

# Efficacy of the LiSN & Learn auditory training software: randomized blinded controlled study

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## Abstract

Children with a spatial processing disorder (SPD) require a more favorable signal-to-noise ratio in the classroom because they have difficulty perceiving sound source location cues. Previous research has

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Conflict of interests: the authors would like to disclose that we distribute a commercial version of the LiSN & Learn training software described in this paper. Financial returns from sales will benefit the National Acoustic Laboratories and Dr. Cameron. Sale of the software did not commence until after the research described in this study was completed and any potential future financial interests in no way influenced the research reported in this paper. The Listening in Spatialized Noise - Sentences (LiSN-S) test also described in this paper is distributed under license by Phonak Communications AG. Financial returns from the sale of this product benefit Dr Cameron and the National Acoustic Laboratories. This has in no way influenced the research reported in this paper.

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shown that a novel training program - LiSN & Learn - employing spatialized sound, overcomes this deficit. Here we investigate whether improvements in spatial processing ability are specific to the LiSN & Learn training program. Participants were ten children (aged between 6;0 [years;months] and 9;9) with normal peripheral hearing who were diagnosed as having SPD using the Listening in Spatialized Noise - Sentences test (LiSN-S). In a blinded controlled study, the participants were randomly allocated to train with either the LiSN & Learn or another auditory training program - Earobics - for approximately 15 min per day for twelve weeks. There was a significant improvement post-training on the conditions of the LiSN-S that evaluate spatial processing ability for the LiSN & Learn group ( $P=0.03$  to  $0.0008$ ,  $\eta^2=0.75$  to  $0.95$ ,  $n=5$ ), but not for the Earobics group ( $P=0.5$  to  $0.7$ ,  $\eta^2=0.1$  to  $0.04$ ,  $n=5$ ). Results from questionnaires completed by the participants and their parents and teachers revealed improvements in real-world listening performance post-training were greater in the LiSN & Learn group than the Earobics group. LiSN & Learn training improved binaural processing ability in children with SPD, enhancing their ability to understand speech in noise. Exposure to non-spatialized auditory training does not produce similar outcomes, emphasizing the importance of deficit-specific remediation.

## Introduction

The ability of the brain to tease apart the cacophony of the sounds that arrive simultaneously at the ears during our everyday experience is referred to as auditory stream segregation. A strong cue for partitioning the spectrum of sound is the perception of the spatial location of the various sound sources.<sup>1</sup> Spatial stream segregation is a primitive, pre-attentive process enabling listeners to consciously attend to a target stimulus whilst simultaneously filtering out irrelevant background noises, and is thus essential for early learning in a wide variety of listening environments, including the classroom. However, a substantial proportion of children with suspected auditory processing difficulties have been found to have a spatial processing disorder (SPD). SPD is a specific type of central auditory processing disorder (CAPD) that is thought to result from an inability to differentiate the very fine differences in the time and intensity of auditory signals arriving simultaneously at the ears from various locations in the immediate environment.<sup>2-7</sup> As a result, children diagnosed with SPD need a significantly greater signal-to-noise ratio (SNR) in order to achieve the same speech reception thresholds (SRTs) as normally-hearing children without the disorder. SPD is diagnosed using the Listening in Spatialized Noise - Sentences test (LiSN-S). The LiSN-S is an adaptive, virtual-reality, test that measures speech perception ability for simple sentences presented in competing speech. Full details of the development and evaluation of the LiSN-S stimuli and software have been previously published.<sup>8-15</sup> Importantly, the LiSN-S measures the

ability of people to use the spatial cues that normally help differentiate a target talker from distracting speech sounds (Figure 1). SPD is characterized by a pattern of depressed scores on the spatially separated conditions of the LiSN-S (high cue speech reception threshold, spatial advantage and total advantage) compared to the co-located conditions (low cue SRT and talker advantage). It was reported that seventeen percent of children referred for assessment for CAPD in various studies have been diagnosed with SPD.<sup>16</sup>

Currently children with a spatial processing disorder must rely on a personal amplification device to improve the signal-to-noise ratio in the classroom if they are to hear as well as other children around them.

The LiSN & Learn auditory training software<sup>2</sup> was developed specifically to remediate SPD. Full details of the software development and evaluation have been previously published.<sup>17</sup> In summary, the software produces a three-dimensional auditory environment under headphones on the user's home computer. The child plays various games in which he or she must identify a target word from a sentence, which is presented in competing speech. In the development of the target stimuli, 324 sentences, six words in length, were developed from 136 semantic items. 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 target sentences from the individual words, of which 90 words (nouns, verbs and adjectives) were utilized as the target words. The listener is required to identify a target word by matching it to an image displayed on the screen. In total, 131,220 unique sentences can be generated by the software. 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 (continuously presented children's stories) appears to come from either side (+ 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.

