Performance-intensity functions for normal-hearing adults and children using CASPA

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Abstract

Objectives—The Computer Aided Speech Perception Assessment (CASPA) is a clinical measure of speech recognition that uses ten-item, isophonemic word lists to derive performance-intensity (PI) functions for adult listeners. Because CASPA was developed for adults, the ability to obtain PI functions in children has not been directly evaluated. The current study sought to evaluate PI functions for adults and four age groups of children with normal hearing to compare speech recognition as a function of age using CASPA. Comparisons between age groups for scoring by words and phonemes correct were made to determine the relative benefits of available scoring methods in CASPA.

Design—Speech recognition using CASPA was completed with twelve adults and four age groups of children (5-6, 7-8, 9-10, and 11-12 year-olds), each with twelve participants. Results were scored by the percentage of words, phonemes, consonants and vowels correct. All participants had normal hearing and age-appropriate speech production skills.

Results—Adults had higher mean speech recognition scores than children in the 5-6 year-old and 7-8 year-old age groups when responses were scored by the percentage of words correct. However, only differences between the 5-6 year-olds and adults were statistically significant when responses were scored by the percentage of phonemes correct. Speech recognition scores decreased as a function of signal-to-noise ratio (SNR) for both children and adults. However, the magnitude of degradation at poorer SNRs did not vary between adults and children, suggesting that mean differences could not be explained by interference from noise.

Conclusions—Obtaining PI functions in noise using CASPA is feasible with children as young as 5 years-old. Statistically significant differences in speech recognition were observed between adults and the two youngest age groups of children when scored by the percentage of words correct. When results were scored by the percentage of phonemes correct, however, the only significant difference was between the youngest group of children and the adults. These results suggest that phoneme scoring may help to minimize differences between recognition scores between adults and children, since children may be more likely to provide responses that are phonemic approximations when words are outside their lexicon.

INTRODUCTION

Clinical speech recognition testing of children is complicated by factors beyond auditory sensitivity, including developmental differences in speech and language skills, cognition, memory and attention. As a result, performance on speech recognition tasks tends to be more variable for children than for adults. Clinicians attempt to limit such variability by using stimuli that are likely to be in a child’s lexicon, such as in the Phonetically Balanced Kindergarten
Several studies have attempted to quantify the contribution of linguistic knowledge on speech recognition differences between children and adults. Using speech materials that varied in lexical, syntactic, and semantic predictability, Nittrouer and Boothroyd (1990) evaluated the recognition of consonant-vowel-consonant (CVC) syllables and sentences for normal hearing children from 4½ – 6½ years of age in comparison to a group of young adults and older adults. Half of these stimuli were commonly occurring CVC words, while the other half were CVC nonsense syllables. Three types of sentences were used: zero probability sentences were both syntactically and semantically anomalous (e.g., “girls white car blink”); low predictability sentences were syntactically appropriate, but semantically anomalous (e.g., “duck eats old tape”); and high predictability sentences were syntactically and semantically appropriate (e.g., “most birds can fly”). By comparing performance across stimuli with differing levels of semantic and syntactic predictability, the relative contributions of each to speech recognition by children were evaluated. The results indicated that, for both young adults and children, the highest performance occurred when lexical, syntactic and semantic cues were available. Overall, adults had better performance for sentences, words and nonsense syllables in noise than the young children. However, when results were scored by the number of phonemes correct, inter-subject variability decreased and the differences in performance between adults and children also decreased. By analyzing the relative contributions of lexical, syntactic and semantic information to overall performance, the investigators concluded that when children possess the appropriate linguistic knowledge, differences in speech recognition between children and adults in noise are minimal.

Hnath-Chisolm et al. (1998) examined the speech perception abilities of children ages 5-10 years old using auditory, visual and auditory plus visual conditions to assess age-related changes in nonsense-syllable recognition. Nonsense syllables were chosen to minimize the influence of lexical knowledge on the task. Results indicated that children less than 7 years-old had lower recognition scores than older children. The authors concluded that these differences may be related to differences in cognitive or linguistic skills between younger and older children. These findings suggest that in order for a speech recognition task to provide useful information about the auditory capacity of children, the test should seek to minimize the influence of cognitive and linguistic demands. To accommodate the short attention spans of young children, the authors recommended that speech recognition tasks be kept brief.

