	Scaled score 7 (low avg.) Scaled score 6 (borderline)	WISC-III	37th
88	ADHD (medicated)	Positive	* School counselor report	91st
89	Visual-motor integration	<8 months below chronological age	Beery & Buktenica Developmental Test	97th
90	Digit span; recalling sentences	Scaled score 7 (low avg.) 2nd percentile (low)	WISC-IV CELF-3	53rd

*Summary provided, but name of assessment tool withheld.

†Full-scale IQ score uninterpretable resulting from wide variation in index scores (range of 2nd to 50th percentile for participant #80, and 2nd to 39th percentile for participant #84).

Note: NA = not applicable; NARA = Neale Analysis of Reading Ability.

checking the electrical voltage delivered to the headphones by the software and sound card for a 1-kHz calibration tone with a level within the software that had a fixed relationship to the speech signals. The combined level of the distracters at $\pm 90^\circ$ was 1 dB higher than when the distracters were at 0° . This difference is a consequence of the head-related transfer functions applied and was intentionally not corrected for. All SNRs are defined relative to the level of the distracters at 0° because both target and noise then shared the same head-related transfer functions.

The dichotic digits test, the MLD, the PPS, and the RGDT were presented using a Panasonic portable CD player connected to the Maico MA 53 audiometer with the Sennheiser HDA 200 headphones. The 1-kHz reference tone on each CD was used to calibrate the input to the audiometer to 0 VU.

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 2 hours per child, including appropriate breaks to avoid fatigue. Participants were assessed on both the LISN-S and a traditional (C)APD test battery, and tasks were counterbalanced between participants. Because normative data on the traditional tests are available only for children age 7 or older, one child in the SusCAPD group (participant #78), age 6 years and 8 months, was assessed only on the LISN-S. One other participant

(#72) was 6 years and 8 months at the time of testing and initially assessed only on the LISN-S. At the request of his mother, however, he was tested on the traditional test battery when he turned age 7 years and 4 months.

Traditional (C)APD Test Battery

The (C)APD tests were administered and scored in accordance with standard clinical recommendations (Bellis, 2003).

Dichotic Digits. Two different pairs of sequential digits were presented under headphones to each ear simultaneously at 50 dB SL (re pure tone average [PTA]; average of 500, 1,000, and 2,000 Hz). The participant was required to repeat back all digits heard, regardless of order. As practice, 10 single digits and 10 double digits were presented. Then 40 double digits were presented and scored for each ear.

MLD. Stimuli consisting of 33 tones at 500 Hz were presented in 3-second bursts of 200–800 Hz noise at various fixed SNRs. Stimuli were presented binaurally at 50 dB HL in (a) a homophasic (SoNo), (b) an antiphase ($S\pi$ No), or (c) *no signal* condition. The participant's task was to indicate whether or not they heard the tone. MLD was calculated as the score on the SoNo condition minus the score in the $S\pi$ No condition.

PPS. Various pitch patterns were presented under headphones at 50 dB SL (re PTA). Each pattern 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 he or she was unable to describe the pattern. First, 20 tone pairs were presented binaurally to ensure that the child could distinguish high and low tones. Next, 10 tone triplets were presented to the right ear as practice. Then, 30 triplets were scored for each ear.

RGDT. Stimuli were pairs of tones at frequencies of either 500, 1000, 2000, or 4000 Hz. The tone pairs were presented binaurally at 55 dB HL. Each tone pair contained a silent gap, ranging in duration from 0 to 40 msec. Nine gap durations were tested at each frequency. The gap interval was defined as the lowest interpulse interval at which two tones were identified for this interval and for all shorter intervals. One practice trial of nine tone pairs was provided.

LISN-S

The LISN-S target sentences were initially presented at a level of 62 dB SPL. The competing discourse (looped children’s stories) was presented at a constant level of 55 dB SPL. The uncorrelated distracter discourse was presented simultaneously either from 0° or from both + and –90° azimuth. The participant’s task was to repeat as many words as possible that had been heard in each sentence. The specific instructions to participants are described in Cameron and Dillon (2007a). Up to 30 sentences were presented in each of four conditions of distracter location and voice: (a) same voice at 0° (SV0°), (b) same voice at ±90° (SV±90°), (c) different voices at 0° (DV0°), and (d) different voices at ±90° (DV±90°). These conditions resulted in a maximum of 120 sentences presented. The presentation order of the LISN-S conditions was DV±90°, SV±90°, DV0°, and SV0°, as recommended in Cameron and Dillon (2007a).