In a previous study,<sup>2</sup> nine children aged between 6 and 11 years with normal peripheral hearing who were diagnosed with the LiSN-S as having SPD, trained on the LiSN & Learn for 15 min a day five days a week until they had completed 120 games, which typically takes about three months. SRTs on the LiSN & Learn improved on average by 10 dB over the course of training. At the end of the training period 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,  $\eta^2$  ranged from 0.694 to 0.873) and were all performing within normal limits. There was no improvement on the two control conditions of the LiSN-S where the target and distracters all emanate from 0° azimuth. Significant improvements were also found for self-reported ability to understand speech in noise. For all but one of these children these improvements were maintained after a three-month period without any further training.

Although the above study provided preliminary evidence as to the effectiveness of the LiSN & Learn software for remediating SPD, the efficacy of auditory training software in general has been questioned in the literature due to lack of randomized controlled trials. For example, whereas Fast ForWord<sup>18</sup> has been used with thousands of children in the past decade, several research publications have shown that the effects of Fast ForWord are not significantly different from, or in some cases are even worse than, the effects that can be obtained using an equally intensive schedule for treatments that do not use the acoustic signal changes that are said to be critical to improvements in language function.<sup>19-22</sup> Thus, the aim of the present study was to determine whether improvements in the ability to understand speech in noise in children diagnosed with SPD following training with the LiSN & Learn auditory training software were *specific* to that training program, or if

such improvements may occur following exposure to *any* computer-based auditory training software. In the present study, Earobics Home Version<sup>23</sup> auditory training software was utilized as the control software. The Earobics programs provide training on phonological awareness, auditory processing and language processing skills through a number of interactive computer games. Specifically, the programs consist 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.<sup>24</sup> The children and their parents and teachers were blinded as to whether the participant was in the experimental or control group.

As the effectiveness of deficit-specific intervention should be gauged, primarily, by improvements seen on central auditory tests, as well as concomitant improvement in functional listening,<sup>25</sup> pre- and post-training performance was measured against the various SRT and advantage measures of the LiSN-S, as well as on participant, parent and teacher questionnaires. It was hypothesized that, as found in the previous study,<sup>2</sup> children training with the LiSN & Learn would show significant post-training improvements in the ability to understand speech in noise, as measured by the spatially-separated conditions of the LiSN-S. It was further hypothesized that children in the control group would not show significant improvements on the LiSN-S, demonstrating that improvements in binaural processing are remediation-specific. In respect to generalized behaviors, it was feasible that the children training with the Earobics software, and their parents and teachers, would notice improvements in auditory processing associated with improvements in non-deficit specific skills such as auditory attention. As such, it was hypothesized that both the experimental and control groups would report post-training improvements in functional listening on the self-report, parent and teacher questionnaires, but that the improvement in ratings for the LiSN & Learn group would be greater due to the deficit-specific nature of the training.

## Materials and Methods

Approval for the study discussed in this paper was granted from the Australian Hearing Human Research Ethics Committee.

### Participants

Children aged 6 to 11 years who were identified, either by a referring professional or by their parent, as experiencing greater difficulty understanding speech in noise than their peers were accepted into the study. Fifty-three children were assessed for possible inclusion in the

LiSN-S SRT and Advantage measures

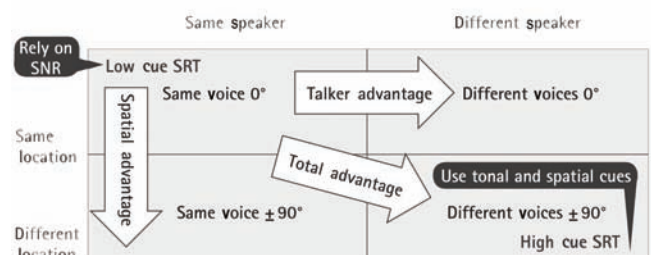


Figure 1. Diagram of the four spatialized noise-sentences test conditions and derived advantage measures.

study. The inclusion criteria stipulated that children with diagnosed attention deficit hyperactivity disorder (ADHD) that was not medicated would be excluded from the study, as well as children who did not have English as a first language. Fourteen were diagnosed as having a SPD, characterized by performance outside normal limits on the LiSN-S pattern measure,<sup>2</sup> and went on to participate in the research. During the training period, two children in the LiSN & Learn group were withdrawn from the study due to non-compliance with the training protocol. Two children from the Earobics group withdrew for family health reasons. Data from the remaining 10 children, who completed the training protocols as stipulated, is reported below. There were five children in the LiSN & Learn group (aged between 6;0 [years;months] and 9;9; mean 7;9) and five children in the Earobics group (aged between 6;5 and 9;6; mean 8;4). There were four males and one female in the LiSN & Learn group and five males in the Earobics group. All participants had English as a first language and pure tone thresholds  $\leq 15$  dB HL at octave frequencies between 500 to 4000 Hz, and  $\leq 20$  dB HL at 250 and 8000 Hz. Each child had normal middle ear pressure and compliance on the day of pre-training and post-training assessment. One child in the LiSN & Learn group had previously been diagnosed with ADHD which was managed by his pediatrician with medication. One child in the Earobics group had previously been diagnosed by an educational psychologist with mild Asperger's disorder. Both children performed within normal limits on the co-located conditions of the LiSN-S, showing that they understood the test instructions and could attend to the assessment and respond to the examiner appropriately. The children were able to undertake and complete the training without incident. No other children in the study had any previously reported diagnosis of learning or attention disorders. None of the participants undertook any other therapy during the course of the training, nor did any participant use a personal amplification device or have access to sound field amplification in the classroom.

