Chapter 8

Volume 2

Remediation of Spatial Processing Issues in Central Auditory Processing Disorder

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/H1/ Spatial Processing

When we are trying to listen to speech in noisy environments auditory processes in the brain help us to focus on the person we want to hear while simultaneously suppressing competing sounds coming from different locations. The target speech appears to *pop out* from the competition, so-to-speak. The technical term for this process is spatial release from masking – or spatial processing - and it allows us to take in the vital information we need to be able to comprehend speech and participate in conversations. But what if we didn't have this ability? What if we when we were listening to speech in noise nothing seemed to *pop out*, but instead all we could hear was a jumble of sounds? We would most likely fail to hear key information, limiting our ability to communicate effectively. This is exactly what happens to children and adults with spatial processing disorder (SPD).

In this chapter we will discuss how spatial processing assists in communication and the underlying mechanisms involved. We will also discuss how deficits in spatial processing ability impact listeners, particularly children who, despite normal hearing thresholds and cognitive ability, have difficulty understanding speech in the classroom when background noise is present. Difficulty understanding speech when there is competing speech or other types of background noise is a commonly reported symptom of central auditory processing disorder (CAPD) (Jerger & Musiek, 2000; Bamiou, Musiek & Luxon, 2001; Vanniasegaram, Cohen & Rosen, 2004). We are certainly not suggesting that spatial processing disorder is the only cause of difficulty understanding speech in background noise for children with normal hearing thresholds, but it is an important cause. For many children, it is the only cause. The main focus of the chapter involves the remediation of spatial processing disorder using the LiSN & Learn, a deficit-specific computer-based auditory training program.

/H2/ Spatial Processing and Communication

Normal hearing listeners effortlessly communicate in very complex acoustic environments which may contain multiple sound sources, as well as room reverberation. In such adverse conditions, the auditory system takes advantage of the temporal-spectral dynamics of the acoustic input at the two ears to analyze the spatial acoustic scene and thus, to understand speech. For example, listeners can use differences in sound source directions to perceptually separate target speech from one or more interfering sources (Hirsch, 1950; Cherry, 1953). This can result in a significant improvement in speech intelligibility.

As previously mentioned, the benefit gained from spatially separating distracting noise from a target signal is known as spatial release from masking (SRM), or alternatively *spatial advantage* (Zurek, 1993; Yost, 1997; Bronkhorst, 2000; Cameron, Dillon & Newall, 2006a; Darwin, 2008). Spatial advantage is particularly large (as much as 14 dB depending on age) when maskers are also speech signals (Cameron & Dillon, 2007a; Behrens, Neher & Johannesson, 2008; Marrone, Mason & Kidd 2008a; Jones and Litovski, 2011). As shown in Figure 8-1, spatial advantage improves with increasing age until late adolescence and remains stable until at least age 60 (Brown, Cameron, Martin, Watson & Dillon, 2010; Cameron et al., 2009; Cameron & Dillon, 2007a; Cameron, Dillon & Newall, 2006b; Cameron, Glyde & Dillon, 2011; Glyde, Cameron, Dillon, Hickson & Seeto, 2013).

Insert Figure 8-1 here.

Crandell and Smaldino (1995) reported that the accurate perception of speech – which is essential for academic achievement – is particularly degraded by noises with spectra similar to the speech spectrum, as these are most effective at masking speech cues (although this effectiveness is influenced by fluctuations in the intensity of the noise over time). Noise generated within a classroom, including children talking, is said to be the most detrimental to a child's ability to perceive speech, because the frequency content of the noise is spectrally similar to the teacher's voice. Thus, the ability of children to utilize spatial processing mechanisms to separate their teacher's voice from background noise is critical to their ability to understand speech in the classroom.

/H2/ Mechanisms Underlying Spatial Processing

Sensing sounds in two ears is referred to as binaural hearing. Binaural hearing makes it possible for a person to locate the source of sounds in the horizontal plane (Dillon 2012). However the main benefit of binaural hearing to humans is to aid the detection of sounds in noisy environments (Moore, 1991). Accurate horizontal localization of sounds coming from a particular location is made possible by analysis of differences in the arrival time and the intensity of such sound between the two ears. Sounds arrive at the ear closer to the source before they arrive at the ear farther away. The resulting difference in arrival time at the two ears is called the interaural time difference (ITD). ITD is zero for sounds located directly in front of the listener (i.e., 0^0 aximuth) and increases to a maximum of about 0.7 ms for sounds coming from 90°, relative to the front. Because any time delay leads to a phase delay, an ITD results in an interaural phase delay. Further, head diffraction produces an attenuation of sound on the side of the head farther from the sound source and a boost on the side of the head nearer to the sound source, referred to as interaural level differences (ILD).

The initial detection of interaural time and intensity differences occurs at the superior olivary complex (SOC; Reuss, 2000), which is located bilaterally at the base of the brainstem in the caudal portion of the pons, ventral and medial to the cochlear nuclei (CN). Neurons within the medial superior olivary nuclei (MSO) receive phase-locked excitatory input to low-frequency stimuli (and the envelopes of high-frequency stimuli) bilaterally from the CN. Responses to ITD similar to those recorded at the MSO are also recorded in the lateral superior olivary nuclei (LSO), except that the input from the contralateral CN is changed from excitatory to inhibitory at the trapezoid body (Fitzpatrick, Kuwada & Batra, 2002). The LSO also is implicated in the detection of ILDs (Grothe, 2000). Inhibitory and excitatory responses from the CN which are used to code ITD in the MSO and LSO of the SOC are preserved in the inferior colliculus (IC). Cohen and Knudsen (1999) stated that a *space map* is formed in the non-tonotopic subdivisions of the IC, where information about spatial cues is combined across frequency channels, yielding neurons that are broadly tuned for frequency and finely tuned for sound source location. Afferents from the IC are relayed to the primary (A1) and secondary (A2) auditory cortex via the medial geniculate body (MGB) (Pickles, 1988). Animal research has shown that the locations of sound sources are represented in a distributed fashion within individual auditory cortical areas and among multiple cortical areas with similar degrees of location sensitivity, including A1 and A2 (Middlebrooks, Xu, Furukawa & Macpherson, 2002). However, these authors suggest that the special role of the auditory cortex is only in distributing pre-processed information about sound-source location to appropriate perceptual and motor stations, not actual computation of source locations. Other cortical areas might utilize auditory spatial information from A1 and A2 to perform functions that are not overtly spatial, but the spatial information might assist those functions by helping to segregate multiple sound sources.