The SNR was adapted in each condition by varying the target level to determine each participant’s SRT. The SNR was decreased by 2 dB if a listener repeated more than 50% of the words correctly, and it increased by 2 dB if he or she scored less than 50%. The SNR was not adjusted if a response of exactly 50% correct was recorded (for example, three of six words correctly identified). All words in each sentence were scored individually; including the definite article “the” and the indefinite articles “a” and “an.” A minimum of five sentences was provided as practice, but practice continued until one upward reversal in performance (that is, the sentence score dropped below 50% of words correct) was recorded. Testing ceased in a particular condition when the listener had either (a) completed the entire 30 sentences in any one condition or (b) completed the practice sentences plus a minimum of a further 17 scored sentences, and their standard error, calculated automatically in real time over the scored sentences, was less than 1 dB.

Normative Data

A child was considered to have failed a test if he or she scored more than two SDs below the mean score for his or her age. Normative data for the PPS and the dichotic digits test were taken from Singer et al (1998). Normative data for the 500-Hz MLD were obtained from Aithal et al (2006). Normative data on the RGDT were provided by Keith (2000). In line with Keith (2000) and Bellis (2003), however, a participant was considered to have failed the RGDT only if his or her gap detection threshold exceeded 20 msec. Normative data for each task in the traditional battery are provided in Table 2.

Table 3 provides normative data for the LISN-S, which were collected from a group of 70 normally hearing children age 6 to 11 (control group), as described in Cameron and Dillon (2007a). Because a strong trend of improved performance with increasing age was found for the various LISN-S performance measures, the cutoff scores were adjusted for age. A regression analysis was conducted with SRT as the independent variable and age (ranging from age 6.00 to age 11.92) as the dependent variable. The cutoff scores were adjusted for age using the formula: cutoff score = intercept + (B-value * age) + (2 * SDs of residuals from the age-corrected trend lines) for the LISN-S SRT measures and cutoff score = intercept + (B-value * age) – (2 * SDs of residuals from the age-corrected trend lines) for the LISN-S advantage measures.

RESULTS

LISN-S SNR and Advantage Measures

To investigate differences among the SusCAPD, LD, and control groups on LISN-S performance, a Kruskal-Wallis H test was performed separately on each SNR and advantage measure. The Kruskal-Wallis test was chosen because of unequal group sizes and potential variances among the three groups. The dependent variable was *SRT/advantage*, and the independent variable was *group* (control, SusCAPD, and LD). Figures 3a to 3e provide scatter plots showing both individual results and mean scores on the various LISN-S performance measures for the participants in the SusCAPD, LD, and control groups. There were no significant differences among the groups on the low-cue SRT and talker advantage measures of the LISN-S ($p = 0.978$ and 0.307). There were, however, significant differences among the groups on the performance measures in which spatial cues were incorporated into the maskers: high-cue SRT ($p = 0.004$), spatial advantage ($p < 0.0001$), and total advantage ($p = 0.002$).

To evaluate the significance of the pairwise differences between groups the Mann-Whitney U test was applied. There were no significant differences between

Table 2. Mean Scores and Standard Deviations, Based on Normative Data for the Traditional Central Test Battery, with Cutoff Scores Calculated as 2 Standard Deviations from the Mean, for Either Right Ear and Left Ear, or Bilateral Presentation

Test	Age	Mean			SD			Cutoff Score		
		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%	-
	10	94%	95%	-	6%	6%	-	82%	83%	-
	11	95%	95%	-	4%	6%	-	87%	83%	-
Dichotic Digits	7	74%	74%	-	6%	6%	-	62%	62%	-
	8	92%	89%	-	5%	6%	-	82%	77%	-
	9	93%	91%	-	6%	5%	-	81%	81%	-
	10	93%	92%	-	5%	4%	-	83%	84%	-
	11	96%	96%	-	3%	3%	-	90%	90%	-
RGDT	7	-	-	7.3 msec	-	-	4.8 msec	-	-	16.9 msec
	8	-	-	6.0 msec	-	-	2.5 msec	-	-	11.0 msec
	9	-	-	7.2 msec	-	-	5.3 msec	-	-	17.8 msec
	10	-	-	7.8 msec	-	-	3.9 msec	-	-	15.6 msec
	11	-	-	7.8 msec	-	-	3.9 msec	-	-	15.6 msec
MLD	All	-	-	11.2 dB	-	-	1.7 dB	-	-	7.8 dB