### Recruitment considerations, blinding and randomization

Recruitment commenced in February 2010 being the start of the first New South Wales school term for that year. It ran for 18 months until June 2011, which date corresponded to the end of the second school term for that year. Recruitment of participants was temporarily halted towards the end of 2010 due to the potential overlap of training with the ten week Christmas vacation break. As teachers were required to provide feedback as to the improvement of the participant from the start to the end of training, the Christmas holiday would cause significant interruption. Also, the new school year commences in the first school term following the Christmas vacation, and it was imperative that participants did not change teachers mid-way through training, as this would also impact the feedback process.

The participants were randomly allocated to either the experimental or control group. Specifically, every second child recruited was assigned to the Earobics group. In respect to blinding, the participants and their parents were advised that *both* the LiSN & Learn and the Earobics software were auditory training software packages but they were not told which the experimental software was and which the control software was. The teachers were not advised which software package had been provided. During the course of the study there were no published papers available on the LiSN & Learn and there was no information about the software on any website. Due to staffing limitations, however, it was not possible for the examiner who administered the LiSN-S diagnostic test to be blinded to group inclusion details.

### Methods: pre- and post-training

The listening performance of children was evaluated pre-and post-training on the following materials. Routine audiological testing and diagnostic assessment with the LiSN-S was carried out in an acousti-

cally treated room suitable for testing hearing thresholds at the National Acoustic Laboratories between 9 am and 3 pm. Test-retest reliability on the LiSN-S measures ranged from  $r=0.3$  for the talker advantage measure to  $r=0.8$  for high cue SRT measure, with test-retest differences ranging from a maximum of  $-1.1$  dB on the high cue SRT to only  $0.1$  dB on the spatial advantage measure.<sup>13</sup> A t-test for related samples calculated between the first and repeated administration of the LIFE student questionnaire showed no significant difference between administrations ( $t=0.812$ ,  $P\leq 0.05$ ).<sup>26</sup> Published test-retest reliability data on the Fisher's Auditory Problems Checklist is not available:

(i) Pure tone audiometric screening was performed using a Maico MA 53 (MAICO part of William Demant Holding A/S, Smørum, Denmark) clinical audiometer with circumaural Sennheiser HDA 200 (Sennheiser Electronic Corp., Wedemark, Germany) audiometric headphones.

(ii) Acoustic immittance data was obtained using a GN Otometrics OTOflex 100 (GN Otometrics, Copenhagen, Denmark) impedance audiometer.

(iii) The LiSN-S was administered using an Optima Pentium D desktop computer (Optima Electronic Packaging Systems, Lawrenceville, GA, USA) and Sennheiser HD215 circumaural headphones. The headphones were connected to the headphone socket of the PC via a Buddy 6G USB soundcard. The sensitivity of the soundcard was automatically set to a pre-determined level by the LiSN-S software in order to achieve pre-designated signal levels, alleviating the need for daily calibration.<sup>11</sup> At this preset level, the combined distracters at  $0^\circ$  had a long-term root mean square (RMS) level of 55 dB SPL as measured in a Brüel and Kjær type 4153 artificial ear attached to a Brüel and Kjær sound level meter, model 2231. The LiSN-S software creates a three-dimensional auditory environment under headphones by pre-synthesizing the speech stimuli with HRTFs. Target sentences are perceived as coming from directly in front of the listener ( $0^\circ$  azimuth). The distracter speech, in the form of looped children's stories, varies according to either their perceived spatial location ( $0^\circ$  vs + and  $-90^\circ$  azimuth), the vocal identity of the speaker/s of the stories (same as, or different from, the speaker of the target sentences), or both these parameters. The target sentences are initially presented at a level of 62 dB SPL. The distracter stories are presented at a constant level of 55 dB SPL (for the combined level of the two competing talkers). The target and competing signals are presented to both ears simultaneously. The listener's task was to repeat back to the examiner the words heard in each target sentence. Up to 30 sentences were presented in each of the four conditions of distracter location and voice: same voice at  $0^\circ$ , same voice at  $\pm 90^\circ$ , different voices at  $0^\circ$  and different voices at  $\pm 90^\circ$ . The SNR was adjusted adaptively in each condition by varying the target level. The adaptive procedure is performed automatically by the software when the examiner enters the number of words in each sentence that is correctly identified by the participant. The SNR was decreased by 2 dB if a listener scored more than 50 percent of words in a sentence correct, and increased by 2 dB if he or she scored less than 50 percent of words correct. The SNR was not adjusted if a response of exactly 50 percent correct was recorded (for example, 3 out of 6 words correctly identified). A minimum of five sentences were provided as practice, however, practice continued until one upward reversal in performance (*i.e.*, the sentence score dropped below 50 percent of words correct) was recorded. Testing ceased in a particular condition when the listener had either (i) completed the entire 30 sentences in any one condition; or (ii) 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. A participant's speech reception threshold was calculated in each condition as the average SNR recorded for the scored sentences. The procedure takes approximately 15-20 min to complete. Performance on the LiSN-S is evaluated on the *same voice*  $0^\circ$  condition (low cue SRT); the differ-



