# Listening in Spatialized Noise- Sentences Test (LiSN-S): Normative and retest reliability data for adolescents and adults up to 60 years of age

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**Disclosure:**

The test described in this paper is distributed under licensed by Phonak Communications AG. Financial returns from the sale of this product benefit Dr Cameron and the National Acoustic Laboratories. This outcome has in no way influenced the research reported in this paper.

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## ABSTRACT

**Background:** The Australian version of the Listening in Spatialized Noise – Sentences test (LISN-S; Cameron & Dillon, 2009) was originally developed to assess auditory stream segregation skills in children aged 6 to 11 years with suspected central auditory processing disorder (CAPD). The LISN-S creates a three-dimensional auditory environment under headphones. A simple repetition-response protocol is used to assess a listener's speech reception threshold (SRT) for target sentences presented in competing speech maskers. Performance is measured as the improvement in SRT in dB gained when either pitch, spatial, or both pitch and spatial cues are incorporated in the maskers.

**Purpose:** To collect additional normative data on the Australian LiSN-S for adolescents and adults up to 60 years of age; to analyse the effects of age on LiSN-S performance; to examine retest reliability in the older population; and to extrapolate findings from the Australian data so that the North American version of the test (NA LiSN-S) can also be used clinically with older adults.

**Research Design:** In a descriptive design, normative and test-retest reliability data were collected from adolescents and adults and combined with previously published data from Australian children aged 6 to 11 years.

**Study Sample:** One hundred and thirty-two participants with normal hearing aged 12 years, 0 month to 60 years, 7 months, took part in the normative data study. Fifty-five participants returned between two and four months after the initial assessment for retesting.

**Results:** ANOVA revealed a significant effect of age on LiSN-S performance ($p < 0.01$ for all LiSN-S measures, $\eta_p^2$ ranging from 0.16 to 0.54). On the low and high cue SRT measures, planned contrasts revealed significant differences between adults and children aged 13 years and younger, as well as between 50-60 year olds and younger adults aged 18-29 years. Whereas there were significant differences between adults and children on the talker, spatial and total advantage measures, there were no significant differences in performance between adults aged 18-60 years. There was a small but significant improvement on retest ranging from 0.5 dB to 1.2 dB across the four LiSN-S test conditions ($p$ ranging from 0.01 to $<0.001$). However there was no significant difference between test and retest on the advantage measures ($p$ ranging from 0.143 to 0.768). Test-retest differences across all LiSN-S measures were significantly correlated ($r$ ranging from 0.2 to 0.7 and $p = 0.023$ to $< 0.00000001$) and did not differ as a function of age ($p = 0.178$ to 0.980).

**Conclusions:** As there was no significant difference between adults aged 18-60 years on the LiSN-S talker, spatial and total advantage measures, it appears that the decline in ability to understand speech in noise experienced by 50-60 year olds is not related to their ability to use either spatial or pitch cues. This result suggests that some other factor/s contributes to the decline in speech perception in noise experienced by older adults that is both reported in the literature and was demonstrated in this study on the LiSN-S low and high cue SRT measures.

**Key words:** auditory stream segregation; central auditory processing disorder; spatial processing disorder.

**Abbreviations:** ANOVA = Analysis of Variance; CAPD = central auditory processing disorder; HpTF = headphone transfer function; HRTF = head related transfer function; LISN-S = Listening in Spatialized Noise – Sentences test; NA LISN-S = North American Listening in Spatialized Noise – Sentences test; SD = standard deviation; SNR = signal-to-noise ratio; SHL = spatial hearing loss; SPD = spatial processing disorder; SRT = speech reception threshold.