the LD group and the control group on the high-cue SRT ($p = 0.697$), spatial advantage ($p = 0.983$), or total advantage ($p = 0.715$) measures. However, the SusCAPD group performed significantly worse than did the controls on all these measures: high-cue SRT ($p = 0.001$), spatial advantage ($p < 0.0001$), and total advantage ($p < 0.0001$). The SusCAPD group also performed significantly worse than did the LD group on the high-cue SRT ($p = 0.025$), spatial advantage ($p = 0.003$), and total advantage ($p = 0.028$) measures.

Identification markers on the scatter plots in Figure 3 indicate individual participants in the SusCAPD and LD groups who scored below the cutoff score for a particular LISN-S measure and who were thus considered to have displayed disordered performance when compared to the normally hearing controls. No child in either group obtained a result below the cutoff score for the low-cue SRT or talker advantage measure. However, four participants in the SusCAPD group (#71, #75, #76, and #77) and one participant in the LD group (#87) were outside normal limits on the high-cue SRT measure. Five participants in the SusCAPD group (#71, #72, #73, #75, and #76) and

one participant in the LD group (#87) were outside normal limits on spatial advantage. Finally, five participants (#71, #73, #75, #76, and #77) in the SusCAPD group and two participants in the LD group (#87 and #88) were outside normal limits on the total advantage measure.

Traditional (C)APD Test Battery

To enable comparison of performance by the children in the SusCAPD and LD groups across age groups, researchers analyzed performance on the traditional (C)APD test battery using z scores. The z scores were calculated as a 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. Cutoff scores were calculated as 2 SDs below the mean for each age group. Figure 4 shows box-and-whiskers plots illustrating the median and interquartile range on the traditional (C)APD test battery and the LISN-S for the 8 children in the SusCAPD group who were old enough to be tested on all assessment tools and for the 11 children in the LD group.

One child in the SusCAPD group (participant #76) performed just below 2 SDs from the mean on the right ear condition of the dichotic digits test (87.5%, cutoff 90%). All other children in the SusCAPD group performed within normal limits on the entire traditional (C)APD test battery. One child in the LD group (participant #87) was outside normal limits on dichotic digits in the right-ear condition (72.5%, cutoff 82%), as well as in the left-ear condition (52.5%, cutoff 77%). This child also presented with an auditory memory

Table 3. Normative Data Used in Calculation of LISN-S Cutoff Scores for 70 Children from Age 6 to 11

Measure	Mean	SD (Residuals)	Intercept	B-Value
	dB	dB		
Low-Cue SRT	-0.8	0.98	2.50	-0.37
High-Cue SRT	-14.2	1.50	-7.17	-0.78
Talker Advantage	3.6	1.73	1.03	0.29
Spatial Advantage	11.7	1.73	7.67	0.45
Total Advantage	13.3	1.47	9.70	0.41