ent voices  $\pm 90^\circ$  condition (high cue SRT), as well as on three difference scores - talker, spatial and total advantage. These advantage measures represent the benefit in decibels (dB) gained when 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. The LiSN-S high cue SRT, spatial advantage and total advantage measures - where the target and distracter stimuli are spatially separated - specifically evaluate binaural processing ability, and as such analyze target behaviors. The LiSN-S low cue SRT and talker advantage measures - where the target and distracter stimuli emanate from the same direction - analyze control behaviors.

(iv) Self-report questionnaire: Listening Inventory for Education - Student Appraisal of Listening Difficulty (LIFE).<sup>26</sup> The questionnaire is comprised of 15 different items, each describing an educational situation. For example, item 4 asks: *The teacher is talking. Other kids are making noise in the hall. Tell me how well you can hear the words the teacher is saying.* The LIFE can be used with either a three - or five-point response scale. To ensure that task comprehension was not an issue for the younger children in the sample the three-point response scale was used. The three response options were *easy* (score=10), *medium* (score=5), *hard* (score=0).

(v) Parent questionnaire: Fisher's Auditory Problems Checklist.<sup>27</sup> The checklist is comprised of 25 questions designed to screen for auditory processing disorders. For example, item 4 reads: *Does not listen carefully to directions - often necessary to repeat instructions.* The observer is asked to place a check mark before each item that is considered to be a concern. A four percent credit is given for each item that is not checked.

(vi) Teacher questionnaire: Listening Inventory for Education - Teacher Appraisal of Listening Difficulty (LIFE).<sup>28</sup> A measure of post-intervention listening difficulty comprised of 16 items, each describing an educational situation. For example, item 4 asks: *Attention has improved when listening to directions presented to whole class.* Item 16 originally read: *Based on my knowledge and observations I believe that the amplification system is beneficial to the student's overall attention.* The words *amplification system* were changed to *auditory training software* for the present study. A five-point response scale is used from +2 (Agree) to -2 (Disagree). All items are added together to produce a composite score on an incremental scale from -35 to +35. A score of 35 is considered to represent strong positive change and that the intervention was highly beneficial. A score of 0 is considered to represent no change, and -35 suggests the intervention was highly unfavorable.

## Methods: auditory training

As both the LiSN & Learn and the Earobics software packages are intended for home use, the auditory training for both the groups was carried out in the participant's own home under the supervision of his or her parent/s. Both the LiSN & Learn software and the Earobics software were installed at home by the parent. Participants returned their software at the post-training assessment. For ethical considerations, participants in the Earobics group were offered the LiSN & Learn software following training and *vice versa*.

Participants who were randomly assigned to the LiSN & Learn group were instructed to play two games per day, for five days each week, until they had completed 120 games (equating to 60 training sessions). Each training session took approximately 15 to 20 min to complete. The length of the training session varied depending on the individual (young children tend to take a little longer and children may perform more quickly as they become more used to using the software). In order to equalize effort expended between groups, the participants who were randomly allocated to the Earobics group were instructed to use the software for 15 to 20 min each day, for five days per week. The children were instructed to complete as many games as possible in that time-

frame. The speech stimuli used in LiSN & Learn software is adapted for use with Sennheiser HD215 headphones<sup>2</sup> which are provided with the software. The Earobics software can be used with or without headphones, however the children in this group were provided with Sennheiser HD215 headphones to ensure that training conditions were constant between groups. Specific details of the software packages follow.

(i) LiSN & Learn auditory training software: Four training games were used - Listening House, Listening Ladder, Answer Alley and Goal Game. The four games differ only in respect to the animations (*e.g.*, the game is set in a bowling alley in Answer Alley and a soccer field for Goal Game) and the auditory stimuli used to provide feedback and positive reinforcement. The target and distracter stimuli and the response protocol are identical for all games. The LiSN & Learn was administered using a PC. The stimuli are presented through Sennheiser HD215 headphones, which are connected to the headphone socket of the PC via a Buddy 6G USB soundcard. As for the LiSN-S, the sensitivity of the soundcard was automatically set to a pre-determined level by the LiSN & Learn software, negating the need for daily calibration. At this pre-set level, the combined distracters at  $\pm 90^\circ$  had a long-term RMS level of 55 SPL, as measured through the left and right ear headphones to a Brüel and Kjær type 4153 artificial ear using a flat plate adaptor attached to a Brüel and Kjær sound level meter, model 2231. All signal-to-noise ratios were defined relative to the level of the combined distracter stories.<sup>2</sup>