It has long been acknowledged that central auditory processing disorder (CAPD) is not restricted to children (Jerger et al, 1989). Therefore diagnostic tests for CAPD need to be valid and reliable for a large cross section of the population if they are to have good clinical utility. The following paper describes a study conducted to collect normative and test-retest reliability data from adolescents and adults for the Australian version of the Listening in Spatialized Noise – Sentences test (LISN-S; Cameron and Dillon, 2009). The LISN-S was originally developed to assess the skills involved in auditory stream segregation in children with suspected CAPD. Auditory streaming has been described as the ability of the brain to tease apart the cacophony of the sounds that arrive simultaneously at the ears during our everyday experience, and to form meaningful representations of the incoming acoustic information (Sussman et al, 1999). This process requires a mechanism for segregating the inputs into their original sources and the accurate identification of auditory cues such as the location of a sound source, or the pitch of a speaker's voice, play an integral role in the process of segregating the total stream of sound (Bregman, 1990).

A detailed description of the development and evaluation of the Australian and North American versions of the LiSN-S can be found in Cameron and Dillon, (2007a, 2007b, 2008a & 2008b), Cameron et al (2009) and Brown et al (2010). A brief overview follows.

The LISN-S is presented using a personal computer. Output levels are directly controlled by the software via an external USB soundcard. A three-dimensional auditory environment under headphones is created by synthesizing the speech stimuli with non-individualized head-related transfer functions (HRTFs). A simple repetition-response protocol is used to assess a listener's speech reception threshold (SRT) for target sentences presented in competing speech maskers (children's stories). Using HRTFs, the targets are made to appear as if they are coming from directly in front of the listener (0° azimuth) whereas the maskers vary according to either their perceived spatial location (0° vs. + and -90° azimuth simultaneously), the vocal identity of the speaker/s of the stories (same as, or different to, the speaker of the target sentences), or both. This test configuration results in four listening conditions: same voice at 0º (SV0 or low cue SRT); same voice at ±90º (SV90); different voices at 0º (DV0); and different voices at ±90º (DV90 or high cue SRT).

Performance on the LISN-S is evaluated on the low and high cue SRT, as well as on three “advantage” measures. These advantage measures represent the benefit in 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 minimal cues are present in the maskers (see Figure 1). By using relative measures of performance (i.e., difference scores) the influence of higher-order language, learning and communication skills on test performance is minimized. For example, as such skills affect both the SRT when the distracters are presented at 0°, and the SRT when they are spatially separated at ±90°, these skills will have minimal effect on the difference in dB between the SRTs in these two conditions. Thus, the differences that inevitably exist between individuals in such functions can be controlled for, allowing for clearer evaluation of their abilities to use spatial and voice cues to aid speech understanding.

It has been demonstrated that the LISN-S is sensitive to auditory stream segregation deficits in children with suspected CAPD whose primary difficulties in the classroom appear to be caused by poor listening behaviour (Cameron and Dillon, 2008a). These children performed significantly more poorly than controls *only* on the conditions of the LiSN-S 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, $p < 0.0001$). This result suggests that the children specifically exhibited a disorder termed by the authors as a spatial hearing loss (SHL), which is now referred to as a spatial processing disorder (SPD; Cameron and Dillon, in press). Normative and test-retest reliability data on the Australian LiSN-S currently exist for children aged 6 years, 0 months to 11 years, 11 months.

Brown et al (2010) collected normative data on the North American LiSN-S (NA LiSN-S) for participants aged 12 years, 0 months to 30 years, 3 months. These data were then combined with pre-existing normative data for children aged 6 years, 0 months to 11 years, 11 months on the NA LiSN-S and analysed. The authors reported a trend of improved performance with increasing age for each measure of the LiSN-S. Planned contrasts revealed that performance on the low cue SRT measure reached adult-like levels at 13 years, talker and spatial advantage were adult-like from 14 years, total advantage had plateaued at 15 years, and performance on the high cue SRT measure reached adult-like level at 16 years. This trend for improved ability to understand speech in noise with increasing age is consistent with the findings of Picard and Bradley (2007) who reviewed 11 studies on the effects of noise on speech understanding by normally hearing children and young adults.