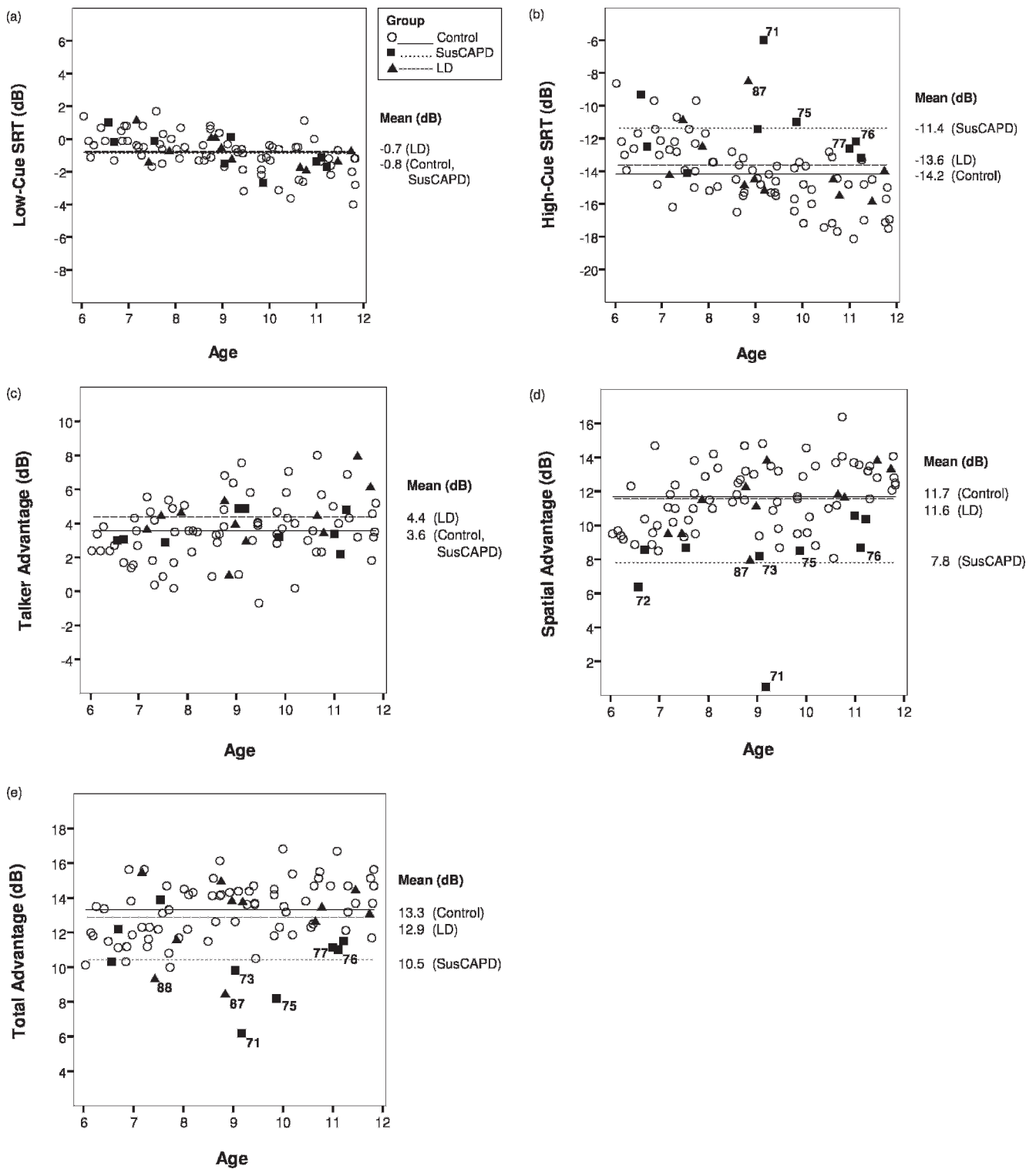


Figure 3. Scatter plots depicting individual results on (a) low-cue SRT, (b) high-cue SRT, (c) talker advantage, (d) spatial advantage, and (e) total advantage. Open circles (mean shown as a solid line) represent the control group, filled squares (mean shown as a dotted line) represent the SusCAPD group, and filled triangles (mean shown with a dashed line) represent the LD group. Symbols with identification markers indicate the participant numbers of children in the SusCAPD and LD groups whose scores were below 2 SDs from the mean, as a function of age.

deficit (scaled scores of 7 and 6 on the digit span and information subtests of the WISC-III). Participant #87 also failed the spatialized conditions of the LISN-S (but was within normal limits on the low-cue and talker advantage measures). His profile will be examined in the discussion section.

Two other children in the LD group were below normal limits on the verbal condition of the PPS. Participant #81 scored 63% (cutoff 77%) in the right ear and 43% (cutoff 60%) in the left ear. He was also below normal limits on the nonverbal (humming) condition, suggested by Bellis (2003) as indicating a reduced ability to recognize acoustic contours. Participant #81 presented with severe deficits in spelling and also had reported ADHD and anxiety. He performed well on all other (C)APD assessment tools. Participant #82 scored 7% in the right ear (cutoff 64%) and 17% in the left ear (cutoff 60%), but was within normal limits when asked to “hum” the tone sequences, suggesting difficulty verbally labeling the stimuli, which may be due to inefficient interhemispheric transfer or other factors. Participant #82 presented with dyslexia. He performed well on all other (C)APD assessment tools. All other children in the LD group performed within normal limits on the traditional (C)APD test battery.