In all games the child's task was to identify a word from a target sentence presented in background noise consisting of two looped distracter stories.<sup>2</sup> The target sentences emanated from  $0^\circ$  azimuth and were presented initially at 62 dB SPL. The distracter stories, emanating from + and -  $90^\circ$  azimuth were presented simultaneously at a constant level of 55 dB SPL. All speech stimuli are produced by the same female speaker so the listener must predominantly rely on processing of spatial cues to separate the target sentence from the distracter speech. A 1000 Hz tone burst, 200 ms in length, is presented before each sentence to alert the child that a sentence will be presented. Immediately following the presentation of the sentence four images and a question mark appear at the top of the screen (Figure 2). In a five-alternative, unforced-choice, adaptive method, the child uses the computer mouse to select one of the images that matches a word from the sentence he or she had just heard (or make an *unsure* response by selecting an image of a question mark). A weighted up-down adaptive procedure is used to adjust the signal level of the target based on participant's



Figure 2. Example of LiSN & Learn screen.

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* (question mark) response is made. If the child selects the *unsure* response for a particular sentence, that sentence is repeated at the higher SNR. However if the child selects the *unsure* response again for that same sentence, a different sentence is presented at a higher SNR. If the child selects a correct image, a short congratulatory sound is presented (such as a bell). If the child selects an incorrect or unsure image a short negative sound is presented (such as a buzzer). Different sounds and animations are used as feedback for each of the four games.

A minimum of five sentences is provided as practice; however practice continues until one upward reversal in performance (that is, the first incorrect or unsure response that occurs after a correct response) has been recorded. The SNR decreases in 3 dB steps during the practice period. 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 items near the start of the game where the target level has not yet started traversing the region containing the true underlying threshold. Data and results were recorded automatically by the software. The participants' parents were requested to generate progress reports in the form of an Excel spreadsheet by selecting the report generation button in the progress report area. Parents were required to email these reports to the research audiologist on a weekly basis. The research audiologist checked the reports each week to ensure that the child was using the software as required by the study protocols. Positive reinforcement was provided.

(ii) Earobics Home Version: An educational software program for teaching auditory and phonological awareness skills. The software was administered using a PC and Sennheiser HD215 headphones. The participants were instructed to set output levels at a comfortable listening level. Four children used the Step 2 version of the software, which is suitable for children aged 7 to 11 years. There are five games in this version, of which four can be completed, on average, in the time allocated each day. The children were instructed to rotate through all five games. *Paint by Penguin* trains counting, sequencing of speech sounds and creating new words by deleting, adding, subtracting and rearranging sounds; *Duck Luck* trains rhyming, vowels, vowel digraphs, diphthongs, word rhymes, consonants, digraphs and blends; *Pesky Parrot* trains blending of syllables and speech sounds into words; *Calling All Engines* trains auditory memory, listening and phonics skills; and *Hippo Hoops* trains recognizing sounds and identifying positions of sounds within words. One child who was 6 years of age at the time of their pre-training assessment trained with the Step 1 version of the software. There are six games in the Step 1 version, all of which can be completed in the time allocated each day. *Caterpillar Connection* trains syllable and phoneme synthesis, auditory attention and memory; *Basket Full of Eggs* trains auditory discrimination skills; *C.C. Coal Car Train* trains long vowels, short vowels and consonant sounds; *Rap-A-Tap-Tap* trains syllable and phoneme segmentation; *Rhyme Time* trains rhyming and *Karloon's Balloons* trains auditory memory skills. Data and results were recorded automatically by the software. At the end of each week the participant's parent took a screen shot of the software's Progress Chart and emailed it to the research audiologist. The research audiologist checked the reports each week to ensure that the child was progressing through the levels of the various games in accordance with the study protocol. Positive reinforcement was provided.

## Statistical analyses

Analyses were performed with Statistica 7.1. A randomized controlled trial with ten participants was considered sufficient because of the precision and known psychometric properties of the LiSN-S outcome measures available, and because the availability of non-spatialized test conditions that, based on previous research,<sup>2</sup> were not expected

to be affected by the training. This latter feature enabled each child to also act as his or her own control. Eta-squared ( $\eta^2$ ) values are a measure of effect size, and represent the proportion of variance in a dependent variable (e.g., LiSN-S score) accounted for by a factor (e.g., training).<sup>29</sup> As evidenced by the effect sizes, the sample size proved to be sufficiently large. For most analyses, *a priori* planned comparisons were conducted to determine whether improvements occurred on the various assessment measures following training.

## Results

### Training software

Figure 3 illustrates the average improvement in SRT in dB achieved by the five children in the LiSN & Learn group over the course of training. The solid blue line represents the average SRT for game 1 through to game 120. The red line shows a five-day running average. For the five participants in the LiSN & Learn group, their SRT on the LiSN & Learn improved on average by 10.9 dB over the course of training, increasing from -10.4 dB to -21.3 dB.