Gelfand et al (1988) examined the effect of age on speech reception in noise with normally hearing participants aged from 20 years to 70 years. The authors used the high-predictability sentences from the Speech Perception In Noise Test (SPIN; Kalikow et al, 1977) presented in 12 speaker babble in the free-field. The babble was presented either from the same loudspeaker as the sentences or from a second speaker at 90 degrees. They found a significant difference between the speech reception thresholds of participants aged 35 years and under and those aged 55 years or over, with the younger group performing significantly better. Gelfand et al (1988) also investigated whether the ability to use perceived spatial location cues was affected by age. The results of their analyses indicated that there was no significant effect of age in normal hearers. This suggests that, despite maintaining the ability to process spatial cues, older adults still require an increased signal-to-noise ratio (SNR) to understand speech.

In order to investigate auditory stream segregation skills in older children and adults on the Australian LiSN-S, it is necessary to collect additional normative and test-retest reliability data. It was hypothesized that performance on the LiSN-S measures up to the age of 30 will mimic the findings of Brown et al (2010). However, given the findings of Gelfand et al (1988), it was predicted that performance on the high-cue and low-cue SRT measures would begin to deteriorate once people reach their fifties while performance on the advantage measures would be maintained.

This paper describes the collection and analysis of such data from participants aged 12 to 60 years of age. These data were combined with those for children aged 6 to 11 years (as documented in Cameron & Dillon, 2007a & 2007b). Australian LiSN-S cut-off scores and critical difference scores (used to determine whether a genuine improvement in performance on the LiSN-S has been achieved following some period of management or remediation) were recalculated from the combined child, adolescent and adult data and documented in this paper. Based on the findings from this study, the North American LiSN-S cut-off scores were extrapolated for adults aged 31 to 60 years.

## METHOD

Approval to conduct this study was obtained from the Australian Hearing Ethics Committee.

### Participants

Data for the current study were collected from a total of 132 participants, comprising 36 adolescents (aged 12 years, 0 months to 17 years, 5 months) and from 96 adults (aged 18 years, 1 month to 60 years, 7 months). There were 51 males and 81 females. Full participant details are provided in Table 1. Fifty-five participants (aged 12 years, 4 months to 60 years, 5 months) returned between two and four months after the initial assessment for retesting. Participants were recruited from friends and family of staff at the National Acoustic

Laboratories, as well as through community noticeboards and letter box drops. The participants were included in the study if they had Australian-English as a first language, no history of hearing disorders, and no reported learning or attention disorders. On the day of testing all participants had pure tone thresholds of ≤ 15 dB HL at 500 to 4000 Hz, and ≤ 20 dB HL at 250 and 8000 Hz, as well as Type A tympanograms. Participants were paid $20 to cover travel expenses to and from the test site.

**Design and Procedure**

Testing was carried out in a sound-proof booth suitable for testing hearing thresholds at either the National Acoustic Laboratories or the Australian Hearing Centre at Mt Gravatt in Queensland between 8 am and 6 pm.

**Materials**

The LISN-S stimuli were administered using a PC and Sennheiser HD215 headphones. The headphones were connected to the headphone socket of the PC via a Phonak branded Buddy 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. As described in Cameron et al (2009) and Brown et al (2010), this alleviated the need for daily calibration. At this pre-set level, the combined distracters at 0˚ had a long-term rms level of 55 SPL as measured in a Brüel and Kjær type 4153 artificial ear.

Target sentences were initially presented at a level of 62 dB SPL. Competing children's stories, looped during playback, were presented at a constant level of 55 dB SPL (for the combined level of the two competing talkers). The target and competing signals were presented to both ears simultaneously. The listener's task was to repeat the words heard in each target sentence. A 1000 Hz 200 ms tone burst was presented before each sentence to alert the listener that a sentence would be presented.  A silent gap of 500 ms separated the tone burst from the onset of the sentence.  The tone burst was presented at a constant level of 55 dB SPL.  The instructions provided to each participant are detailed in Cameron et al (2009).  Up to 30 sentences were presented in each of the four conditions of distracter location and voice.