Correlations

A Spearman rank order correlation matrix was plotted using the z scores for the 8 children in the SusCAPD group and the 11 children in the LD group for the various tests in the traditional (C)APD battery and for the SRT and advantage measures of the LISN-S. Results are shown in Table 4. Again, participant #78 was excluded from the correlation analysis because she was age 6 years and 8 months at the time of testing and was thus assessed only on the LISN-S. Statistically, it could be expected that—within a correlation matrix—1 in 20 correlations would be significant by chance alone if an alpha level of 0.05 were used. Because the current analysis used 55 comparisons, approximately 3 correlations may erroneously be found significant. To reduce the chance of finding an erroneously significant correlation, the authors have highlighted in the table only correlations with a significance level of $p < 0.01$.

The LISN-S high-cue SRT measure correlated significantly with the spatial advantage measure ($r = 0.70, p = 0.0008$). This finding is reassuring because both measures are affected by the participant’s ability to use spatial cues. Similarly, the high-cue SRT measure correlated significantly with the total advantage measure ($r = 0.93, p < 0.0001$). The very high correlation is not surprising because the total advantage measure is explicitly derived from the high-cue measure. The LISN-S spatial advantage measure also correlated

significantly with the total advantage measure ($r = 0.69, p = 0.001$). Both the advantage measures involve the low-cue SRT score, but both are also affected by the participant’s ability to use spatial cues.

The LISN-S low-cue SRT and talker advantage measures were not significantly correlated with performance on any other LISN-S measure or traditional assessment tool. The left- and right-ear scores on the PPS were also significantly correlated ($r = 0.70, p = 0.001$), as were the left- and right-ear scores of the dichotic digits test ($r = 0.71, p = 0.0007$).

DISCUSSION

Comparison of LISN and LISN-S

As hypothesized, the results of the SusCAPD group on the LISN-S test in the present study are comparable to those obtained for the 10 participants in the Cameron et al (2006c) study (APD group) on the prototype LISN test. In both studies, no child was outside normal limits on the low-cue SRT condition, and the greatest disparity between the SusCAPD/APD groups and the control participants was on the spatial advantage measure. The LISN and LISN-S were developed along similar principles, and both the SusCAPD and APD groups comprised children who exhibited observed deficits listening in noise in the absence of any other audiological, attention, or learning disorder to explain their difficulties in the classroom, so the similarity of the results is not surprising.

There were, however, some notable differences between results of the SusCAPD and APD groups on the LISN-S and LISN, respectively. In the Cameron et al (2006c) study, the APD group performed significantly worse than did the controls on all LISN performance measures. The authors concluded that other unknown deficits existed in the APD group that affected performance on the prototype LISN test across the board. In the present study, there were no significant differences between the SusCAPD group and controls for the LISN-S measures where spatial cues were not manipulated (low-cue SRT and talker advantage), only for the conditions where the participants were required to use spatial cues to differentiate the target sentences from the distracter stories.

One explanation for this result is that the groups in the two studies were intrinsically different—that is, the APD group in the Cameron et al (2006c) study did indeed have unknown deficits that reduced their performance across the board on the LISN, and the SusCAPD group in the present study did not. More likely, however, is that the higher-task demands of the LISN test (that is, the need to attend to a story for up to 3 minutes and to hold the details of that story in auditory memory for recounting to the examiner) may have resulted in the lowered scores across measures.

