Spatial Hearing Deficits as a Major Cause of Auditory Processing Disorders: Diagnosis with the LISN-S and Management Options

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Introduction

(Central) auditory processing disorder [(C)APD] can be defined as an auditory-specific perceptual deficit in the processing of auditory stimuli which occurs in spite of normal intellectual capacity and normal peripheral hearing thresholds. For children with (C)APD, internal distortions degrade the auditory signal so that top-down processing typically predominates in most listening situations, particularly those in which complex linguistic and cognitive demands are coupled with background noise (Putter-Katz et al. 2002). According to Jerger (1998), a likely culprit contributing to the internal distortion is an auditory figure-ground discrimination deficit, whereby a target auditory signal lacks perceptual prominence against a background of noise. Figure-ground discrimination can be related to the perceptual concept of auditory stream segregation. Auditory cues such as the location of the sound, or the pitch of a speaker’s voice, help the listener to separate the total stream of sound into its original sources (Bregman 1990).

In this paper we discuss the use of the Listening in Spatialized Noise – Sentences test (LISN-S®; Cameron and Dillon 2006) to diagnose auditory stream segregation deficits in children experiencing listening difficulties in the classroom. The LISN-S was developed specifically to assess how children utilize binaural cues, such as variances in inter-aural time and intensity differences between speech streams to separate a target auditory stimulus from distracting auditory stimuli (a process referred to as spatial stream segregation). The test also differentially assesses how the children utilize the frequency-related differences between speaker voices to separate speech streams (a process referred to as vocal stream segregation). Management options for children with auditory steaming deficits are described. Monitoring the effectiveness of management strategies using the LISN-S critical differences scores is also discussed.

Development of the LISN-S

Full details of the LISN-S test development, administration, sentence equivalence study, normative data study, and test-retest reliability data, have been reported in Cameron and Dillon (2007a, b) and are also discussed in Cameron and Dillon (in press). In summary, a simple repetition response protocol is utilized 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). This offers an alternative to free-field testing, which is limited by factors such as listener head movement, which can affect the sound at the eardrum by several dB (Wilber 2002), as well as replication of loudspeaker and listener placement between clinics, and the effects of reverberation between clinics (Koehnke and Besing 1997). Output levels are directly controlled by the software via an external USB soundcard. Experiments were conducted that enabled the sentences to be adjusted in amplitude for equal intelligibility (Cameron and Dillon 2007a).
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° vs. ±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 measures and three “advantage” measures. The advantage measures represent the benefit in dB gained when either vocal, spatial, or both vocal and spatial cues combined, are incorporated in the maskers, compared to a baseline condition where neither vocal or spatial cues are present in the maskers (see figure 1). 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, as 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.

Administration of the LISN-S

The screen used in the administration of the LISN-S appears as figure 2. The LISN-S target sentences are initially presented at a level of 62 dB SPL. The competing discourse is presented at a constant level of 55 dB SPL. The uncorrelated distracter discourse is presented simultaneously from either 0°, or both + and −90° azimuth. The participant’s task is to repeat as many words as possible heard in each sentence. The specific instructions to participants are described in Cameron and Dillon (2007a). Up to 30 sentences are presented in each of four conditions of distracter location and voice: same voice at 0° (SV0°), same voice at ±90° (SV ±90°), different voices at 0° (DV0°) and different voices at ±90° (DV ±90°).

The signal-to-noise ratio (SNR) is adjusted adaptively in each condition by varying the level of the target sentence to determine each participant's SRT. The SNR is decreased by 2 dB if a listener scores more than 50 percent of words correct, and increased by 2 dB if he or she scores less than 50 percent of words correct. The SNR is not adjusted if a response of exactly 50 percent correct is recorded. All words in each sentence are scored individually. A minimum of five sentences is provided as practice, however practice continues until one upward reversal in performance (i.e., the sentence score dropped below 50 percent of words correct) is recorded. Testing ceases in a particular condition when the listener has 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 his or her standard error, calculated automatically in real time over the scored sentences, is less than 1 dB.

LISN-S Normative Data and Retest Reliability Data

A regression analysis of normative data across all LISN-S performance measures (Cameron and Dillon 2007a) showed a strong trend of decreasing SRT and increasing advantage as age increased. Cut-off scores, calculated as two standard deviations below the mean adjusted...
for age, were calculated for each performance measure for 70 children aged 6 to 11 years. 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 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 dB to 4.4 dB.

**LISN-S (C)APD Study**

A study was conducted to assess a group of nine children 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) on the LISN-S and a traditional (C)APD test battery. In order to study the effect of higher-order deficits on the LISN-S, a group of 11 children were also included in the study who presented with a range of documented learning or attention disorders, such as auditory memory deficits, dyslexia, specific language impairments and attention deficit hyperactivity disorder (LD group). This study is described in detail in Cameron and Dillon (in press).