The SNR was adjusted adaptively for each condition by varying the target level to determine each participant's SRT.  The SNR was decreased by 2 dB if a listener scored more than 50 percent of the words correct, and increased by 2 dB if he or she scored less than 50 percent of the 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).  All words in each sentence were scored individually; including the definite article "the" and the indefinite articles "a" and "an".  A minimum of five sentences 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 (a) completed the entire 30 sentences in any one condition; or (b) completed the practice sentences plus a minimum of a further 17 scored sentences, and their standard error, calculated automatically in real time over the scored sentences, was less than 1 dB.  The presentation order of the LISN-S conditions was consistent with the recommendations made by Cameron and Dillon (2007) and was as follows: DV90º, SV90º, DV0º and SV0º.

## RESULTS

Where appropriate in the following analyses, data from the 132 participants aged 12 to adult from the present study were combined with the normative data from the 70 children aged 6 to 11 published in Cameron and Dillon (2007a) in order to ascertain the effects of age on Australian LiSN-S performance, and to calculate revised Australian and NA LiSN-S cut-off scores. Data from the 55 adolescents and adults who took part in the present test-retest reliability study were also combined with the data from the 40 children published in Cameron and Dillon (2007b) to assess test-retest reliability and calculate revised one-sided critical difference scores applicable for ages 6 to 60. Analyses were performed with Statistica 7.1. For the purposes of this study, the term "children" was used to define participants aged 6 to 17 years; "young adults" was used to define participants aged 18 years to 29 years; and "older adults" was used to define participants aged 30 to 60 years.

**Effect of Age on Australian LiSN-S Performance Measures**

The mean SRT and advantage measures in the normative data study are shown in Figure 2 (a) to (e). There was a trend of decreasing SRT, and increasing advantage, as age increased (6 to young adult). However, whereas the talker, spatial and total advantage measure scores remained stable across adulthood (to age 60), older adults showed declining ability to understand speech in noise, as shown by the results on the LiSN-S SRT measures. Separate tests of analysis of variance (ANOVA) were performed to determine the effect of age group on the performance measures. As for previous analyses (Cameron & Dillon, 2007a, 2007b, Cameron et al, 2009, Brown et al, 2010), the alpha level of 0.05 was multiplied by 4/5 to give an adjusted level of 0.04 to avoid inflating the Type I error rate. For planned comparisons, data from young adults aged 18 to 29 years were grouped and compared to those for children aged 6 to 17 years (as in Brown et al, 2010) and to those for older adults aged from 30 to 60 years.

For the low cue SRT there was a significant main effect of age, $F(14, 187) = 6.746$, $p < 0.0000001$, $\eta_p^2 = 0.34$. Planned comparisons revealed significant differences between young adults and children 13 years and younger. There were also significant differences between the younger adults and the 50-60 year-olds. There was a significant main effect of age for the high cue SRT, $F(14, 187) = 15.35$, $p < 0.0001$, $\eta_p^2 = 0.54$. Planned comparisons revealed significant differences between young adults and children 13 years and younger, and between the young adults and older adults aged 50 to 60 years.

There was a significant main effect of age for the talker advantage measure, $F(14, 187) = 7.019$, $p < 0.0000001$, $\eta_p^2 = 0.35$. Planned comparisons revealed significant differences between both young and older adults and children 13 years and younger. A significant main effect of age was also found for the spatial advantage measure, $F(14, 187) = 3.459$, $p = 0.00005$, $\eta_p^2 = 0.21$. Planned comparisons revealed significant differences between young and older adults and children 9 years and younger. Finally, there was a significant main effect of age for the total advantage measure, $F(14, 187) = 2.51$, $p = 0.003$, $\eta_p^2 = 0.16$. Planned comparisons revealed significant differences between young and older adults and children 7 years and younger, although the difference between the adults and the 9 year-olds nearly reached significance ($p = 0.056$).