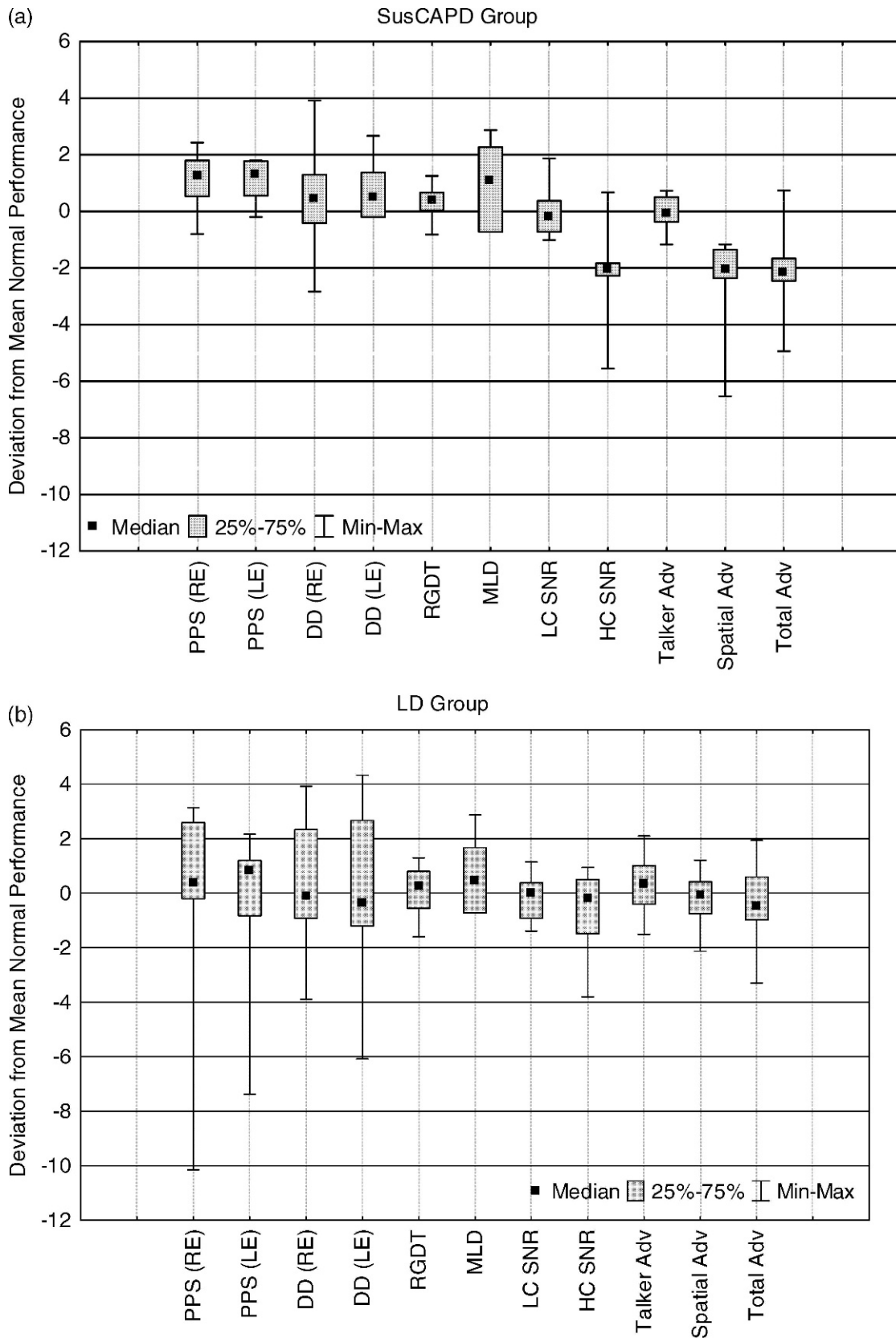


Figure 4. Box-and-whiskers plots depicting the median, inter-quartile range, and total range for all measures for (a) the SusCAPD group and (b) the LD group. The results are expressed as deviations of the scores for the children in SusCAPD and LD groups relative to the mean scores of children with normal hearing, expressed in units of SDs from the normative data, that is, z scores.

Table 4. Spearman Rank Order Correlation Matrix of z Scores from the SusCAPD and LD Groups on the Traditional (C)APD Test Battery and the LISN-S Measures

PPS (LE)	0.70*										
DD (RE)	0.23	0.33									
DD (LE)	0.28	0.35	0.71*								
RGDT	0.13	-0.16	-0.36	-0.14							
MLD	0.04	0.01	-0.23	-0.09	-0.12						
LC SRT	-0.07	0.18	0.18	0.08	-0.30	-0.05					
HC SRT	-0.32	-0.07	0.23	0.09	-0.47	0.20	0.05				
Talker Adv	-0.16	-0.19	0.30	0.05	-0.07	0.06	-0.07	0.29			
Spatial Adv	-0.41	-0.35	-0.07	-0.25	-0.22	0.00	0.16	0.70*	0.45		
Total Adv	-0.34	-0.21	0.11	0.02	-0.32	0.29	-0.19	0.93*	0.25	0.69*	
	PPS (RE)	PPS (LE)	DD (RE)	DD (LE)	RGDT	MLD	LC SRT	HC SRT	Talker Adv	Spatial Adv	

* $p < 0.01$

Note: Adv = Advantage; DD = dichotic digits; HC = high cue; LC = low cue; LE = left ear; RE = right ear.