Although more time consuming to obtain than speech recognition at a single intensity level, Mackersie and colleagues (2001) have suggested that performance intensity (PI) functions provide a more comprehensive estimation of speech recognition. PI functions can have a variety of clinical applications in situations where a measure of speech recognition at a single level is inadequate (Boothroyd 2008). For comparison of aided and unaided speech recognition results with hearing aids and/or implantable devices, two PI functions are measured to determine the extent to which performance improves with their device. PI functions also may be useful to evaluate changes in hearing-aid settings or in the assessment of speech perception for individual
listeners over their dynamic range (Boothroyd 2008). PI functions also have been used to detect retrocochlear hearing loss by testing for “rollover” effects at high intensities (Jerger & Jerger 1971). However, because the variability of speech recognition is influenced by both the number of items correct and the number of stimuli (Thornton & Raffin 1978), obtaining a PI function across a range of intensities requires a greater time commitment than the monosyllabic word list, single intensity-level approach.

Although it has been well documented that PI functions can provide a more comprehensive picture of speech recognition than the current clinical practice of word recognition at a single intensity (Donaldson & Allen 2003; Sherbecoe & Studebaker 2002), PI functions are not often used clinically. According to a survey of 276 audiologists, 98% routinely include speech recognition tasks in hearing evaluations (Martin et al. 1994). The most common speech recognition tasks are the Speech Reception Threshold (SRT) and monosyllabic word recognition in quiet. Given the time limitations in typical clinical settings, word recognition is frequently measured at a single level (typically 40 dB above the SRT). While it is often assumed that this represents the maximum word recognition score (i.e., PB max), Kamm et al. (1983) reported that PB max estimates obtained at 40 dB sensation level reflected maximum word recognition in only 60% of their subjects. To obtain valid PI functions in less time, Boothroyd (2006) developed the Computer Aided Speech Perception Assessment (CASPA). In this computer-based test, lists of 10 CVC words are presented over a range of intensity levels and the tester enters subject responses into a computer. The software automatically scores results in terms of words, phonemes, consonants, and vowels correct, and generates separate PI functions for each analysis. CASPA can be used to obtain a PI function in less than five minutes. Stimuli can be presented via earphones or in the sound field either in quiet or with competing noise.

Prior to the development of CASPA, phonemic scoring was much more time-consuming than scoring based on the number of words correct. Phonemic scoring offers several advantages over scores based on the number of words correct (Markides 1978; Gelfand 1998). Scoring based on phonemes correct increases the number of data points in CVC words by a factor of three, decreasing variability and improving the precision of interpreting small differences in performance across presentations (Gelfand 2003). Boothroyd (2008) suggested that phonemic scoring might reduce the influence of differences in linguistic knowledge on speech recognition for young children compared to adults, as phonemic scoring is presumed to better reflect the ability of the listener to repeat acoustic phonetic cues instead of requiring recognition of the entire word. Some of the speech recognition differences between adults and children are considered to be related to differences in lexical knowledge. Phonemic scoring may minimize age-related differences in performance, as children will likely use phonemic approximations of words that are not within their lexicon. While several studies have evaluated the use of phonemic scoring with adults, few have studied the effects of this approach with children, and a comparison of word and phoneme scoring for the same group of listeners has not been directly evaluated in previous studies.

For CASPA, PI functions have been obtained for normal-hearing adults under three conditions: binaural sound-field presentation in quiet, monaural headphone presentation in quiet and monaural headphone presentation in noise (Boothroyd 2008). At present, similar PI functions using the CASPA software have not been obtained for normal-hearing children. Since age-related differences in performance would be expected for children, such differences should be explored. The goals of the current investigation were to: 1) assess PI functions in noise for normal-hearing children in four age groups and for adults with normal hearing; 2) determine if CASPA is a clinically feasible tool for the audiological assessment of young children; 3) identify the age at which normal-hearing children achieve speech recognition comparable to
that of adults; and 4) compare differences in speech recognition between children and adults for the various scoring methods available in CASPA.

