EMOTION PERCEPTION AND TALKER DISCRIMINATION IN PEDIATRIC HEARING AID USERS

by

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***Abstract:** The primary goal of this study is to examine the ability of pediatric hearing-aid listeners, with mild to moderately-severe hearing loss, to perceive emotion and to discriminate talkers. These listeners' performance is compared to that of similarly-aged listeners with normal hearing and who use cochlear implants.*

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In Loving Memory of

Thomas J. F. Sherman (1917-2000)

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Abbreviations

A	Auditory
A/V	Auditory + Visual
BTE	Behind-The-Ear
CI	Cochlear Implant
dB	Decibel
dBA	Decibel with A-Weighting (sound pressure level)
dB HL	Decibel Hearing Level
DSL	Desired Sensation Level
FM	Frequency Modulation
HA	Hearing Aid
HEI-ESD	House Ear Institute Emotional Speech Database
HI	Hearing Impaired or Hearing Impairment
HL	Hearing Loss
HRPO	Human Research Protection Office
Hz	Hertz
IMTSD	Indiana Multi-Talker Sentence Database
IRB	Institutional Review Board
JND	Just-noticeable-difference
NH	Normal Hearing
PTA	Pure-Tone Average
RECD	Real-Ear-to-Coupler Difference

SII	Speech Intelligibility Index
SPL	Sound Pressure Level
UNBHS	Universal Newborn Hearing Screening
V	Visual
WNL	Within Normal Limits

INTRODUCTION:

Human speech encompasses both linguistic and indexical information, i.e., both types of information are encoded simultaneously in the acoustic waveform. Linguistic information encompasses the meaning of the message or “what is said” and non-linguistic information encompasses attributes of the speaker or “how it is said.” Effective communication of the speech signal depends on both types of information. Perception of individual phonemes, words and sentences are necessary requisites for conveying linguistic information. Since indexical information reflects characteristics of the talker, such as age, gender, dialect, and emotional state, much indexical information can be perceived easily when a talker is seen. However, visual cues are not always available, such as when talking with someone located in a different room, talking on the telephone, and listening to the radio (Cleary & Pisoni, 2002). Consequently, it is worth knowing how well indexical information is perceived from acoustic cues alone. Additionally, recent studies indicate that the processing of indexical and linguistic information is interwoven in a complex way (Johnson, Westrek, Nazzi, & Cutler, 2011), and that development of these processes may take years even in children with normal hearing (NH). Children with impaired hearing often have delays in spoken language development, and these delays may be due, in part, to atypical development of these interwoven processes. Thus, it seems especially worth knowing whether children with hearing impairment (HI) are able to perceive both the linguistic and indexical information in the speech signal.

There are a growing number of studies assessing the perception of indexical information by listeners with HI and by listeners with simulated hearing-loss (HL). One of the earliest studies, by Ross, Duffy, Cooker, & Sargeant (1973), examined the ability of adults with NH to recognize emotions when their hearing was restricted to low-frequency information via low-pass filtering of speech. Low-pass filtering produces a speech signal similar to that heard by listeners with a typical presbycusic high-frequency HL. Speech materials were recorded with nine different emotions (anger, indifference, grief, amusement, doubt, fear, love, contempt, & astonishment), and were then low-pass filtered with cutoff frequencies of 150, 300, 450 and 600 Hz. The 600- and 450-Hz low-pass filtered conditions yielded emotion recognition scores that were fairly similar to those for broadband speech, while the 300- and 150-Hz low-pass filtered conditions yielded scores that were substantially poorer. The authors concluded "… intended emotion of a speaker could be identified with perception of only the lower audible frequencies of speech."

In 1986, Oster & Risberg examined the abilities of various groups of listeners to identify the mood of a speaker. Sentences were produced, in Swedish, by one male and one female talker using four emotions or moods (angry, astonished, sad, and happy). Adults (N=22) and children (N=20, age 10 years) with NH identified the mood in these recordings with 98% and 93% accuracy, respectively. When these sentences were low-pass filtered at 500 Hz, emotion identification accuracy of a smaller group of adults with NH (N=10) decreased to 76% correct overall (86% correct for the male and 66% for the female talker). Children with NH were not tested in the low-pass filtered condition. These same speech recordings were also presented to adults (N=45, age: 26-74 yrs old) and children (N=18, age: 11-14 yrs old) with HI who use hearing aids (HAs). In contrast to the high scores of the listeners with NH, the listeners with HI were much less accurate in identifying emotion; children with HI scored 63% correct and adults with HI scored 84% correct. None of the 18 children with HI identified all four moods correctly while 12 of the 45 adults with HI were able to correctly identify all of the intended moods. Response confusions were somewhat similar between the listeners with HI and the adults with