## Gender Effects

An analysis was conducted to investigate gender effects across age groups. Mean scores and standard deviations (SDs) for the 125 females and 77 males on the various LiSN-S SRT and advantage measures are provided in Table 2, along with the results of ANOVAs which were performed with each LiSN-S measure as the dependant variable, a fixed factor of gender, and age as a covariate. There was no significant effect of gender for any LiSN-S measure (p ranging from 0.661 to 0.910).

**Regression Analysis and LiSN-S Cut-Off Scores**

The LiSN-S cut-off scores, calculated as two SDs below the mean, represent the level below which performance on the LiSN-S is considered to be outside normal limits. As a strong trend of improved performance with increasing age was found for children aged 6 to 11 years across LiSN-S measures, Cameron and Dillon (2007a) determined that the cut-off scores would need to be adjusted for age for each performance measure. When the data for the present study were combined with the data for the children aged 6 to 11 years, it was found, as previously noted, that performance deteriorated on the SRT measures for older adults. Thus, for the low and high cue SRT measures, a regression analysis utilising a piecewise linear function was fitted (with three pieces), with SRT as the independent variable and age as the dependent variable. For the talker, spatial and talker advantage measures a piecewise linear function was fitted (with two pieces). The cut-off scores were adjusted for age using the formulas, where "intercept" refers to the intercept of the first segment at age zero; "b" is the slope of the first segment; "c" is the SRT level of the second (horizontal) segment; "d" is the intercept the third segment would make if extended back to age zero; and "e" is the slope of the third segment.

1. Low and High Cue SRT: mean = max (intercept + b * age, max(c, d + e*age))

   Cut-off score = mean + (2 * SDs of the residuals from the age-corrected trend lines).

2. Talker, Spatial and Total Advantage: mean = min (intercept + b * age,c)

   Cut-off score = mean – (2 * SDs of the residuals from the age-corrected trend lines).

All regression data are presented in Table 3. Figure 3 (a) to (e) provides scatter plots of the regression analysis showing the individual data points and the age-dependent cut-off scores.

**Derivation of cut-off scores for the North American LiSN-S (NA LiSN-S)**

The NA LiSN-S (Cameron & Dillon, 2009) normative data were derived from 192 participants aged 6 to 30 years, taken from the combined studies of Cameron et al, 2009 and Brown et al, 2010. The cut-off scores for individuals aged 6 to 30 years are given in Brown et al (2010). As there was no effect of age for adults on the LiSN-S talker, spatial and total advantage measures found during the present Australian study, the current NA LiSN-S cut-off scores can be used for the advantage measures for adults aged up to 60 years. However, to control for the effect of age for older adults found on the Australian low- and high-cue SRT measures, the NA LiSN-S cut-off score formulas for these measures have been adjusted so that individuals aged up to 60 years can be assessed. To this end, it is assumed that the effect of greater age on LiSN-S performance commences for North Americans at the same age and at the same rate as observed for Australians. As such, the NA LiSN-S low- and high cue SRT measure formulas were adjusted by applying the Australian e-value (slope) in the formula (as shown in Table 3). The d-value (intercept) that determines the age at which performance begins to decline in older adults in the Australian data ($d_{Aus}$) was used to derive a d-value for the NA LiSN-S ($d_{NA}$). The formula $d_{NA} = (d_{Aus}) + c_{NA} - c_{Aus}$ was used. The NA LiSN-S d values for the low and high cue SRT measures are -3.08 and -19.57, respectively.