**METHOD**

**Participants**

Forty-eight normal-hearing children between the ages of 5 years, 0 months and 12 years, 7 months with no history of speech and language concerns participated in this study. Twelve children (6 male, 6 female) were recruited into each of four age groups: 5-6 year-olds (mean age = 5 years, 8 months), 7-8 year-olds (mean age = 8 years), 9-10 year-olds (mean age = 9 years, 11 months) and 11-12 year-olds (mean age = 11 years, 5 months). All participants were required to pass a hearing screening at 15 dB HL bilaterally at octave frequencies from 250 Hz through 8000 Hz. One 10 year-old participant was excluded due to thresholds > 15 dB HL in both ears. The Bankson-Bernthal Quick Screen of Phonology (BBQSP; Bankson & Bernthal 1990) is a norm-referenced screening tool which uses picture identification to elicit speech production using 28 color pictures of objects. The BBQSP was administered by the examiner, and children with significant production errors outside the normal range (± 1 standard deviation) for their age were excluded. One 8 year-old child was excluded due to significant speech production errors on the BBQSP. The adult group was comprised of 12 normal-hearing adults (6 male, 6 female) between the ages of 24 and 37 years (mean age = 28.9 years). The native language of all participants was English. All participants were paid an hourly rate and children were also provided with a toy and a book.

**Stimuli**

CASPA (Boothroyd 2006) is comprised of 20 lists with 10 CVC words per list. Each list is isophonemic, which means that it contains one instance of the same set of 30 phonemes (20 consonants and 10 vowels). The CASPA software allows the experimenter to control the presentation level. In the version of CASPA utilized for this study (Version 3.3), the stimuli are spoken by an adult female.

**Instrumentation**

The CASPA software was installed on a personal computer that controlled the stimulus level and recorded subject responses. Stimuli were generated by a Sound Max Digital PCI sound card and routed to a Sony SMS-1P powered monitor speaker. As recommended in the CASPA procedure manual (Boothroyd 2006), the sound field was calibrated so that the noise level was 55 dB SPL measured at the position of the listener.

**Procedure**

Participants were tested in a sound-treated booth. Results were obtained in a single session of 30 to 45 minutes. Two examiners were present for each session. Participants were seated two feet from the loudspeaker and instructed to repeat the words presented. Children were instructed to repeat each CVC, and the examiner in the control room entered their responses into CASPA. In cases where a child was inattentive or vocalizing during stimulus presentation, the test item was repeated once. If a response was unclear, the two examiners conferred to make a decision and/or the child was asked to repeat his/her response. All subjects were encouraged to guess, if they were not sure what they heard. Additionally, because one of the goals of the study was to examine the accuracy of phonemic scoring, all participants were told that some words are real and others are “made up” but each word should be repeated as heard, even if it did not sound like a word they knew.
The speech-shaped noise used in the CASPA software is spectrally matched to the longterm average speech spectrum of the talker. This noise was presented continuously at 55 dB SPL during all stimulus presentations. The level of speech varied systematically for each list, resulting in the SNRs shown in Table 1. Although the specific lists presented to each subject were varied randomly without replacement by the software, the order of SNR was held constant across subjects. Examiners entered the participants’ responses into the CASPA software via the keyboard, and after each trial, the software automatically scored the item based on the orthography. In cases where the examiner disagreed with the automated scoring, the examiner could override the score. At the end of each test, the software scored the responses and analyzed the data in terms of percent correct words, phonemes, consonants (initial, final, and total) and vowels. Feedback as to the correctness of the response was not provided to the subjects. For some of the younger participants, a second examiner sat with the child to help maintain the child’s attention, but did not provide feedback during the task.

RESULTS

Figure 1 displays PI functions in children and adults for the different scoring methods offered in CASPA, showing speech recognition performance (as mean percent correct) as a function of SNR for each of the four scoring approaches. The filled squares and hatched area represent the mean and range between the 5% and 95% confidence intervals for the adult listeners, respectively. The various open symbols represent children’s mean performance by age group. Performance for all age groups was highest for vowels, followed by phonemes (consonants and vowels combined), consonants, and words. Note that the performance for words was more variable for each age group than performance for phonemes. Percentage of words correct was less variable at higher SNRs, although at the highest SNR there was almost no variability across age groups or scoring methods.