Thus, although both localization and spatial release from masking rely on intensity and time differences between the two ears, there is no reason to believe that the two phenomena rely on the same brain processes using these cues. Based on observations of patients with damage to specific brain regions, it seems unlikely that the same brain processes are responsible for both abilities (Thiran & Clarke, 2003; Litovsky, Fligor & Tramo (2002). When the task of a listener is to understand a speech signal presented in noise, the improvement in speech reception threshold (SRT), relative to diotic stimulation is referred to as the binaural intelligibility level difference (BILD). Whereas both ITDs and ILDs contribute to BILD, recent studies have shown that in people with normal hearing, ILDs are the dominant mechanism enabling spatial release from masking when speech maskers are symmetrically positioned around the listener and a target talker is in front of the listener (Glyde, Buchholz, Dillon, Hickson, & Cameron, in preparation c). Moment-by-moment fluctuations in the amplitude and spectrum of each masker cause one masker to dominate over the other at each specific frequency and point in time. At that frequency and point in time, the ear on the side of the head opposite to the dominant masker has a better signal-to-noise ratio (SNR) than the ear closer to the dominant masker. Referred to as *cross-ear dip listening* (Brungart and Iyer, 2012; Glyde et al., in preparation b), this dynamic process, originally hypothesized by Zurek (1993), involves integrating information across the two ears, by selecting, separately for each frequency band, the signal from the ear with the better SNR at each point in time. Cross-ear dip listening effectively creates an optimal signal which has a better SNR than that available at either ear.

/H2/ Diagnosing deficits in spatial processing

As for other types of CAPD, it is essential that any test of SPD not spuriously indicate the presence of SPD as a consequence of the child having a memory, attention, or language disorder. The LiSN-S is an adaptive speech-in-noise test conducted under headphones that has been designed to avoid such confusions. The target and distracter (i.e., masker) sounds are speech materials that have been synthesized with head-related transfer functions in order to create a three-dimensional effect (Brown et al., 2009; Cameron & Dillon, 2007; Cameron et al., 2011a). A simple repetition-response protocol is used to assess a listener's speech reception threshold (SRT), which is defined as the SNR that yields 50 percent intelligibility. The target stimuli (sentences) are spoken by a female speaker and always appear to emanate from 0° azimuth (directly in front of the listener). The distracters (looped children's stories) are manipulated so that they appear to come from either 0° azimuth (collocated) or ±90° azimuth simultaneously (spatially separated). The distracter stories are spoken by either the same female speaker as the target sentences or two different female speakers. This test configuration results in four listening conditions: same voice at 0º (or low cue SRT); same voice at ±90º; different voices at 0º; and different voices at ±90º (or high cue SRT), as shown in Figure 8-2.

Insert Figure 8-2 here.

Performance on the LiSN-S is evaluated on the low and high cue SRT conditions, as well as on three derived *advantage* measures. These advantage measures represent the benefit in decibels (dB) gained when either talker (pitch), spatial, or both talker and spatial cues are incorporated in the maskers, compared to the baseline (low cue SRT) condition where no talker or spatial cues are present in the maskers. It is the use of these advantage measures that avoids any chance of an attention, memory or language disorder leading to a false designation of a SPD. Any of these conditions could lead to elevated (i.e., poorer) SRTs, but there is no reason why they would consistently increase the SRTs more in the spatially separated conditions than in the collocated conditions. The impact of higher order processes on diagnosis of CAPD is discussed further in the following section.

/H2/ Spatial Processing Deficits in Children with Normal Hearing Thresholds

The LiSN-S test can detect spatial processing deficits in children with suspected CAPD (SusCAPD) whose primary difficulties in the classroom stem from poor listening behavior, despite having normal hearing thresholds. Cameron, Dillon and Newall (2006c) used a prototype of the LISN-S test, to assess a group of ten children who presented with difficulties hearing in the classroom, but who tested as having no routine audiological or language, learning or attention deficits. The spatial advantage measure for the ten children was significantly poorer ($p < 0.000001$) than for a group of 48 normally-hearing, age-matched controls. Nine of the ten children were outside normal limits on this task (on average by 5 standard deviations). In contrast, none of the ten children were outside normal limits on the baseline condition where the maskers were co-located (low-cue SRT measure).

Cameron and Dillon (2008) assessed a group of nine children (SusCAPD group) on both the LISN-S and a traditional CAPD test battery (Pitch Pattern Test, Dichotic Digits, Random Gap Detection Test, and Masking Level Difference Test). The SusCAPD group 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. In order to study the effect of higher-order deficits on the LISN-S, a group of 11 children (LD group) 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. There were no significant differences on any LISN-S performance measure between the LD group and 70 age-matched controls (p ranging from 0.983 to 0.136). There were, however, significant differences between the SusCAPD group and the controls, but only on the LiSN-S conditions where the physical location of the maskers was different to that of the target speaker (high cue SRT, $p = 0.001$; spatial advantage, $p < 0.0001$, and total advantage, $p < 0.0001$). These results support Jerger's (1998) hypothesis that a high proportion of children with suspected CAPD have a deficit in the mechanisms that normally use the spatial distribution of sources to suppress unwanted signals. (Note, however, that the proportion will be distorted if the assessment process ascertains the presence of memory, attention, and language deficits which may co-occur with CAPD.)

The LISN-S did not correlate significantly with any test in the traditional central auditory test battery, nor were the non-spatial and spatial performance measures of the LISN-S correlated. This is the result one would expect if the only problem these children had involved spatial processing, and the only test conditions affected by spatial processing were the spatially separated conditions of the LiSN-S. The average spatial advantage score for the SusCAPD group was 2.0 standard deviations below the age-appropriate mean score whereas the average for the LD group was only 0.1 standard deviation below the age-appropriate mean. All the children in the SusCAPD group performed within normal limits on the traditional central auditory test battery, except for one participant who was just outside normal limits on the dichotic digit test. One child in the LD group (who presented with an auditory memory deficit) was outside normal limits on both the left and right ear conditions of the dichotic digit test. Two other participants in the LD group were outside the normal range on the pitch pattern test. All other children in the LD group performed within normal limits on the traditional battery.

Some readers might wonder how the children in the SusCAPD group could have such a deficit in spatial processing ability and yet pass a commonly used CAPD test battery. This should not be a surprise when one realizes that none of the tests in the standard battery attempt to test the same auditory skills as those assessed in spatially separated condition of the LiSN-S. This pattern is therefore precisely what would be expected for children who had reduced ability to separate a target sound from competing sounds on the basis of their direction of arrival, but had no other deficit in their auditory processing ability.