Improvement on the Earobics Home Version software is measured in levels for each game. Each game varies in difficulty and in the amount of time required to move up a level. Therefore the number of levels achieved varies for each game over the course of training. The four participants in the Earobics group who undertook the Step 2 training improved on average by 4.3 levels on *Paint by Penguin*, 5 levels on *Duck Luck*, 15 levels on *Pesky Parrot*, 7.3 levels on *Calling All Engines*, and 3 levels on *Hippo Hoops*. The participant who undertook the Step 1 training improved by 7 levels on *Caterpillar Connection*, 2 levels on *Basket Full of Eggs*, 2 levels on *C.C. Coal Car Train*, 8 levels on *Rap-A-Tap-Tap*, 11 levels on *Rhyme Time*, and 2 levels on *Karloon's Balloons*.

### Listening in Spatialized Noise – Sentences test

Table 1 documents the mean scores and standard deviations pre- and post-training on the LiSN-S SRT and advantage measures for the LiSN & Learn and Earobics groups. Mean scores are calculated from the indi-

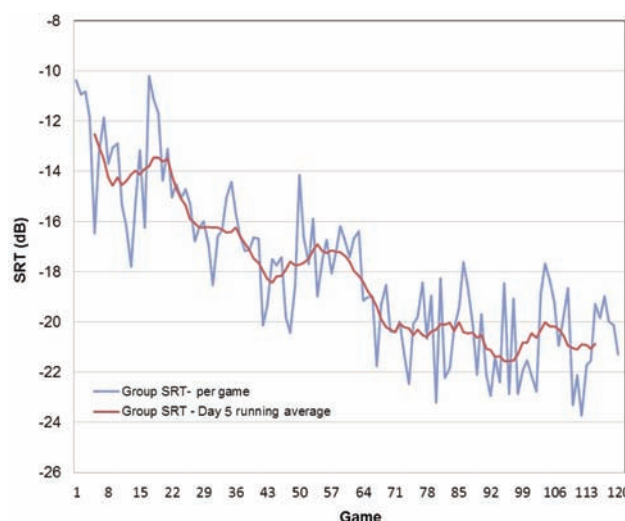


Figure 3. LiSN & Learn results from the start until the end of training, averaged across the five children in the study. Performance is measured as the speech reception threshold (SRT) in dB achieved over the 120 games played.

vidual standard scores (*i.e.*, z-scores) for the participants in each group. Performance as a function of training is also illustrated in Figure 4. On the LiSN-S measures where the target speech was spatially separated from the distracters planned comparisons revealed that there was a significant improvement between pre- and post-training performance for the LiSN & Learn group. For the high cue SRT,  $F(1, 4)=23.669$ ,  $P=0.008$ ,  $\eta^2=0.855$ . For the spatial advantage measure,  $F(1, 4)=82.118$ ,  $P=0.008$ ,  $\eta^2=0.954$ . For total advantage measure,  $F(1, 4)=12.140$ ,  $P=0.025$ ,  $\eta^2=0.752$ . In contrast, there was no significant improvement on the spatially separated conditions of the LiSN-S for the Earobics group. For the high cue SRT,  $F(1, 4)=0.409$ ,  $P=0.557$ ,  $\eta^2=0.093$ . For spatial advantage,  $F(1, 4)=0.448$ ,  $P=0.540$ ,  $\eta^2=0.101$ . For total advantage,  $F(1, 4)=0.160$ ,  $P=0.709$ ,  $\eta^2=0.039$ .

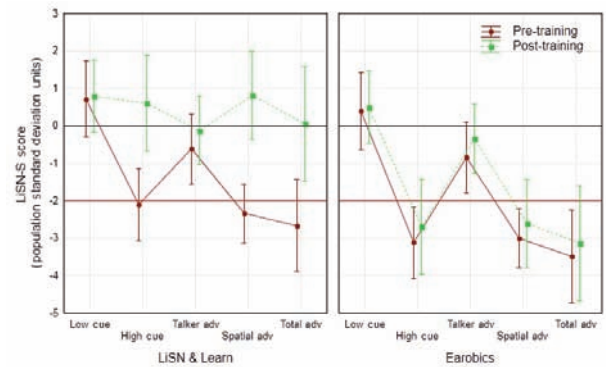
Further, there was no significant improvement found for either group post-training on the control conditions of the LiSN-S where the target and distracters all emanate from the same physical location ( $0^\circ$ ). For the LiSN & Learn group, low cue SRT was  $F(1, 4)=0.008$ ,  $P=0.933$ ,  $\eta^2=0.002$ ; talker advantage was  $F(1, 4)=1.824$ ,  $P=0.248$ ,  $\eta^2=0.313$ . For the Earobics group, low cue SRT was  $F(1, 4)=0.065$ ,  $P=0.811$ ,  $\eta^2=0.016$ ; talker advantage was  $F(1, 4)=0.341$ ,  $P=0.591$ ,  $\eta^2=0.079$ .