NH listening to low-pass filtered speech. The authors attributed these results to: i) the fact that frequency discrimination is more difficult with pure-tones than with complex tones, and ii) frequency discrimination ability is often reduced in listeners with HI compared to listeners with NH. The higher number of confusions by NH listeners in the low-pass filter condition than in the unfiltered condition can be attributed to the first factor. Especially for the female talker's stimuli, low-pass filtered voiced speech is more like a pure-tone than a complex tone. However, these results should be interpreted with caution. The language for these recordings and tests is Swedish (not English, and emotion perception may be language-dependent), no details are provided about the HAs or their fitting parameters, and perhaps most important, there was poor repeatability in the older HI adults' identification scores (when the mood test was repeated after a three-week interval the correlation was 0.42).

Peters (2006) evaluated the ability of adult cochlear implant (CI) listeners to perceive emotion through speech alone. In this study, perception of emotion was assessed using two types of experiments, emotion identification and emotion discrimination. Three semantically-neutral sentence scripts were spoken by two female talkers with four different emotions (angry, scared, happy, and sad), with repeated recordings for each emotion and each sentence script. For the emotion identification task, the listener heard a single sentence and then chose one of four images on a touchscreen, where each image was a young girl displaying these four emotions. For the emotion discrimination task, the listener heard two sentences, and then selected on the touchscreen the shapes/words associated with either the response "same feeling" or "different feelings." Eleven adult CI listeners (7 female; mean age = 57 yrs), three adult listeners with NH (2 female, ages 24-55 yrs), and 4 children with NH (2 female; age 6-12 yrs) participated, and various conditions were tested (e.g., only one talker in a test run, both talkers in a test run, same sentence script within a trial of the discrimination test, different sentences within a trial of the discrimination test, etc.). Listeners with NH performed very well on both emotion tests, with average identification scores of 98.6 and 97.2% correct, and average discrimination scores of 98.4 and 92.8% correct, for adults and children, respectively. By contrast, the adult CI listeners identified emotions with an accuracy of only 69% correct, and discriminated emotions with an accuracy of 76% correct. For these CI participants, 'anger' was identified most accurately (86% correct), followed by 'sadness' (75%), 'happiness' (64%), and fearfulness (54%).

Luo, Fu, & Galvin (2007) also assessed the vocal recognition of emotion for adult listeners, both with CIs and with NH. These experiments were conducted to examine the effects of preserving overall level in the original speech productions, number of channels in the CI, and envelope filter-cutoff frequencies, for listeners with CIs and with CI simulations. Eight adults with NH (5 women; median age of 28 yrs) and 8 adults postlingually deafened with CIs (4 women; median age of 58 yrs) took part in this study. Sentences from the House Ear Institute Emotional Speech Database (HEI-ESD) were produced by one male and one female talker with five target emotions: angry, anxious, happy, sad, and neutral. When overall level was preserved, participants with NH performed near perfectly (90% correct), while CI listeners recognized fewer than half of the target emotions correctly (45% correct). Removing overall level cues degraded performance slightly for both NH (87%) and CI listeners (37% correct). Also, for both CI listeners and CI-simulation listeners, performance improved as the number of channels or the envelope filter-cutoff frequency was increased. However, CI listeners did not benefit as much as the CI-simulation listeners did from increases in either number of channels or envelope cutoff-frequency. Overall, CI listeners seem to perceive intensity and speaking-rate cues coded in emotionally produced speech, but seem to have limited access to pitch and spectral-envelope cues.

Most & Aviner (2009) evaluated emotion perception for adolescents with NH and with impaired hearing using different sensory modalities. There were ten participants in each of four listener groups: i) CI listeners implanted before age 6, ii) CI listeners implanted after age 6, iii) HA listeners, and iv) NH listeners. A semantically-neutral sentence was produced with six emotions (happiness, anger, surprise, sadness, fear, disgust). Sentences, spoken in Hebrew, were presented in auditory (A) alone, visual (V) alone, and auditory + visual (A/V) conditions. For all three listener groups with HI, average performance in the A/V and V conditions was similar and very good, 75-80% and 77-81% correct, respectively. By contrast, the same groups' average performances in the A condition were poor, 16-22% correct. Listeners with NH performed similar to those with HI in both the A/V (86%) and V conditions (80%), but performed much better than listeners with HI in the A condition (51% correct). In conclusion, participants with NH performed significantly better than all other groups. None of the three HI groups were significantly different from one another, but the mean identification scores suggest that the early-implanted-CI listeners performed better than later-implanted-CI and HA participants.