Finally, as noted by Chermak, Bellis and Musiek (2007), the clinician must be aware that a difficulty understanding spoken language in the presence of competing noise can be caused by deficits other than a CAPD. Inadequate language resources may prevent the child from using linguistic knowledge to compensate for the degraded signal. Similarly, attention-based deficits can interfere with the child’s ability to selectively attend to a target signal. To mitigate the impact of higher-order functions on LiSN-S performance, spatial processing is quantified by calculating the difference in dB between two test conditions where only one variable (spatial location) is manipulated. As such, it is expected that the child’s higher order processing ability will equally affect the SRT when the distracters are presented at 0°, and when they are spatially separated at ±90°. Language and executive functioning should have minimal effect on the difference in dB between the SRTs in these two conditions (see the spatial advantage measure in Figure 8-2). Thus, the differences that inevitably exist between individuals in such functions is controlled for, allowing for clearer evaluation of their abilities to use spatial cues to aid speech understanding (Brown et al., 2010; Cameron et al., 2011).

/H2/ Spatial Processing Disorder – Diagnosis, Prevalence and Management Options

Children who present with a pattern of depressed scores on the spatially-separated conditions of the LiSN-S (high cue SRT, spatial advantage and total advantage) combined with near-normal scores on the co-located conditions (low cue SRT and talker advantage) are said to have a spatial processing disorder, or SPD (Cameron & Dillon, 2011; Cameron, Glyde & Dillon, 2012). In other words, SPD is diagnosed by looking at the individual's pattern of results on the LiSN-S. However there are many small variations to this typical scenario, such as performance just inside normal limits on spatial advantage or performance well above normal limits on another measure (such as low cue SRT and/or talker advantage), and these can be more difficult for a clinician to interpret. To minimize any error in the interpretation of LiSN-S results caused by these other scenarios, the LiSN-S relies on a *spatial pattern measure*, as described in Cameron and Dillon (2011), which is equal to the release from masking provided by spatial separation, averaged across both the same voice and different voice contexts. The spatial pattern measure is therefore a better indicator of whether a set of LiSN-S results is indicative of a spatial processing disorder. The pattern measure score, which is calculated automatically by the LiSN-S software, is more reliable than just observing the spatial advantage score alone, as it uses all four LiSN-S condition scores in its calculation. Like the other measures, the spatial pattern measure score is described as being outside normal limits if the result is more than two standard deviations from the age-adjusted mean. This criterion has some degree of arbitrariness: deviations much greater than this indicate a deficit more serious than deviations only slightly greater than two standard deviations. Similarly, deviations between one and two standard deviations below the mean may still be associated with greater than average difficulty in communicating in noise.

Dillon, Cameron, Glyde, Wilson and Tomlin (2012) reported that seventeen percent of children referred for assessment for CAPD across various studies have been diagnosed with

SPD. A large proportion of the children in these studies presented with a history of chronic otitis media. Reduced transmission through the middle ear can disturb interaural differences in two ways. First, asymmetrical attenuation in the two ears will change the usual interaural level differences by the amount of the asymmetry. Second, if the attenuation is sufficiently great that the transmission path through bone conduction induced by the incoming sound field vibrating the whole skull is comparable to the transmission path through the impaired middle ear system, interaural time differences may also be disturbed. This is because the time differences applicable to the bone conduction path are much less than those for the air conduction path (Stenfelt, 2005). It may be hypothesized that fluctuating access to the normal binaural cues may negatively influence the development of spatial processing mechanisms within the central auditory nervous system.

SPD might be managed through the provision of an assistive listening device, such as an FM system or other remote-microphone hearing aid, in order to improve the signal-to-noise ratio in the classroom. In addition, a child with SPD can be seated at the front of the class. Central resources training can also be provided to help the child to compensate for their disorder by utilizing high-order cognitive skills to deduce the meaning implied from fragmented information received (see Chapter 10 for Chermak's overview of intervention incorporating cognitive, metacognitive and metalinguistic skills and strategies). However, as mentioned by Dawes and Bishop (2009), the aim of such approaches is to lessen the impact of the impairment, rather than attempting to ameliorate the auditory problems directly. Below we will discuss auditory training to ameliorate SPD.

/H2/ Spatial Processing Deficits in People with a Hearing Impairment

Spatial processing ability is often reduced in listeners with hearing impairment who commonly report difficulty in understanding speech in background noise despite amplification (Gelfand, Ross & Miller, 1988; Marrone, Mason & Kidd., 2008b; Helfer & Freyman, 2008; Glyde et al., 2013). Glyde et al. (2013) assessed 80 adults and children aged 7 to 89 years, with a wide range of hearing thresholds. They were tested on a version of the Listening in Spatialized Noise – Sentences Test (LiSN-S; Cameron & Dillon, 2009) that incorporated individually prescribed frequency-dependent amplification of the target and distracter stimuli. Those with a hearing impairment were less able than normal hearers to use spatial cues to help them understand speech in noise. In fact, even very mild hearing losses were associated with spatial processing deficits and as hearing loss worsened so did spatial processing ability. This result was not significantly correlated with age or cognition.

In people with hearing impairment, reduced audibility (which effectively lessens access to the weaker speech sounds that remain unmasked in the ear closer to the momentarily weaker distracter) explains most of their observed spatial processing deficits (Glyde et al., in preparation a). The remaining deficit may perhaps be explained by reduced ability to use cross-ear dip listening mechanisms, most likely due to widened auditory bands in the cochlea, and/or by reduced temporal processing which restricts the ability to use ITD information to differentiate the frontal target from the non-frontal distracters (Glyde et al., in preparation b).

/H1/ Overview of the LiSN & Learn Auditory Training Software

The LiSN & Learn software was developed as an at-home training system to specifically remediate SPD (Cameron & Dillon, 2011; Cameron et al., 2012). As such, this training is intended to remedy the deficit observed in children who perform outside the normal range on the LiSN-S. It is therefore training the ability to hear in spatially-separated noise, not the ability to localize the direction from which individual sounds emanate. The LiSN & Learn software produces a three-dimensional auditory environment under headphones (Sennheiser HD215) on a personal computer. There were four training games in the research software - Listening House, Listening Ladder, Goal Game and Answer Alley. An additional game, Space Maze, was added to the commercial version of the software (Cameron & Dillon, 2012), along with various motivational and reward features as described below.