### Listening performance questionnaires

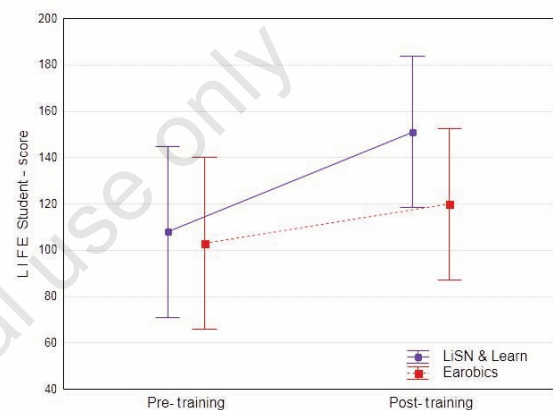
Table 1 documents the mean scores and standard deviations pre- and post-training on the self-report and parent questionnaires for the LiSN & Learn and Earobics groups, as well as post-intervention ratings of listening performance on the teacher questionnaire. Means and 95% confidence intervals for these measures are illustrated in Figures 5 to 7.

On the self-report questionnaire (LIFE - Student) 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 (LIFE - Teacher) showed a mean rating of listening performance following intervention of 15.8 for the LiSN & Learn group compared to 6.6 for the Earobics group (where a score of 0 represents no change in performance following intervention). For the LIFE - Student and LIFE-Teacher questionnaires, the differences in pre- and post-training ratings were not significantly different for either group.

The listening skills of children in the LiSN & Learn group improved



**Figure 4.** Pre- and post-training performance on the spatialized noise-sentences test speech reception threshold and advantage measures for the LiSN & Learn group compared with the Earobics group. Performance is expressed in population standard deviation units from the mean. Error bars represent 95 percent confidence intervals.



**Figure 5.** Pre- and post-training ratings of listening performance on the Listening Inventory for Education: Student Appraisal of Listening Difficulty (LIFE) questionnaire for the LiSN & Learn and Earobics groups. Error bars represent 95 percent confidence intervals.

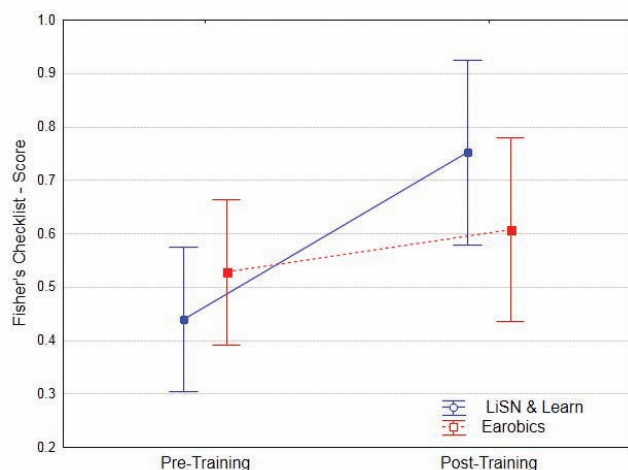
**Table 1.** Mean scores and standard deviations pre- and post- training on the various measures used to assess the ten children in the study. For the spatialized noise-sentences test means are calculated from the individual standard scores (or z-scores) for each of the participants. For the self-report, parent and teacher questionnaires the mean scores are calculated from the raw ratings.

Measure	Group	Pre-training		Post-training	
		Mean z-score	SD	Mean z-score	SD
Low cue SRT (SV0°)	LiSN & Learn	0.72	1.19	0.80	1.15
	Earobics	0.40	0.73	0.50	0.66
High cue SRT (DV90°)	LiSN & Learn	-2.10	0.44	0.60**	1.12
	Earobics	-3.12	1.24	-2.70	1.35
Talker advantage	LiSN & Learn	-0.62	0.38	-0.12	0.93
	Earobics	-0.84	1.23	-0.34	0.85
Spatial advantage	LiSN & Learn	-2.34	0.39	0.82**	1.01
	Earobics	-3.00	1.01	-2.60	1.25
Total advantage	LiSN & Learn	-2.66	0.48	0.06*	1.43
	Earobics	-3.48	1.63	-3.14	1.54
LIFE - Student	LiSN & Learn	108	43.53	151	26.79
	Earobics	103	25.85	120	35.88
Fishers checklist	LiSN & Learn	0.44	0.17	0.75**	0.14
	Earobics	0.53	0.07	0.61	0.19
LIFE - Teacher	LiSN & Learn	N/A	-	15.80	11.90
	Earobics	N/A	-	6.60	9.99