There are also several reports on talker discrimination abilities of CI listeners, both adult and children. One of the earliest reports, by Cleary et al. (2002), evaluated the abilities of two groups of children to discriminate female talkers. Eight to 9-year-old prelingually-deafened children with CIs and 5-year-old children with NH participated. Children heard pairs of sentences spoken by three female voices (chosen from the Indiana Multi-Talker Sentence Database [IMTSD]), and were asked to respond for each sentence pair whether the sentences were spoken by the "same talker" or by "different talkers." Additionally, 'fixed' and 'varied' sentence conditions were examined: i) fixed - linguistic content, or sentence script, was the same for each sentence of a sentence pair, and ii) varied - linguistic content was varied, i.e., the sentence script was different for each sentence of a sentence pair. Mean scores for children with CIs in the ‘fixed’ and ‘varied’ conditions were 68% and 57% correct, respectively. By comparison, the mean score for children with NH in the ‘varied’ condition was 89% correct (the ‘fixed’ condition was not tested). Thus, even though the children with NH were younger, their performance in the ‘varied’ condition was much better than that of child CI users (89% vs. 57% correct). In fact, 37 of the 44 CI listeners simply could not perform the talker discrimination task when the sentences were different.

Uchanski, Davidson, Quadrizius, Reeder, Caudieux, Kettel, & Chole (2009) report the results of both emotion perception and talker discrimination for a single child listener as part of a comprehensive study comparing the benefits of two devices (bimodal: left ear HA and right ear CI) vs. three devices (left ear HA and right ear CI + HA). Talker discrimination was assessed using sentence stimuli produced by eight female and eight male talkers from the IMTSD. Three types of talker discrimination tests were conducted: i) across-gender (male vs. female), ii) within-female, and iii) within-male. Emotion perception was evaluated in a manner similar to Peters (2006), but in this case only one female talker’s speech was used. Overall, this single listener was able to perceive emotion quite well through either type of device (HA or CI). For talker discrimination, this listener generally could discriminate male from female voices, but had great difficulty with both the within-male and within-female talker discrimination tests regardless of the device(s) used. This result, better across-gender than within-gender discrimination, is consistent with results from adult CI listeners (Spahr & Dorman, 2004).

However, adding the HA to the CI ear seemed to interfere with across-gender talker discrimination for this one pediatric listener (Uchanski et al., 2009).

Two studies by Kovačić & Balaban (2009, 2010) examine the ability of 41 CI listeners (5-18 yrs old) to perceive and identify talker gender. Two types of gender perception tests were employed, a one-interval gender identification test and a two-interval gender discrimination test. For the gender discrimination task, an adaptive procedure was used to estimate the just-noticeable-difference (JND) in fundamental frequency. Speech samples were 2 seconds in duration for all talkers. More than half of the CI group (23 of 41) could not identify gender. That is, the performance of this CI group was not beyond the 95% confidence interval for chance performance. The remaining 18 listeners with CIs performed better than chance, but still identified gender much more poorly than even younger children with NH (84% vs. 98% correct). Fundamental frequency JNDs were large for some CI listeners (> 90 Hz) and somewhat smaller for others (~56 Hz), though all estimates were very large compared to those of children with NH (near 0 Hz). The fact that some in the CI group could discriminate but not identify gender indicates that long-term categorical memory of voice gender may not be developed in these CI listeners. CI group performance was analyzed with respect to listener characteristics such as chronological age, age at implant surgery, and duration of deafness (Kovačić & Balaban, 2010). They found that gender identification performance was significantly and negatively related to duration of deafness before cochlear implantation.

Finally, in a very recent study, Cullington & Zeng (2011) compared the performance of two groups of adults who were post-lingually deafened, those with bilateral CIs and those with bimodal devices (CI one ear, HA other ear). The main goal of this study was to test the hypothesis that the bimodal group would perform better than the bilateral CI group on tasks that require good pitch perception, such as talker, emotion, and music perception tasks. Emotion perception was evaluated using the Aprosodia Battery (Ross, Thompson & Yenkosky, 1997) which has five subtests to examine perception of affective prosody and recognition of sarcasm. Talker identification was performed using /hVd/ syllables spoken by 10 different talkers (three men, three women, two boys, and two girls). Both groups with CIs performed much worse than the group with NH on 3 of the 5 Aprosodia subtests and on the talker identification test (identifying the 10 different talkers). Since both CI groups performed similarly, the hypothesis was rejected, and the authors concluded that the tasks in their battery are simply not providing a measure of pitch perception ability.