/H2/ Speech Stimuli and Spatialization

In the four standard LiSN & Learn games the child's task is to identify a single word from a target sentence presented in background noise (two looped children's stories). All the target sentences are six words in length (e.g., The clown dropped three red cars). A total of 136 semantic items were used to develop a base list of 324 sentences. The sentences were recorded, synthesized with head related transfer functions (HRTFs) and edited into individual words (with each word maintaining its co-articulation). An algorithm was developed to generate natural-sounding target sentences from these individual words. In total, 131,220 unique sentences can be generated by the software. Ninety of the 136 semantic items (nouns, verbs and adjectives) were utilized as the target words which the listener is required to identify. All the target words are acquired by 30 months of age (Fenson et al., 1992).

Akin to the Same Voice 90° condition of the LiSN-S, the LiSN & Learn target sentences appear to come from directly in front of the listener (at 0° azimuth), whereas the competing speech appears to come from either side of the listener simultaneously (+ and - 90° azimuth).

The sentences and competing stories are all spoken by the same female speaker, so the child must rely on spatial cues (i.e., differences in the physical location of the speech streams) to be able to distinguish the sentence (and hence the target word) from the distracting speech. A tone burst is presented before each sentence to alert the child that a sentence will be presented.

In the four standard games, four images and a question mark appear at the top of the screen immediately following the presentation of the sentence. In a five-alternative, forced-choice, adaptive method, the child uses the computer mouse to select either one of the images that matches a word from the sentence he or she had just heard or to make an '*unsure*' response by selecting an image of a question mark (see Figure 8-3).

Insert Figure 8-3 here.

As previously noted an additional game, Space Maze, was added when the commercial version of the software was released. In this game the child hears an instruction (e.g., *move up three spaces*) and must use the computer mouse to select a direction (up, down, left, right) and a number (from one to ten) in order to move around the maze. The direction and number buttons remain on the screen throughout the game. When the child gets four instructions correct, the maze GUI (graphical user interface) changes so that the child remains entertained by the visual properties of the game (see Figure 8-4).

Insert Figure 8-4 here.

/H2/ Training Hierarchy and Adaptive Difficulty Levels

The starting level of 7 dB SNR utilized in the LiSN-S diagnostic test is also used in the LiSN & Learn training program. This starting level was chosen to ensure that the child can begin training with relatively high success. A weighted up-down adaptive procedure is used to adjust the signal level of the target based on the child's response. The advantage of an adaptive program is that the task can continually adjust to more difficult levels as the listener answers correctly. Specifically, the target sentence is decreased when the child correctly identifies the target image and increased if the wrong image or an "unsure" (question mark) response is made. Thus, after an incorrect response, the difficulty level is lowered so that the next trial is more likely to be completed correctly. Such a tracking rule may be considered more enjoyable by some children (Bamiou, Campbell & Sirimanna, 2006; Thibodeau, 2007) and therefore contribute to program completion.

A minimum of five sentences are provided as practice; however practice continues until one upward reversal in performance has been recorded. There are 40 sentences in any game. The child's SRT for each game is measured as the average SNR over all sentences, excluding the practice.

Calibration is undertaken at startup using a reference signal (whooshing sound) that is adjusted by the child using a slider bar. The child is instructed to move the slider bar until he or she can barely hear the whooshing sound. The reference signal is level normalized so that its rms level is 40 dB less than the rms level of the combined distracters. Thus, when presented, the sensation level of the combined distracters is at least 40 dB SL.

/H2/ Feedback, Positive Reinforcement and Motivation

In line with the principles of learning theory (Wolfle, 1951), information regarding a child's performance during a game is provided following each response and this feedback is tailored to the GUI used for each particular game. For example, when the child makes a correct response in Answer Alley the LiSN & Learn Ear knocks over the all the bowling pins and the word "strike" is heard over the headphones. This type of positive reinforcement encourages the child to persist with the training despite increasing difficulty (Thibodeau, 2007). In a review of research on computer aided auditory rehabilitation, Sweetow and Henderson Sabes (2010) stipulated that measurement and feedback to the user should be provided regarding progress or lack of progress. As such, feedback is also provided by presenting the child's score at any point in the LiSN & Learn game in the "Current Level" box following each response. A progress bar shows the child how far through the game they have progressed.

As well as providing engaging graphics, feedback, positive reinforcement and progress indicators, external motivators are incorporated in the commercial version of the software to motivate the child to continue training over the course of the treatment schedule. When the software is installed the user is prompted to create a "buddy", who provides additional feedback during the game in the form of speech bubbles, such as "well done". The buddy is an avatar that the child designs from a number of options, including the buddy's shape, color and facial features Additional motivators are provided in the form of "LiSN & Learn currency" which children earn for identifying correct target words and for beating their best game score.   LiSN & Learn currency can be used by the child in the LiSN & Learn Reward Shop to play non-training games incorporated in the software and to buy accessories for their buddy (see Figure 8-5).

Insert Figure 8-5 here.

Some children may require additional motivators in the form of physical rewards. Reward charts can be downloaded from the LiSN & Learn Additional Resources section of the National Acoustic Laboratories CAPD website (http://capd.nal.gov.au/). It is also suggested that a caregiver be present during each training session to motivate the child to focus and do their best while training.

/H1/ LiSN & Learn Research Studies

According to Chermak et al. (2007), the effectiveness of deficit-specific auditory intervention should be gauged, primarily, by improvements seen on central auditory tests, as well as concomitant improvement in functional listening skills. In a preliminary study, Cameron and Dillon (2011) aimed to evaluate the effectiveness of the LiSN & Learn to remediate SPD based on the abovementioned principles. A second study (Cameron et al., 2012) aimed to determine whether improvements in the ability to understand speech in noise in children diagnosed with SPD following training with the LiSN & Learn were specific to that training program, or if such improvements might occur following exposure to any computer-based auditory training software. Both studies were conducted using the research version of the software (i.e. without the Space Maze game and reward shop). All training occurred in the client's own home except for one child in the Cameron & Dillon (2011) study who trained for part of the time at school under his teacher's supervision.

/H2/ Preliminary Study

Nine children aged between 6 and 11 years with normal peripheral hearing took part in the Cameron and Dillon (2011) study. All participants were diagnosed with SPD using the LiSN-S. The participants trained on the LiSN & Learn for fifteen minutes a day five days a week for three months, until they had completed 120 games. Participants were assessed on the LiSN-S, as well as on the auditory subtests of Test of Variables of Attention (TOVA; Greenberg, Kindschi, Dupuy, & Hughes, 2007), the memory subtest of the Test of Auditory Processing Skills – 3 (TAPS-3; Martin and Brownell, 2005) and a version of the Speech, Spatial and Qualities of Hearing Scale questionnaire (SSQ; Noble and Gatehouse 2004) developed by Flinders University in South Australia specifically for children with CAPD. In order to determine whether any improvements in performance were maintained, performance on all tasks was re-assessed after three months post-training.