The individual variability of results for children compared to adults is plotted in Figures 2 and 3. The filled circles in Fig. 2 show individual percentage correct data for words as a function of SNR for the four age groups of children. Fig. 3 shows similar data for phonemes as filled triangles. The gray shaded area represents the range of recognition scores for the adult group. Note that the performance for words was more variable for each age group than performance for phonemes. Percentage of words correct was less variable at higher SNRs, although at the highest SNR there was almost no variability across age groups or scoring methods.

In order to address mean differences in performance across age group as a function of scoring approach, a multivariate analysis of variance (MANOVA) was completed with scoring method (word, phoneme) and SNR (−10, −5, 0, 5 dB) as within-subject factors and age group as a between-subject factor. Because word and phoneme scoring data were obtained from the same task, each score was analyzed as a separate dependent variable using a planned comparison. All percent correct speech recognition results were converted to Rationalized Arcsine Units (RAU; Studebaker 1985) prior to statistical analyses in order to normalize covariance as a function of percent correct. Box’s M analysis on RAU was not significant (Box’s M = 254.924, F(144,5508) = 1.184, p = 0.07), indicating that observed covariances did not differ significantly across conditions or groups and that the assumption of homogeneity of covariances was not violated. Although figures show results for vowel and consonant scoring, only word and phoneme scores were included in the MANOVA since these scoring methods would be of most utility in clinical applications of CASPA. Data at +10 dB and +15 dB SNR were excluded from the MANOVA due to consistent ceiling performance and lack of variance across all participants.

There was a significant effect of age group (5-6 year-olds, 7-8 year-olds, 9-10 year-olds, 11-12 year-olds and adults) on the combined dependent variable of scoring method [F (8,108) = 3.041,
p = 0.004, Wilks’ λ = 0.667, η²p = 0.184]. Further analysis of each dependent variable (word, phoneme), using a Bonferroni adjusted alpha level of 0.025 (0.05/2), indicated that significant mean differences existed between age groups for both word [F (4,55) = 6.155, p < 0.001 η²p = 0.309] and phoneme [F(4,55) = 4.655, p=0.003, η²p = 0.253] scoring methods. Figure 4 compares results by scoring method as a function of age group for mean phoneme scores (black bars) and mean word scores (white bars). In order to determine which differences across age groups contributed to the significant effect for each scoring method, post hoc pairwise comparisons using Tukey’s HSD were made with a calculated minimum mean difference of 5.792. Table II contains the means and standard deviations for percent correct word and phoneme scores for each age group collapsed across SNR. Several patterns were observed based on the post hoc pairwise comparisons. When comparing the two scoring methods for each age group, phoneme scores were consistently higher than words scores for all age groups. Comparison of word scores across age groups revealed three different levels of performance. Adults had significantly higher word scores compared to all four groups of children. Differences in word scores between 7-8 year-olds, 9-10 year-olds and 11-12 year-olds were not significant, but all three groups had higher word scores than the 5-6 year-olds. When pairwise comparisons were made for phoneme scores across age, only two distinct levels of performance emerged. Adults had significantly higher phoneme scores than 5-6 year-olds and 7-8 year-olds, but differences between adults and older children were not significant. When phoneme scores were compared across the age groups of children, the only significant difference in recognition was between 5-6 year-olds and 11-12 year-olds. Overall, this pattern of results suggests that phoneme scoring resulted in smaller differences in speech recognition scores between adults and children, but that adults still had significantly higher phoneme scores than the two youngest groups of children.

The interaction between age group and SNR was explored to determine if the differences in speech recognition across SNR were consistent across age groups. The interaction between age group and SNR was not significant [F (12,165) =1.465, p =0.142, Wilks’ λ = 0.732, η²p = 0.096], suggesting that changes in speech recognition across SNR were consistent across age groups. Each age group showed a similar pattern of improved performance as SNR improved, as would be predicted from previous studies. The interaction between SNR and scoring method was also examined. There was a significant effect of SNR on the combined dependent variable of scoring method [F (6,328) = 78.286, p < 0.001, Wilks’ λ = 0.169, η²p = 0.589]. Analysis of each dependent variable (word, phoneme), using a Bonferroni adjusted alpha level of 0.025 (0.05/2), indicated that significant mean differences existed across SNR for both word [F (3,165) = 179.996, p < 0.001 η²p = 0.766] and phoneme [F(3,165) = 240.927, p< 0.001, η²p = 0.814] scoring methods. Post hoc analyses of the mean differences between scoring methods at each SNR were completed using Bonferroni adjusted alpha levels of 0.0125 (0.05/4). Mean differences between word and phoneme scores were significant with phoneme scores significantly higher than word scores at each SNR. As the SNR increased, word recognition improved more rapidly and showed greater variability than phoneme scoring. Collapsed across all groups, mean phoneme scores ranged from 52 – 63 % at the −10 dB SNR, while mean word scores ranged from 16 – 30% at the same SNR. However, at the highest SNR, percent correct scores for words and phonemes were essentially the same, (92 -99% for words and 97 - 99% for phonemes). These results reflect the robustness of phonemic cues, even at poor SNRs, where listeners are given credit for being able to identify some of the phonemes in a word when listening conditions are challenging.