The implication of such an assumption is that an auditory streaming deficit—and specifically a spatial stream segregation deficit—results in, or coexists with, some other attention or memory deficit that affects a child's ability to listen in noise over time and that such a deficit cannot be detected by conventional educational psychology tests such as the WISC.

An additional difference between the two studies is that the magnitude of the deficit detected by the LISN was much greater than for the LISN-S. For example, Cameron et al (2006c) found that 9 of the 10 children in the APD group were outside normal limits on the spatial advantage measure, on average by five SDs. In contrast, in the present study, 5 of the 9 children in the SusCAPD group (and 1 in the LD group) were outside normal limits on spatial advantage on the LISN-S, on average by two SDs. However, because a single child in the SusCAPD group (participant #71) scored more than five SDs from the mean on spatial and total advantage, as well as the high-cue SRT condition, it appears that the LISN-S has the sensitivity to detect deficits of this magnitude.

It should also be acknowledged that the children in the SusCAPD group who failed the spatialized measures of the LISN-S in the current study all reported difficulties listening in the classroom that were debilitating enough to warrant investigation for (C)APD, even in the absence of any other presenting deficit. In this respect, like the LISN, the LISN-S appears to be a valuable tool for identifying a spatial processing disorder in children with hearing deficits in the classroom, particularly when the nonspatial measures of the test are well within normal limits, as was the case for all the children in the SusCAPD group in the present study.

LISN-S Performance by Children with a Learning Disorder

As hypothesized, there was no significant difference in performance between the LD group and the controls on

any of the LISN-S measures, supporting the claim by ASHA (2005) that (C)APD—at least in relation to auditory stream segregation—is not due to higher-order language, learning, and communication functions. However, although the LD group as a whole performed as well as the controls on the various LISN-S measures, two participants in the LD were outside normal limits on the LISN-S.

Participant #88 performed below normal limits only on the total advantage measure of the LISN-S (<2 SDs from the mean). Participant #88 presented with ADHD, which was medicated at the time of testing. His WISC-IV scores were all in the average to superior range. A speech pathology report noted that participant #88 was approximately 6 months delayed in phonological awareness and relied heavily on sight reading of words. A school counselor's report noted that participant #88 constantly complained about being distracted by noises made by other children around him. Such a complaint could certainly be due to the affects of ADHD, although when medicated participant #88 was reported by an educational psychologist as being alert and oriented to tasks. He was well within normal limits on all traditional (C)APD assessment tools. However, his overall pattern of results on the LISN-S was typical of a spatial stream segregation deficit, with low-cue and talker advantage within normal limits (1 SD above the mean) and high-cue SRT and spatial advantage much poorer (1 SD below the mean).

Whereas the results of the LISN-S were not conclusive regarding a spatial stream segregation deficit in that participant #88 was technically within normal limits on spatial advantage, his total advantage scores and overall pattern of results suggested that his ability to hear in noise was not as developed as that of his peers. Therefore, the fitting of a frequency modulation (FM) system was suggested, with monitoring to determine if such compensation effectively reduced his listening problems in class. The guidelines of the study as approved by the various Ethics Committees overseeing the project did not allow us to

report on the outcomes of participants following assessment, but such a study would certainly be of value in any future research.

One other child in the LD group, participant #87, was outside normal limits on all the spatialized measures of the LISN-S (high-cue SRT and spatial and total advantage). This child presented with a low-average working memory and borderline long-term memory score on the WISC-III, and whereas his difficulties performing in the classroom could certainly be explained by his WISC-III profile, his results on the LISN-S may suggest a co-morbid spatial streaming segregation deficit. Participant #87 was reported by his mother as having experienced repeated episodes of ear infections when younger, and he had been fitted with ventilation tubes on four occasions. He was also reported by his teacher as having difficulty listening in the classroom, particularly in the presence of background noise.