It was found that SRTs on the LiSN & Learn improved on average by 10 dB over the course of training (see Figure 8-6). At the end of the training period there was no significant improvement on the two control conditions of the LiSN-S (low cue SRT and talker advantage) where the target and distracters all emanated from 0° azimuth (p ranging from 0.07 to 0.86, η^2 ranging from 0.362 to 0.004). In contrast, all of the children improved significantly on the three conditions of the LiSN-S that evaluate spatial processing (p ranging from < 0.003 to 0.0001, η^2 ranged from 0.694 to 0.873) and were all performing within normal limits (see Figure 8-7). SRTs in the high cue condition (which is the condition most similar to real life listening) improved by an average of 2.4 standard deviations (3.9 dB). For all but one of the children these improvements were maintained after a three month period without any further training.

Insert Figure 8-6 here.

Insert Figure 8-7 here.

Significant improvements were also found post-training on the memory subtest of the TAPS-3 and in commission errors on the TOVA. These improvements were not seen as being specific to the LiSN & Learn spatial discrimination training. Rather, we attributed improvements in the memory tests to the nature of the LiSN & Learn task, which required remembering a sentence while selecting a matching image. We attributed improvements in attention to increased auditory vigilance attained from playing the LiSN & Learn games five days a week over the three month training period. Importantly though, participants reported a very significant improvement post-training in their ability to understand speech in noisy environments ($p = 0.000007$, $\eta^2 = 0.930$). The average rating on a modified version of the SSQ developed for children with CAPD, improved from 3.10 (between "hard" and "very hard") to 1.78 (between "easy" and "OK"). There were no significant differences between post- and three-month post-training scores on any of the assessment tools. It was concluded that the initial LiSN & Learn study showed that children as young as six years of age were able to complete the training (although some coaxing was needed in a minority of cases) and that training led to significant improvements in spatial processing ability.

/H2/ Randomized Blinded Controlled Study

Cameron et al. (2012) utilized a randomized blinded controlled design to evaluate whether post-training improvements in spatial processing ability in children diagnosed with SPD were specific to LiSN & Learn or if training with non-spatially separated stimuli could also result in improvements in this ability as measured with the LiSN-S. Participants were ten children between 6 and 9 years of age who were diagnosed as having SPD with the LISN-S. The children were randomly allocated to train with either the LiSN & Learn or another auditory training program – Earobics Home Version (Cognitive Concepts, 2008) - for approximately 15 minutes per day for twelve weeks. The Earobics software provides training on phonological awareness, auditory processing and language processing skills through a number of interactive computer games. Specifically, the program consists of audiovisual exercises, presented either in quiet or in non-spatialized noise, that incorporate training in phoneme discrimination, auditory memory, auditory sequencing, auditory attention, rhyming and sound blending skills (Hayes, Warrier, Nichol, Zecker & Kraus, 2003). Participant, parent and teacher questionnaires as detailed below were administered to determine the real-life listening benefit of the training. The children and their parents and teachers were blinded as to whether the participant was in the experimental or control group.

Over the course of training the experimental group improved on average by 10.9 dB in respect to their SRT on the LiSN & Learn. As expected, based on the 2011 preliminary study, there were no significant improvements post-training by either the LiSN & Learn or Earobics group on the control conditions of the LiSN-S where the target and distracter stimuli were co-located. Also, as expected, there was a significant improvement post-training on the LiSN-S scores that are affected by spatial processing ability for the LiSN & Learn group ($p = 0.03$ to 0.0008, $\eta 2 = 0.75$ to 0.95, $n = 5$). As hypothesized there was no significant improvement on these scores for the children who had trained with the Earobics software ($p = 0.5$ to 0.7, $\eta 2 = 0.1$ to 0.04, $n = 5$), as shown in Figure 8-8. SRT in the high cue condition (the condition most similar to real-life listening condition) improved on average by 2.7 standard deviations (4.4 dB) for the LiSN & Learn group but only by 0.4 standard deviations (1.0 dB) for the Earobics group.

In respect to measures of real-world listening ability, group results of post-training listening performance by children, parents and teachers also reflected post-training LiSN-S performance in the two groups. On the self-reported questionnaire, the Listening Inventory For Education (L.I.F.E.) Student (Anderson & Smaldino, 1998a), the children in the LiSN & Learn group rated their own listening skills as improving by 22% post-training compared to 9% in the Earobics group. The teacher questionnaire was the L.I.F.E. – Teacher (Anderson & Smaldino, 1998b) which utilizes an incremental listening improvement rating scale from -35 to +35, where 0 is considered "No Change: Benefit of Use Not Identified" and 17 is considered "Support for Positive Change: Use is Beneficial". The LiSN & Learn group showed a mean post-training improvement rating of 15.8 compared to 6.6 for the Earobics group. Using the Fisher's Auditory Problems Checklist (Fisher, 2008), parents reported that the listening skills of children in the LiSN & Learn group had improved on average by 31% following training, compared to 8% for the children in the Earobics group. The increase in parent-reported scores for the experimental group was significantly larger than for the controls ($p = 0.028$).

Insert Figure 8-8 here.

It was concluded that LiSN & Learn training improved binaural processing ability in children with SPD, enhancing their ability to understand speech in noise, as directly measured in the spatially separated conditions of the LiSN-S test. These results were specific to the LiSN &

Learn training protocol, as expected. Exposure to non-spatialized auditory training did not produce similar outcomes, emphasizing the importance of deficit-specific remediation.

Improvements in academic performance following training were not specifically measured in either the preliminary LiSN & Learn study or the randomized blinded control study. A child with SPD characteristically presents as not understanding speech in the classroom as well as his or her peers, most notably when background noise is present. It should be noted that the typical presenting profile of a child with SPD is a history of chronic otitis media, not a language or learning disorder (Cameron & Dillon, 2008). The SPD itself may result in auditory fatigue. The child may also miss important information during lessons if the listening environment is noisy. Following training, a general improvement in listening ability in the classroom and reductions in auditory fatigue that will benefit general classroom performance over time is expected, as found from post-training self-report, parent and teacher questionnaires (Cameron & Dillon, 2011; Cameron et al. 2012). Improvements in any academic area that had suffered due to a child's difficulties hearing in noise over time due to SPD would likely take some time to reverse, possibly requiring additional, specialized tutoring if the child was seriously behind his or her peers.