**Test-Retest Paired Comparisons**

The mean scores and SDs for the various LiSN-S conditions and the advantage measures derived from the various conditions for both the test and retest are provided in Table 4. Differences in scores in dB between test and retest, as well as the t- and p-values of paired-samples t-tests are provided. Differences were in the direction representing an improvement in performance, except for the spatial and total advantage measures, for which the (non-significant) paired difference was only 0.3 dB and 0.1 dB, respectively. Averaged across all participants, the maximum improvement in performance on retest was 1.2 dB for the DV0˚ condition. The minimum improvement was 0.1 dB for the total advantage condition. Improvements in performance (ranging from 0.5 dB to 1.2 dB) were significant between test and retest on all LiSN-S conditions (SV0˚, SV90˚, DV0˚ and DV90˚). However, there were no significant differences between test and retest scores for any of the LiSN-S advantage measures (talker, spatial or total).

**Effect of Age on LiSN-S Test-Retest Performance**

Figure 4 (a) to (e) depicts the mean test and retest scores for each of the LiSN-S SRT and advantage measures as a function of age (6 to adult). An ANOVA was performed on each LISN-S measure, with test and retest as a repeated-measures factor, and age group as a between-participants factor, to determine whether test-retest differences differed with age. There was no significant interaction of test session and age for the low-cue SRT, $F(14,80) = 0.36$, $p = 0.980$; the high-cue SRT, $F(14,80) = 1.21$, $p = 0.281$; talker advantage measure, $F(14,80) = 1.23$, $p = 0.270$; spatial advantage, $F(14,80) = 1.39$, $p = 0.178$; or total advantage, $F(14,80) = 1.21$, $p = 0.279$.

**Test-Retest Correlation Analysis**

A Pearson product-moment correlation analysis between test and retest scores was performed for each of the LiSN-S SRT and advantage measures. All correlations were significant. For the low-cue SRT, $r = 0.6$, $p < 0.00000001$; high-cue SRT, $r = 0.7$, $p < 0.0001$; talker advantage, $r = 0.5$, $p < 0.000001$; spatial advantage, $r = 0.2$, $p = 0.023$; and for total advantage, $r = 0.4$, $p < 0.0001$. Scatter plots in Figure 5 (a) to (e) show the correlation of test versus retest scores for each of the LiSN-S SRT and advantage measures.

**Test-Retest Correction Factors**

Table 5 displays the calculations of the one-sided critical differences required to determine whether an individual has improved on the LiSN-S following remediation or compensation, taking the mean test-retest differences into account. The 95 percent one-sided confidence limit for a normal distribution lies 1.64 standard deviations from the mean. Thus, for the increase in an individual advantage measure score to be significant at the 95 percent confidence interval level, the score must increase by 1.64 x SD of the test-retest difference, plus the mean test-retest difference. Similarly, for a significant improvement on an SRT measure score to have occurred, the magnitude of the decrease must be greater than 1.64 x SD of the test-retest difference, plus the mean test-retest difference. Across measures, the SDs of paired test-retest differences were similar for adolescents, adults and children. Critical difference measures, including the correction factor, ranged from 3.3 dB on the total advantage measure to 4.7 dB on the talker advantage measure.

## DISCUSSION

As noted in the literature (Brown et al, 2010; Gelfand et al, 1988) the ability to understand speech in noise deteriorates in older adults. In line with published literature, the performance of normally-hearing adults on the LiSN-S high- and low cue SRT measures - which develops with age and becomes adult-like by age 14 - declines significantly by age 60. Further, as reported by Brown et al (2010), the ability to use spatial cues, pitch cues, or a combination of both, to understand speech in noise remains constant as age increases up to 30 years. Gelfand et al (1988) also found that the ability to use perceived spatial location cues was unaffected by age. Extending the work of Brown et al (2010), in the present study, we have found that even up to age 60 the ability to use spatial and pitch cues to discriminate speech from noise does not decline significantly in normally-hearing individuals,. This indicates that the significant decline in performance on the low- and high cue SRT measures in normally-hearing older adults is related to some other factor or factors.