There were no significant differences on any LISN-S measure between the LD group and 70 age-matched controls (p ranging from 0.98 to 0.14). There were significant differences between the SusCAPD group and the controls; however, these differences were only on the conditions of the LISN-S where the physical location of the maskers was manipulated (p ranging from 0.001 to < 0.0001). On the spatial advantage measure of the LISN-S, five children in the SusCAPD group (and one child in the LD group) were outside normal limits.

The LISN-S did not correlate significantly with any of the assessment tools in the traditional (C)APD test battery: the dichotic digits test (Wilson and Strouse 1998); 500 Hz Masking Level Difference Test (Wilson, Moncrieff, Townsend and Pillion 2003); Pitch Pattern Sequence Test (Pinheiro 1977); or the Random Gap Detection Test (Keith 2000). Further, the non-spatial 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. Only one child in the SusCAPD group and three children in the LD group were outside normal limits on one of the traditional (C)APD test battery assessment tools. The deviation from normal performance across assessment tools for the SuSCAPD and LD groups is shown in figure 3.

**Implication of the Research**

As discussed in Cameron and Dillon (in press), the implication and significance of these results, and earlier research using a prototype version of the LISN test (Cameron, Dillon and Newall 2005, 2006), is 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 unwanted signals. The present study also supports the position of ASHA (2005) as to 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.

**General Management Options for Children with a Streaming Deficit**

A comprehensive review of management options can be found in the literature, including Bellis (2003). It must be stressed that management of auditory processing disorders is a complex and developing area, where extensive research is needed to be undertaken, and the recommended strategies and approaches to intervention discussed are intended as a guideline only.

**Classroom Modifications and ADLs**

The results of the Cameron and Dillon (in press) study suggest that it is likely that children with a spatial stream segregation deficit will require a higher SNR in the classroom than normally hearing peers. The children who presented with a spatial stream segregation deficit in the LISN-S (C)APD study – that is, those children who obtained a score of greater than two standard deviations below on the spatial measures of the LISN-S – were able to repeat back fifty percent of the words in the target sentence correctly. They simply required a higher signal-to-noise ratio to achieve it.

A SNR ratio of 15 dB in the classroom is suggested for all students and staff to have full auditory access to the spoken message (Nelson, Soli and Seltz 2002), whereas Crandell and Smaldino (2002) report that typical classroom SNRs range from 4 to –7 dB. Disadvantageous SNRs can impact academic performance for all children, but can have a particularly adverse effect for children with (C)APD for whom the acoustic signal is internally degraded.

Modifications to the classroom can be suggested if acoustic characteristics do not conform to recommended standards. For example, installation of carpet and placement of cloth poster boards around the classroom can help to minimize reverberation. Further, preferential seating in the classroom, as close as possible to the teacher, will make facial expressions clearly visible, and maximize the ratio of direct sound to reverberant sound. The seating position should also be away from noisy equipment, such as overhead fans, to maximize the signal-to-noise ratio.

Assistive listening devices (ADLs) such as personal FM systems and sound-field amplification systems can also be utilized to improve the SNR in the classroom. By making the teacher’s voice perceptually louder than the background noise, the target auditory signal will be more likely to be perceived as a separate stream. This may exert less demand on the mental resources required to attend to the target, reducing fatigue and improving overall performance in class.

**Teacher-Directed Strategies**

A number of strategies may be implemented by the child’s schoolteacher to assist children with listening difficulties to extract as much information from the auditory signal as possible. These strategies include speaking in short, simple sentences; repeating a message if not comprehended; slowing the speed of delivery; providing visual cues and hands-on demonstrations, as multimodal cues add to the auditory information so that the whole message can be understood; pre-teaching new information and vocabulary so that the child has a greater chance of inferring missed information from the context of the message; gaining attention prior to speaking; frequently checking for comprehension; using positive reinforcement generously; and planning regular listening breaks to avoid auditory fatigue.

**Child-Directed Strategies**

The child, too, can be instructed to recognize and find a solution to difficult listening situations, by asking for missed information to be repeated, or requesting to be moved to a quieter location in the classroom if excessive background noise is present. The child can also be taught whole-body listening techniques, such as sitting up straight and leaning slightly forward, focusing attention on the speaker of interest, to encourage him or her to focus and maintain attention.

**Auditory Closure Training**

Auditory closure training can be implemented to strengthen top-down processing skills. This is a cognitive approach to (C)APD management that utilizes knowledge and experiences within the world to assist the child in interpreting acoustic stimuli that may have been missed due to internal degradation caused by his or her central processing disorder. Auditory closure is the ability to fill in missing or distorted auditory information – a skill that requires integration with vocabulary knowledge and contextual cues. The more advanced the child’s language and vocabulary, the better
The child will perform in respect to auditory closure, thus vocabulary building will assist in auditory closure training. Examples of top-down processing drills are provided in Heine (2004); Heine and Panayiotou (2004); and Mokhemar (1999).