/H1/ Other Considerations

/H2/ System Requirements and Headphones

The LiSN & Learn software is designed for use in the child’s home, avoiding the need for daily trips to a clinic. Version 3.0.0 of the software can be installed on any PC running Windows XP, Vista, 7 or 8. It is recommended that Sennheiser HD215 headphones, provided with the software, be used during playback as the stimuli have been filtered to correct for the response of these specific headphones (Cameron & Dillon, 2011).

/H2/ Treatment Schedule and Environment

The recommended training schedule is for the child to play two LiSN & Learn games per day, five days per week, until at least 100 games have been completed. As each game takes about 5-10 minutes to complete, this program can generally be completed by training for 15 minutes per day for 10 weeks. Chermak and Musiek (2002) stipulate that auditory training should be conducted in an intensive manner, and suggest five to seven sessions be scheduled weekly. The authors further noted that research has shown that regular and consistent training for as little as ten to fifteen minutes a day over a number of weeks provides the intensity needed to maximize success in the training task.

Bellis (2002) points out that because therapy is costly in terms of time and money, research is needed to determine the frequency and intensity of a particular therapy that is necessary but sufficient to achieve desired results. A total of 120 games were played in the Cameron & Dillon (2011) and Cameron et al. (2012) studies. However, as can be seen from Figure 8-6, maximum improvement in SRT (around 10 dB) is achieved by around game 95. Once children achieve their maximum improvement it becomes more challenging to continue training as they are less likely to beat a previous high score and as a consequence reward currency is earned less frequently. At this point the child should be encouraged to continue playing until the minimum 100 game level has been reached in order to consolidate the improvements in skills already achieved.

A graph of the child's progress over time can be accessed by the parent from the main menu by selecting the *Progress Report* button. The parent is also able to generate progress reports which can be forwarded to any professional involved in the child's management program.

Of course, training can be conducted in any environment, including schools, as long as the training can occur on a daily basis, the environment is quiet and child is not distracted by other children or nearby activities. It is recommended that, particularly for younger children, an adult supervise training to ensure that the child stays on task throughout each training session (see Figure 8-9).

Insert Figure 8-9 here.

Whereas the software was designed for children aged between 6 and 11 years, it could be used with older children as long as he or she is prepared to accept that the software is tailored for younger children and does not become disheartened with the graphical user interface. It should be noted that research has not be conducted to determine the efficacy of training with anyone over the age of 12 years.

Finally, Cameron and Dillon (2011) found that spatial processing ability was maintained three months post-training with no further use of the LiSN & Learn. However, once a child has completed the recommended number of training games he or she may wish to use the software occasionally to check that their spatial processing, measured as an SRT on the various LiSN & Learn games, has not deteriorated. Simple real-world listening strategies should also be practiced, such as maintaining eye contact with the target speaker and avoiding any activity, such as fidgeting, that diverts attention from the speaker.

/H1/ Summary

In this chapter we have discussed the diagnosis and remediation of spatial processing disorder (SPD), which is a specific type of CAPD. SPD presents as a markedly reduced ability to selectively attend to sounds coming from one direction and suppress sounds coming from other directions. The disorder likely results from an inability to utilize binaural cues, such as variances in inter-aural time and intensity differences between speech streams, and consequent differences in target-to-masker SNRs at the two ears, to separate a target auditory stimulus from distracting auditory stimuli. As is common in CAPD, SPD leads to difficulty in understanding speech in noisy situations. The exact cause of SPD in children with normal hearing thresholds is not known; however, we believe that it is much more likely to be present in children who have had prolonged or repeated bouts of otitis media during childhood.

SPD is differentially diagnosed by presenting target stimuli with and without spatial separation from competing signals. The Listening in Spatialized Noise – Sentences Test (LiSN-S) accomplishes this using speech processed through head-related transfer functions presented under headphones. Our research, presented in this chapter, demonstrates the potential to treat SPD successfully by giving children practice at listening to frontally-oriented speech in the presence of competing signals coming from other directions. The LiSN & Learn auditory training program achieves this using sounds processed through head-related transfer functions and presented over headphones on the child’s home computer. Research studies such as Cameron and Dillon (2011) have shown that ten weeks’ training at home (15 minutes per day, 5 days per week) is sufficient to remove all signs of SPD and results in improvements in spatial processing that are maintained without further training. Further, in a randomized blinded controlled study, Cameron et al. (2012) found that improvements in ability to understand speech in noise following training were specific to the LiSN & Learn training protocol and that exposure to non-spatialized auditory training does not produce similar outcomes. This research emphasizes the importance of deficit-specific remediation for SPD. The effect of the remediation in both studies was evident as improved speech in noise scores on LiSN-S test. The changes were also evident from the progressive improvement in SRT over the three months of training with the LiSN & Learn. Further changes were reflected in questionnaires addressing listening ability in real life.

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Figure Legends

Figure 8-1. Normative data for the spatial advantage measure of the LiSN-S (n=202). Error bars represent the 95% confidence intervals from the mean. (Adapted from Cameron et al. [2011], with permission.)

Figure 8-2. The four subtests of the LiSN-S test, and the three difference scores (advantage measures) that can be derived from them. The target speech, T, always comes from the front, whereas the two distracter stories, D1 and D2, come from the front or the sides, in different conditions. D1 and D2 can be the same voice as T or different voices. (Adapted from Cameron et al. [2011], with permission.)

Figure 8-3. Image of a LiSN & Learn training game from Cameron and Dillon (2012).

Figure 8-3. Image of the Space Maze game from Cameron and Dillon (2012).

Figure 8-5. Image of the LiSN & Learn Reward Shop from Cameron and Dillon (2012).

Figure 8-6. LiSN & Learn results from the start until the end of training, averaged across the nine children from the Cameron & Dillon (2011) study. Performance is measured as the speech reception threshold (SRT) in decibels achieved over the 120 games played. (Adapted from Cameron & Dillon [2011], with permission.)

Figure 8-7. Pre-, post- and 3 month post- (3M) training performance on the LISN-S for the nine children in the Cameron & Dillon (2011) study. Performance is expressed in population standard deviation units from the mean. Error bars represent 95% confidence intervals. (Adapted from Cameron & Dillon [2011], with permission.)

Figure 8-8. Pre- and post-training performance on the LiSN-S SRT and advantage measures for the LiSN & Learn group compared with the Earobics group for the ten children in the Cameron et al. (2012) study. Performance is expressed in population standard deviation units from the mean. Error bars represent 95 percent confidence intervals. (Adapted from Cameron et al. [2012], with permission.)

Figure 8-9. Sophie, aged 7, using the LiSN & Learn software with her mother, Sonia. July 2012. (Used with permission.)