Only one other child in the LD group was reported as having recurrent ear infections. In contrast, 4 of the 9 children in the SusCAPD group were reported as having recurrent ear infections, either resulting in a perforated tympanic membrane or requiring ventilation tubes. Three of those children (participants #73, #75, and #76) were below normal limits on the LISN-S spatial and total advantage measures. Whereas the current study is not large enough to establish a link between a history of recurrent ear infections and a spatial stream segregation deficit, the presenting profiles of the children identified as having such a disorder suggest that further investigation of the correlation between early recurrent otitis media and subsequent spatial hearing deficits may be warranted. There is a strong theoretical basis for such a causative link. A sufficiently large conductive loss results in an increased level of bone-conducted sound relative to air-conducted sound, which reduces the magnitude of interaural differences and hence the cues available to segment sources on the basis of their direction of arrival. Such skills may not be learned if the cues are either too weak or too inconsistent as a result of fluctuating hearing status during early childhood.

Correlation of LISN-S and Other Assessment Tools

The final hypothesis of the study was that the LISN-S assessed unique auditory processes that are distinct from the processes evaluated by other traditional (C)APD assessment tools. This hypothesis was indeed the case. Whereas the small sample size must be taken into account when one draws conclusions from the study, the analyses showed that the LISN-S did not correlate significantly with the dichotic digits test, MLD, PPS, or RGDT. In fact, the nonspatial and spatial performance measures of the LISN-S were also uncorrelated, providing further evidence that the

LISN-S is sensitive in differentiating various forms of auditory streaming. The ability to identify not only auditory processes in general but also auditory streaming processes in particular makes the LISN-S a valuable tool in auditory processing assessment.

The results also support a hypothesis of hierarchical binaural processing within the central auditory nervous system. Both this study and Cameron et al (2006c) found no significant correlation between the relatively simple MLD task, which is believed to assess processing at the lower level of the brainstem, and the more complex LISN and LISN-S tests, which, it is speculated, assess auditory streaming at higher levels, including the cortex and association areas for spatial stream segregation (as posited by Cohen & Knudsen, 1999; and Middlebrooks et al, 2002) and the primary auditory cortex, thalamus, and planum temporale for vocal stream segregation (as posited by Alain, 2007; and Michey et al, 2007).

CONCLUSION

As concluded by Cameron et al (2006c), the results of the present study support the hypothesis that a high proportion of children presenting with listening difficulties despite normal hearing thresholds have a deficit in the mechanisms that normally use the spatial distribution of sources to suppress unwanted signals, an ability referred to as spatial stream segregation. Thus, future large-scale studies in this regard appear warranted.

The present study also supports the position of ASHA (2005) concerning the auditory processing-specific nature of (C)APD. The majority of children in the learning disorder group did not present with an auditory processing deficit on either the LISN-S or the traditional (C)APD test battery. While acknowledging, however, that (C)APD may coexist with other disorders, ASHA (2005) cautions that it would not be appropriate to apply the diagnostic label of (C)APD to the listening difficulties exhibited by children with a learning or attention disorder unless a co-morbid deficit in the CANS can be demonstrated. If one bears this caution in mind, the LISN-S is a potentially valuable tool for assessing auditory streaming deficits in the learning-disabled population as a result of the simplified response protocol and the use of difference scores to minimize the effects of between-listener variation in factors such as linguistic skills and general cognitive ability on performance. Two participants with pre-identified learning disorders in the current study exhibited deficits on only the spatialized measures of the LISN-S test, providing further differential identification of not only an auditory versus language disorder, but also a spatial versus vocal streaming segregation disorder.

It is imperative, however, that the management of a child with (C)APD of any sort does not end with

diagnosis. This study further supports the conclusions of Cameron et al (2006c) that it is likely that children with a spatial stream segregation deficit will require a higher SNR in the classroom than will normally hearing peers. Personal FM devices and sound-field amplification systems can be used to improve the SNR in the classroom. If the teacher's voice is made perceptually louder than the background noise, the target will more likely be perceived as a separate stream. This adaptation may exert less demand on the mental resources required to attend to the target, thereby reducing fatigue and improving overall performance in class.

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