**Deficit-Specific Auditory Training for Children with a Streaming Deficit**

In a review on the history of auditory training, Kricos and McCarthy (2007) reported that compelling neurophysiologic evidence suggests that auditory training can alter neural activity in the auditory system. They posited that "... auditory training may be the most powerful, underutilized, and not completely understood tool in the audiologist's armamentarium (p. 96)." According to Bellis (2002), intervention for (C)APD should arise logically from the nature of the individual's auditory deficit and how that deficit relates to functional difficulties and behavioral sequelae.

**The LISN and Learn Auditory Training Software**

An auditory training software package – the LISN and Learn (Cameron and Dillon 2007c) – has recently been developed for children whose performance is outside normal limits on the LISN-S spatial advantage measure, and are thus considered to have a spatial stream segregation deficit. The software consists of four games – Listening House, Listening Ladder, Answer Alley and Goal Game. The games are played on the child’s home computer. Output levels are controlled by the software and presented over headphones via an external USB soundcard.

The child’s task is to identify a word from a target sentence – initially presented at 62 dB SPL and coming from 0º azimuth. The target sentence is presented in background noise – at 55 dB SPL and coming from + and – 90º azimuth. The background noise is looped children’s stories spoken by the same female speaker as the target sentences. The child uses the computer mouse to select an image displayed on the computer screen after the sentence is presented which best matches one of the words in the target sentence.

A weighted up-down adaptive procedure is used to adjust the signal level of the target based on participant’s response. The target is decreased by 1.5 dB when the child correctly identifies a target image. It is increased by 2.5 dB if the wrong target is identified, and it is increased by 1.5 dB if an “unsure” response is made. Each target sentence is generated from a random combination of 1,944 individual words edited from 324 recorded (and spatialized) sentences. There are 131,220 potential unique sentences that can be generated.

The child plays two games per day, five days per week, over a 12-week period. Each game takes between 5 to 10 minutes to complete. This type of training represents a bottom-up approach to (C)APD management, focusing on accurate reception and transfer of the acoustic aspects of the signal as it moves from the peripheral auditory system through the central auditory nervous system to the upper cortex.

**Monitoring Auditory Training and General Management Strategies**

The listening and cognitive performance of children using the LISN and Learn auditory training software will be evaluated pre-, post- and three months-post training on a number of assessment tools, including: a version of the Speech, Spatial and Qualities of Hearing Scale (SSQ; Noble and Gatehouse 2004) developed by Flinders University in South Australia for children with (C)APD; the Test of Variables of Attention – Auditory (TOVA-A, Swalwell, Greenberg and Dupuy 2007); and the Test of Auditory Processing Skills – 3 (TAPS-3; Martin and Brownell 2005). Cortical auditory evoked potentials to spatialized stimuli will also be utilized.

Children will also be assessed pre- and post-training on the LISN-S, using one-sided critical difference scores calculated from the LISN-S test-retest reliability data (Cameron and Dillon 2007b). These scores represent the change in dB needed to infer that there has been a genuine improvement in auditory performance if a child is re-test on the LISN-S, taking into account mean practice effects and day-to-day fluctuations in performance. The one-sided critical difference on the spatial advantage measure, for example, calculated as mean test-retest difference + (1.64 x SD of mean test-retest difference), is 2.8 dB. It is hypothesized that children receiving training on the LISN and Learn auditory training software will improve on the spatial advantage measure of the LISN-S beyond this critical difference post training, and that this improvement will be significantly greater than any improvement on the non-spatialized measures of the LISN-S, that is the low-cue SRT and talker advantage measures.

It could also be hypothesized that the LISN-S critical difference scores may be useful in monitoring listen-
ing performance for children using assistive listening devices or receiving remediation based on other general management programs in order to determine whether improvements in listening performance have occurred due to, say, maturation of the central auditory nervous system.

Conclusions and Clinical Implications

In this paper we have described the administration of the LISN-S test to diagnose auditory streaming deficits in children and provided results of studies using the LISN-S and a traditional (C)APD test battery, with children presenting with either a suspected (central) auditory processing disorder and no other learning or attention deficit, or with a confirmed learning disorder. The research suggests that an inability adequately to combine information at the two ears in order to directionally suppress noise coming from non-target directions appears to be a major cause of (C)APD, and presumably of listening difficulties in classrooms. As the non-spatial and spatial performance measures of the LISN-S were uncorrelated, the LISN-S appears to be sensitive in differentiating vocal from spatial auditory streaming deficits. It could also be suggested that traditional (C)APD test batteries may not identify children with an auditory stream segregation deficit. Assistive listening devices are a logical management option for children diagnosed with auditory stream segregation deficits, to improve the signal-to-noise ratio and thus auditory comprehension. Finally, the LISN-S one-sided critical difference scores may assist in monitoring improvements in auditory processing not only due to auditory training, but possibly also to maturation of the central auditory nervous system over time.

References


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