RESEARCH AIM:

The primary goal of this study is to examine the ability of pediatric HA listeners, with mild to moderately-severe HL, to perceive emotion and to discriminate talkers. Predictions are: i) pediatric HA listeners will perform more poorly than children with NH on all tasks, and ii) pediatric HA listeners will perform better than similarly-aged pediatric CI listeners. The second prediction was made because HA listeners presumably can perceive voice fundamental frequency better than CI listeners, and because HA listeners are expected to have better frequency resolution than CI listeners.

METHODS AND MATERIALS:

Recruitment materials, informed consent, and protocol for this study were approved by the Institutional Review Board (IRB) and the Human Studies Committee at Washington University School of Medicine in St. Louis. Participants were recruited from audiology clinics and oral schools in the greater St. Louis area via HRPO-approved letters asking colleagues for eligible participant referrals. All participants were given a token amount of remuneration for their participation and travel expenses.

Design:

This is a cross-sectional observational, prospective study.

Participants:

All participants met the following inclusion criteria: chronological age of 6 – 17 years, mild-to-moderately-severe bilateral sensorineural hearing loss with audiometric thresholds in the better ear $\leq$ 70 dB HL for test frequencies 250 Hz - 6000 Hz, currently fit with unilateral or bilateral digital hearing aids that had been worn at least 3 months, native speaker of English, enrolled in an oral education program or mainstream school, no diagnosis of auditory neuropath/dys-synchrony, and hearing loss as primary disability with normal cognitive function.

Participant Demographics and Hearing Aid Characteristics:

Participant demographics are presented in Table 1. Eight children (5 females, 3 males) ranging in age from 6.2-11.1 years old participated (mean = 8.2; SD = 1.9). Their duration of HA use ranged from 4.2-7.8 years (mean = 6.1; SD = 1.5). All 8 children wore bilateral behind-the-ear (BTE) HAs; subject 1 wore bilateral Widex Inteos, subjects 2 and 5 wore bilateral Phonak Naida III SPs, subject 3 wore bilateral Phonak Savias, subject 4 wore bilateral Phonak Naida V SPs, subject 6 wore bilateral Phonak Micro IIIs, subject 7 wore bilateral Phonak Naida III SP dAZs, and subject 8 wore bilateral Phonak Naida III UP dAZs. All participants had been identified with a hearing loss at birth via Universal Newborn Hearing Screenings (UNBHS) and were fit with HAs at ages ranging from 0.4-6.0 years (mean, 2.1, SD = 2.0). Cause of HL varied:

subjects 1 and 7 were identified as having a genetic HL; subjects 2, 3, 4, and 6's HLs were due to unknown causes; and subject 5 had several high risk factors at birth though the exact cause of HL is unknown.

Testing was done using the participants' personal HAs as programmed by their school or clinical audiologist, and no changes were made to the HAs prior to or following testing. The frequency-specific gain and output were verified using real ear measures or test box measures with real-ear-to-coupler differences (RECD) and the child's personal earmolds. The Audioscan Verifit hearing aid analysis system was used to verify that output levels approximated Desired Sensation Level (DSL) 5.0 (Scollie, Seewald, Cornelisse, Moodie, Bagatto, Laurnagaray, Beaulac, & Pumford, 2005) fitting targets. Real-ear-to-coupler differences (RECDs) were measured for all test box verifications unless the participant's audiologist provided RECDs taken in the last 6 months with the current earmold(s). In addition, a Speech Intelligibility Index (SII; ANSI S3.5-1997) was calculated for the output response of the HA at each ear and at three different input levels for each child (i.e., 50, 60 and 70 dB SPL). The Verifit ™ system calculates the SII based on the 1/3-octave band method and includes level distortion effects (see Table 2).

Audiological Tests & Facilities:

Standard audiological tests were conducted: otoscopy, tympanometry, and both unaided and aided pure-tone audiometry. The modified Hughson-Westlake procedure (Carhart & Jerger, 1959) was used to obtain unaided and aided thresholds at 250 - 6000 Hz with a GSI 61 audiometer. Participants were exempted from unaided audiometry if an unaided audiogram (from within the last 6 months) was provided by the participant's audiologist. Aided thresholds were obtained in the sound field using frequency modulated (FM) tones with the subject seated 1 meter from a loudspeaker positioned at 0° azimuth.

All experimental tests were completed in a single-walled IAC sound booth located in the Central Institute for the Deaf audiology department on the Washington University School of Medicine Campus, St. Louis, Missouri. Speech materials were stored on a laptop, and delivered through a GSI 61 audiometer, in quiet, in the sound field at a level of approximately 60 dBA, when seated at a distance of 1 meter from an audio speaker positioned at 0° azimuth.