Figures

Figure 8-1

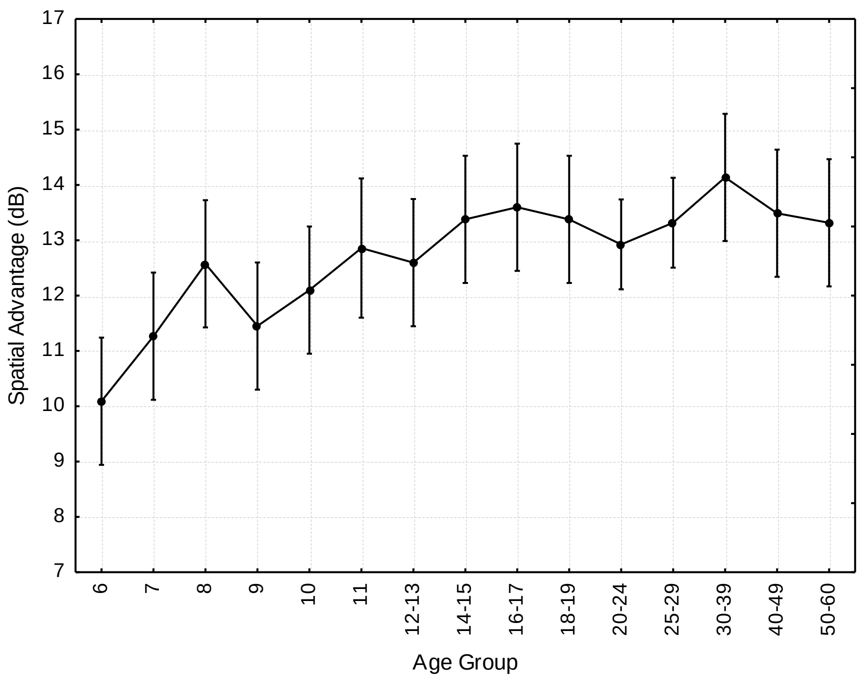

Figure 8-2

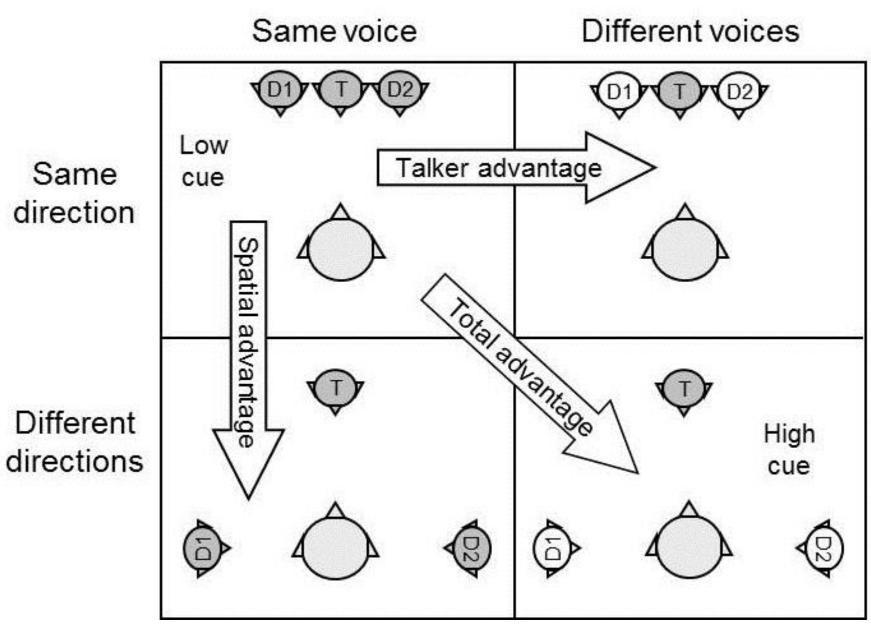

Figure 8-3

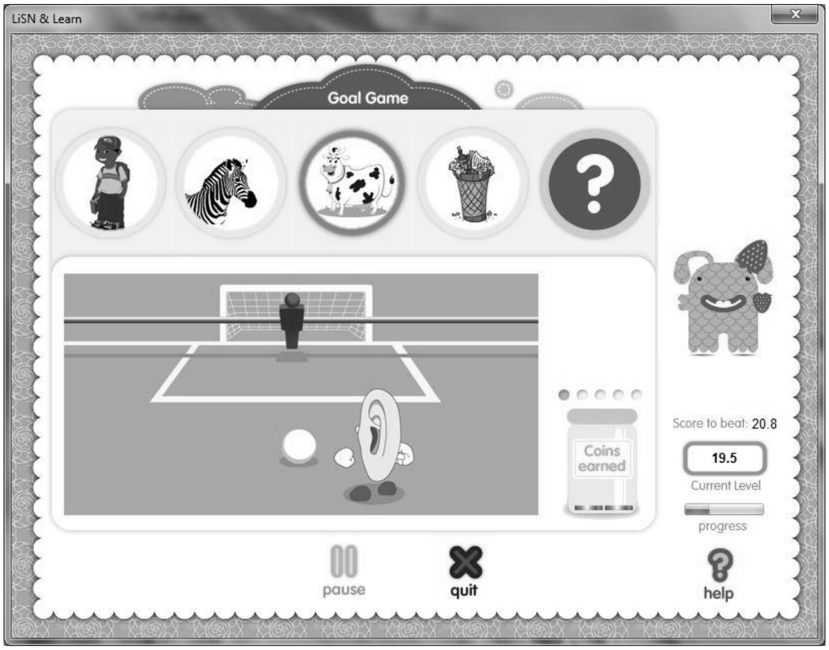

Figure 8-4

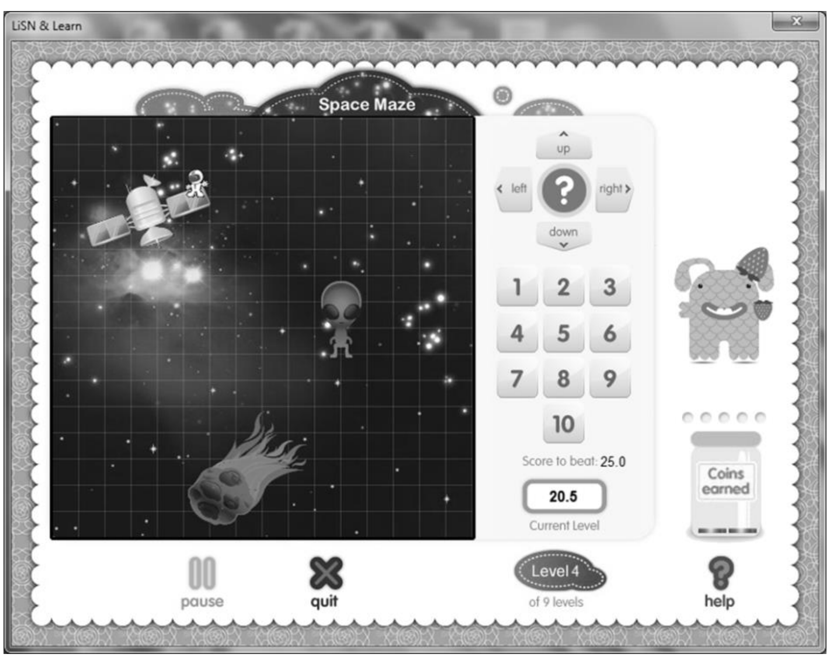