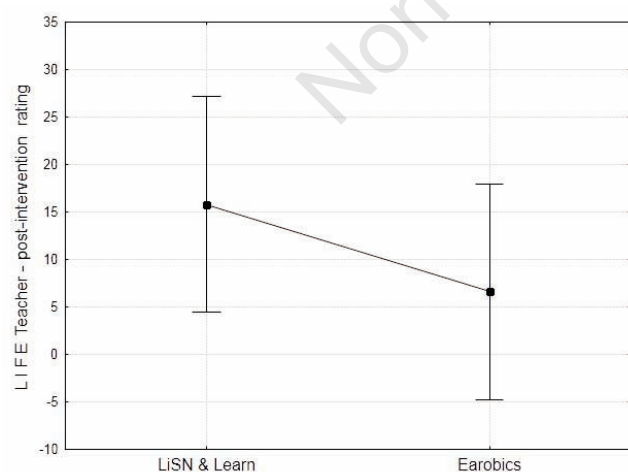
SD, standard deviation; SRT, speech reception threshold; LIFE, Listening Inventory for Education. \*Significant post-training improvements ( $P<0.05$ ); \*\*Post-training improvements ( $P<0.01$ ).



by 31% on the parent questionnaire (Fisher's Auditory Problems Checklist) following training, compared to 8% for the children in the Earobics group. The post-training improvement was significant for the LiSN & Learn group [ $F(1, 4)=16.267$ ,  $P=0.016$ ,  $\eta^2=0.803$ ], but not for the Earobics group [ $F(1, 4)=1.290$ ,  $P=0.319$ ,  $\eta^2=0.244$ ]. A one-sided  $t$ -test for independent groups indicated that the 31% increase in score for the LiSN & Learn group was significantly larger than the 8% increase in score for the Earobics group ( $t_8=2.22$ ,  $P=0.028$ ).



**Figure 6.** Pre- and post-training ratings of listening performance on the Fisher's Auditory Performance Checklist for the LiSN & Learn and Earobics groups. Error bars represent 95 percent confidence intervals.



**Figure 7.** Ratings of benefit of intervention on the Listening Inventory for Education: Teacher Appraisal of Listening Difficulty (LIFE) questionnaire for the LiSN & Learn and Earobics groups. Error bars represent 95 percent confidence intervals.

## Conclusions

The present study demonstrates the value of deficit-specific remediation for auditory processing disorders. Previous research had shown that the LiSN & Learn auditory training software can remediate SPD in children as young as six years of age.<sup>2</sup> The aim of the present study was to further examine the efficacy of the LiSN & Learn and to determine whether the improvements in ability to understand speech in noise following training were not simply related to exposure to auditory training in general, but were specific to the use of spatialized auditory stimuli and the adaptive protocols utilized in the LiSN & Learn software. Using a randomized blinded controlled design, children with SPD trained with either the LiSN & Learn or Earobics Home Version software. It was found that only the LiSN & Learn group showed significant improvements on the spatially separated conditions of the LiSN-S post-training. As noted in the introduction section, it was hypothesized that there would be no difference between the experimental and control groups on the various questionnaires. We postulated that whereas the experimental group may show improvements in listening skills due to the reversal of SPD, it was possible that the children training with the Earobics software, and their parents and teachers, may notice improvements in auditory processing associated with changes in non-deficit specific skills such as auditory attention or closure. The results from the present study showed, however, that the LiSN & Learn group outperformed the Earobics group in respect to post-training listening ability. The degree of positive change on the LIFE - Student, Fisher's Auditory Performance Checklist, and the LIFE - Teacher questionnaires was greater for the LiSN & Learn group than the Earobics group for all three measures, the improvement being significant for the Fisher's checklist. Although it can be said that there are benefits in undertaking any type of auditory training, the results of this study show that when the child's difficulties arise from a specific auditory deficit, deficit-specific remediation appears to be more beneficial in addressing generalized listening behaviors than non-deficit specific management options. Further, there may be longer-term consequences of administering remediation that is non-specific to the diagnosed auditory processing issue. One could theorize that should the underlying deficit remain unaddressed, the child will need to divert cognitive resources to compensatory strategies, such as auditory closure, leaving fewer resources to direct towards either auditory processing or dealing with the educational content being discussed in the classroom. In this scenario, issues - such as auditory fatigue - resulting from the primary deficit, will continue to impact on the child's functional learning capacity. It should be noted that despite the benefits reported following LiSN & Learn training, two children withdrew from the LiSN & Learn group due to non-compliance with the training protocol. In comparison to the Earobics software, which has many different tasks, the LiSN & Learn program trains one specific skill, and even though the graphical user interfaces for each game are different, the repetitive nature of the task may be less engaging for some children than for other auditory training packages. To address the potential motivational issues associated with a repetitive training task, the software was upgraded at the conclusion of this study to include a supplementary training game (Space Maze), additional rewards (such as non-training games) and an avatar, or *buddy* for the child to personalize who presents information to the child throughout the training sessions. The objective results in this experiment were very marked. Spatial advantage improved significantly following training for all five children in the LiSN & Learn group, and for none of the five children in the control group. The sample size is, however, small for a randomized controlled trial. A larger randomized controlled trial would be needed before we could be confident that the treatment will be effective for every child with spatial processing disorder. In conclusion, based on the results of the blinded randomized con-

trolled study, we conclude that LiSN & Learn training improved binaural processing ability in children with SPD, enhancing their ability to understand speech in noise, and that the results are specific to the LiSN & Learn training protocol.

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