**DISCUSSION**

The goals of the current study were to: 1) evaluate differences in PI functions obtained in noise between adults and children using CASPA, 2) determine if CASPA is a feasible assessment tool to use with young children, 3) assess the age at which children reach adult-like performance
on CASPA, and 4) compare word and phoneme performance between adult and child listeners. Overall, several trends emerged. Adults had significantly higher word recognition scores than all four age groups of children. The three older groups of children all had significantly better word scores than the 5-6 year-old age group. Therefore, word scoring on the CASPA resulted in significant differences in percent correct across age groups, both between adults and children and within different age groups of children. For phoneme scores, adults had significantly higher scores than the two youngest groups of children, but the differences between the adults and the two older groups of children were not significant. When comparisons were made for phoneme scores between age groups of children, the only significant difference was between the 11-12 year-olds and the 5-6 year-olds, with significantly better phoneme recognition scores for the older children. Scoring the results of the CASPA by phonemes correct results in fewer significant differences in performance across age groups, but does not result in equivalent performance for all the age groups in the current study.

The expected trend of decreasing performance and increasing variability in word and phoneme recognition as SNR decreased also was observed. In addition, the pattern of degradation in speech recognition scores as a function of decreasing SNR was similar for both children and adults in the current study. As SNR decreased, phoneme recognition did not decrease as rapidly as word recognition, suggesting the preservation of some phoneme information even at the lowest SNRs. In comparing PI functions for adult and child listeners, all participants in the current investigation showed a trend of increasing performance as SNR improved regardless of age or scoring method. However, when comparing mean word recognition for each of the child age groups to the adults, it is evident that the majority of children in the 5-6 year-old and 7-8 year-old groups scored outside the range of performance for adult listeners at each SNR. For phoneme scoring, the variability in recognition decreased with age and a larger number of children fell within or above the range of performance for adult listeners at each SNR. Of clinical importance is the fact that even with phoneme scoring, some children in each age group had PI functions that were outside the range of performance for adults, despite the fact that the average data were not significantly different when phoneme scoring was used. However, for those children who had PI functions outside of the range for adults, the differences were much less for phoneme scoring than for word scoring.

Based on the current results, it appears that CASPA can be utilized reliably in a clinical setting to assess speech recognition for children as young as 5 years of age. However, future studies should attempt to obtain data from a larger sample of children so that normative PI functions can be developed for these age groups. Given the differences in word recognition scores observed between adults and children, CASPA adult normative data may overestimate scores for children in this age range. While performance was not significantly different between the adult group and the two older groups of children when phonemic scoring was used, the 5-6 year-olds and 7-8 year-olds had poorer mean phoneme recognition scores than adult listeners, suggesting that phoneme scoring does not eliminate age-related differences in speech recognition for this age group. These results are consistent with the findings of Hnath-Chisolm and colleagues (1998), who reported age-related differences in recognition of nonsense syllables for children less than 7 years of age.

In this study, complete PI functions at 6 intensity levels were obtained for each participant in approximately ten minutes. All participants in the current study were able to complete the task without difficulty. Given that many listeners in the current study achieved maximum performance at SNRs of +5 or +10 dB, clinical implementation of CASPA could include fewer presentation levels or SNRs than were used in the current study. In many cases, a valid PI function could be obtained using only three or four different intensity levels or SNRs depending on the point where the listener reaches maximum performance. In order for any test of speech recognition to be clinically useful for children, the test must also be able to be administered...
effectively in a short amount of time. PI functions in CASPA can be obtained with cooperative children in less than ten minutes.