Figure 8-5

Figure 8-6

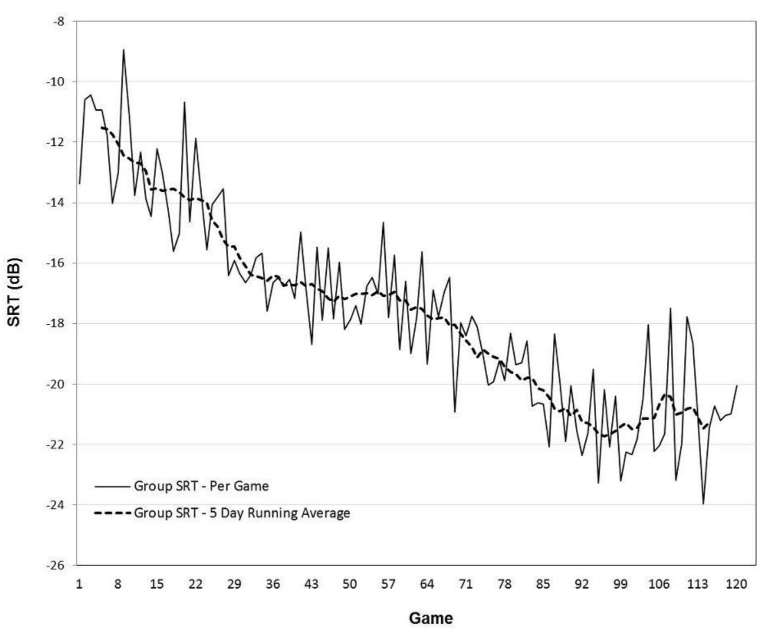

Figure 8-7

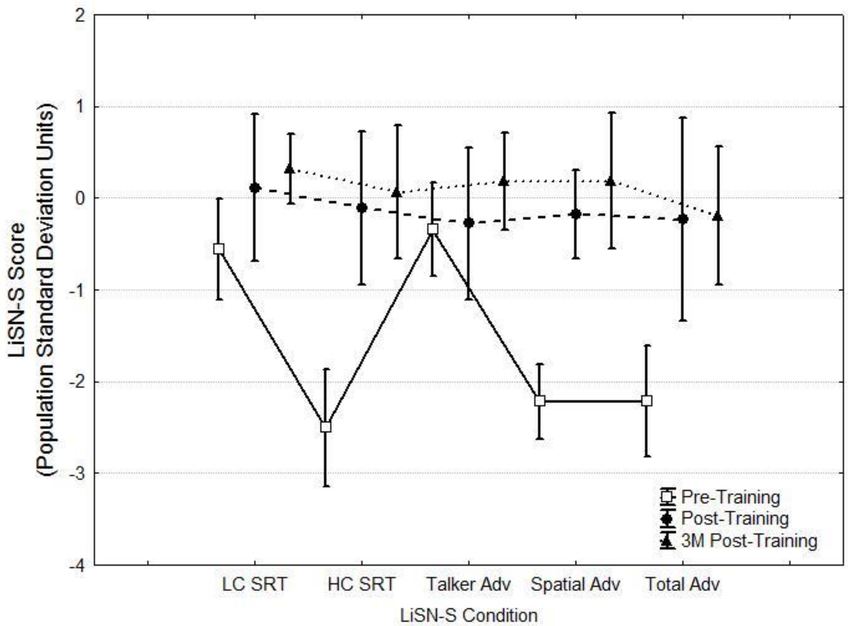

Figure 8-8

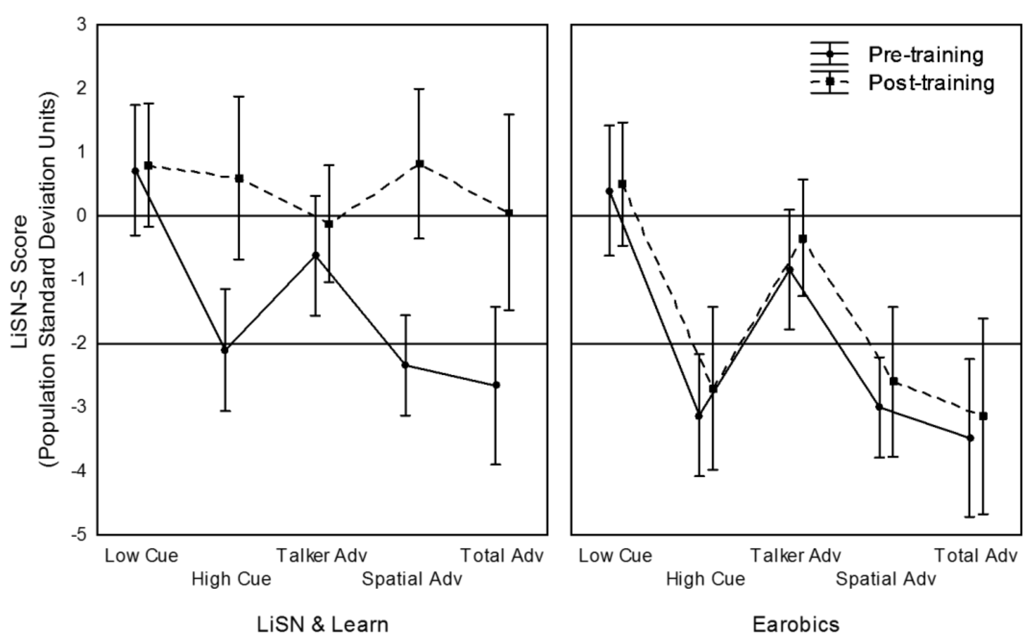

Figure 8-9