The Australian LiSN-S data collected in the present study also confirms the findings of Brown et al (2010) on the North American LiSN-S in that despite the fact that the ability to use pitch cues does not reach adult-like levels until about 14 years of age, the performance on the total advantage measure of the LiSN-S reaches adult-like levels by around 9 years of age, around the same age that adult-like levels are reached on the spatial advantage measure. As concluded by Brown et al (2010), this would suggest that the ability to use spatial cues is the dominant factor employed by younger children when confronted with the task of processing speech in noisy environments. Also, given the fact that there is only a 1.3 dB difference between mean spatial advantage and mean total advantage across age groups for both the Australian and North American normative data, it appears that the reliance on spatial cues to differentiate speech in noise continues into adulthood.

The Australian LiSN-S cut-off scores as published in Cameron and Dillon (2007a) for children 6 to 11 years of age were recalculated based on the additional data collected from the present study, so that the LiSN-S can now be used for individuals aged from 6 to 60 years. The cut-off scores, calculated as two SDs below the mean, represent the level below which performance on the LiSN-S is considered to be outside normal limits. The cut-off scores for the low- and high cue SRT measures were calculated from a regression analysis utilising a piecewise linear function fitted with three pieces, with SRT as the independent variable and age as the dependent variable. The three-segment fit takes into account the gradual improvement in LiSN-S performance with increasing age, the plateau effect, and the decline in performance in older adulthood. For the talker, spatial and talker advantage measures a piecewise linear function fitted with two pieces was utilized, as performance remains stable across age groups once adult-like performance is reached. It is assumed that the effect of greater age on LiSN-S performance commences for North Americans at the same age and deteriorates at the same rate as observed for Australians. Based on the data collected from the current study the NA LiSN-S low and high cue SRT measure formulas were adjusted by applying the Australian e-value (slope) in the formula, and adjusting the d value (intercept) using the Australian data to derive a d value for the NA LiSN-S. Thus, from a clinical perspective, the present study has greatly extended the age range of individuals who can be assessed for CAPD for both the Australian and North American LiSN-S.

Finally, an examination of test-retest data has shown that whereas there is a very slight but significant test-retest improvement (of between 0.5 and 1.2 dB) across all age ranges on the four LiSN-S conditions, there was no significant difference between test and retest scores on the spatial, talker or total advantage measures, and correlations between test and retest were significant for all measures. The one-sided critical difference scores documented in Cameron and Dillon (2007b), which represent the differences required to determine whether an individual has improved on the LiSN-S following remediation or compensation taking the mean test-retest differences into account, were adjusted using the new test-retest data from the present study. This now allows the Australian critical difference scores to be used with both children and adults.

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**List of Figures**

**Figure 1.** 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.

**Figure 2.** Normative data for the 132 adolescents and adults in the current study and the 70 children in the Cameron and Dillon (2007a) study on the LiSN-S SRT (a and b) and advantage measures (c-e). Error bars represent the 95 percent confidence intervals from the mean (dots).

**Figure 3.** Scatterplots of the normative data for the 132 adolescents and adults in the current study and the 70 children in the Cameron and Dillon (2007a) study on the LiSN-S SRT (a and b) and advantage measures (c-e). Solid lines show the piecewise linear regression (mean values) and dashed lines show the cut-off scores two standard deviations from the mean.

**Figure 4.** Mean test and retest scores for each of the LISN-S SRT (a and b) and advantage measures (c to e), as a function of age. Circular filled symbols connected by solid lines represent the mean test scores. Square unfilled symbols connected by dashed lines represent the mean retest scores. Error bars represent the 95% confidence intervals from the mean. The

figure incorporates data from the 40 children from Cameron and Dillon (2007b) and the 55 adolescents and adults from the current study.

**Figure 5.** Scatter plots depicting correlation of test vs. retest scores for each of the LISN-S SRT (a and b) and advantage measures (c to e). Lines show the 95% confidence interval of the regression of retest scores on test scores. The figure incorporates data from the 40 children from Cameron and Dillon (2007b) and the 55 adolescents and adults from the current study.