The CASPA results for adults in the present study are similar to those reported in a previous study of speech recognition of adults using CASPA (Mackersie et al. 2001). In the previous study, the mean percentage of phonemes correct for adults at 0 dB SNR was 74% compared to 79% in the current study. Mackersie and colleagues did not evaluate speech recognition performance of their adult participants at the other SNRs used in the current study, so additional comparisons between studies are not possible. Nittrouer and Boothroyd (1990) found that, at SNRs of 0 dB and 3 dB, children between 4 1/2 years and 6 1/2 years had poorer performance for individual words and nonsense syllables than a group of young adults. When the current results for the 5 to 6 year-old group at 0 dB SNR are compared to results obtained at the same SNR for children of similar age in Nittrouer and Boothroyd’s study, phoneme recognition is similar (64% in the current study vs. 68% in the previous study). A statistical comparison of scoring method as a function of age was not included in the Nittrouer and Boothroyd study.

Effects of age and scoring method on speech recognition in the current study suggest that use of PI functions for adults and children is clinically feasible and may provide greater information than the assessment of word recognition at a single intensity. The ability to simultaneously obtain and compare words correct and phonemes correct offers clinicians a tool that can provide clinically-relevant information in a relatively short period of time. Phoneme scoring helped to minimize age-related differences in recognition between adults and children as young as 9 years of age. Phoneme recognition at poorer SNRs was also less variable and did not decrease as rapidly as word recognition, since some phonemic cues remain salient even at poor SNRs. Thus, phoneme scoring may provide a viable alternative for individuals with extremely poor word recognition who clinicians wish to quantify residual auditory skills.

Acknowledgments

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Figure 1. Mean percent correct speech recognition scores plotted across signal-to-noise ratio (SNR). Filled squares are mean results for adults. Hatched area represents the range between the 5% and 95% confidence intervals for adults. Open symbols represent mean results for each age group of children. Each panel represents a different scoring method: upper left, words; upper right, consonants; lower left, phonemes; lower right, vowels.
Figure 2.
Percentage of words correct across signal-to-noise ratio (SNR). Shaded gray area represents the range of word recognition scores for adults. Filled circles represent individual mean data for children. Each panel includes data for a separate age group: upper left, 5-6 year-olds; upper right, 7-8 year-olds; lower left, 9-10 year-olds, lower right 11-12 year-olds.
Figure 3.
Percentage of phonemes correct across signal-to-noise ratio (SNR). Shaded gray area represents the range of phoneme recognition scores for adults. Filled triangles represent individual mean data for children. Each panel includes data for a separate age group: upper left, 5-6 year-olds; upper right, 7-8 year-olds; lower left, 9-10 year-olds, lower right 11-12 year-olds.
Figure 4.
Mean percent correct for phonemes (black) and words (white) for each age group. Error bars represent standard deviation.
Order of presentation levels and signal-to-noise ratios (SNR) for each participant.

<table>
<thead>
<tr>
<th>Speech Level (dB SPL)</th>
<th>1st List</th>
<th>2nd List</th>
<th>3rd List</th>
<th>4th List</th>
<th>5th List</th>
<th>6th List</th>
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<td>Resulting SNR</td>
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<td>−10</td>
<td>+15</td>
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## Table II
Means and standard deviations for word and phoneme scores by age group

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Phoneme Mean (std)</th>
<th>Word Mean (std)</th>
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<tr>
<td>5-6 year-olds</td>
<td>77.44 (6.58)</td>
<td>51.16 (10.9)</td>
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<tr>
<td>7-8 year-olds</td>
<td>80.37 (7.64)</td>
<td>56.3 (11.4)</td>
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<tr>
<td>9-10 year-olds</td>
<td>82.58 (3.46)</td>
<td>61.08 (6.85)</td>
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<td>11-12 year-olds</td>
<td>83.57 (4.03)</td>
<td>60.31 (7.82)</td>
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<tr>
<td>Adults</td>
<td>88.14 (6.01)</td>
<td>69.34 (10.2)</td>
</tr>
</tbody>
</table>

Percent correct in RAU averaged across SNR