Behavioral Tests with Speech:

CNCs: Open-set word recognition was assessed using a CNC word test developed by Peterson & Lehiste (1962). One list of 50 words, List #3, was presented to each listener in the sound field.

Emotion Perception: Two types of emotion perception tests were administered, emotion identification and emotion discrimination. For the identification task, a single sentence was presented, and the listener was instructed to choose amongst four photos on the laptop screen of a young girl expressing facially the emotions ‘angry,’ ‘scared,’ ‘happy,’ and ‘sad.’ Speech materials consisted of simple, semantically-neutral sentences (“It’s time to go.”, “Give me your hand.”, “Take what you want.”) spoken by a single adult female, with multiple tokens of each sentence with each intended emotion. A total of 36 trials (36 = 3 sentence scripts × 4 emotions × 3 tokens) were presented. For the emotion discrimination task, pairs of sentences were presented in each trial. Sentences were pooled from the same set of speech recordings. Within each trial the sentence script was fixed (i.e., the script was the same for both sentences in the pair). The emotions in the sentence pair were the ‘same’ in half the trials and ‘different’ in the other half. When the emotion was the same, the tokens differed for the two sentences. The sentence script was chosen randomly from trial to trial, and a total of 24 trials were presented. After each trial, the listener chose ‘same feeling’ or ‘different feelings’ as his/her response by pointing or clicking on one of two schematic images corresponding to ‘same feeling’ and ‘different feelings.’

Talker Discrimination: Three types of talker discrimination tests were conducted: a) across-gender (male vs. female), b) within-female, and c) within-male. For all three types of tests, two sentences were presented sequentially in each trial, and the listener responded by pointing or clicking the schematic/cartoon image corresponding to ‘same person’ or to ‘different people.’ In each trial, the sentences were always different. Note, the listener did not need to understand the words in the sentences to make his/her response. Sentence recordings were from 8 female and 8 male speakers selected from the IMTSD (Indiana Multi-Talker Speech Database). For the Across-Gender Talker Discrimination test, ‘different people’ trials correspond to a sentence spoken by a female talker paired with a sentence spoken by a male talker, presented in either order. For ‘same person’ trials in the Across-Gender condition, the pair of sentences was spoken by either one particular female talker or by one particular male talker. A total of 32 trials were presented; half ‘same person’ and half ‘different people.’ For the Within-Female Talker Discrimination test, ‘different people’ trials correspond to sentences spoken by two different female talkers while ‘same person’ trials had pairs of sentences spoken by a particular female talker. A total of 32 trials were presented. The Within-Male Talker Discrimination test was entirely analogous to the Within-Female Talker Discrimination test.

RESULTS:

<u>Audiological Tests:</u>

Otoscopy, performed with a Welch Allyn 3.5V Halogen Diagnostic Otoscope, revealed an unremarkable examination for all but one participant. Subject 1 had a perforation at the right ear from a previously-placed Pressure Equalization Tube. Standard tympanometry, performed using an Interacoustics AT235 Impedance Audiometer, revealed subjects 3, 5, 7, and 8 had peak pressure and static compliance values within normal limits (WNL) bilaterally. Tympanometry also revealed: for subject 1, a high volume consistent with a perforated tympanic membrane; for subject 2, static and peak pressure values WNL for the right ear with slight negative pressure at the left ear; for subject 4, values WNL at the right ear with a hypercompliant static value at the left ear; and for subject 6, values WNL for the right ear with a low static value at the left ear.

The group average PTAs (500, 1000 & 2000 Hz) were 53 dB HL (SD = 16 dB) and 50 dB HL (SD = 13 dB) for the right and left ears, respectively. Unaided thresholds for both ears ranged from mild to moderately-severe at 250-6000 Hz (see Figures 1 & 2). The group average aided PTA in the sound field was 19 dB HL (SD = 4.5 dB), and individuals' aided thresholds ranged from 0 to 35 dB HL from 250-6000 Hz (Figure 3).

Correlations:

Scores from the emotion perception and talker discrimination tests were correlated with several demographic/audibility measures. Specifically, demographic/audibility items in this set, {age at test, aided sound-field PTA, SII at 60 dB SPL}, were correlated with the behavioral outcomes in this set {CNC word, CNC phoneme, emotion identification, emotion discrimination, across-gender talker discrimination, within-female talker discrimination, within-male talker discrimination}. Associations were estimated with Pearson correlations (Partek) and are reported in Appendix B, along with p-values for testing significance.

Behavioral Tests with Speech:

Individual participant's results for each behavioral test are provided in Appendix A. For the CNC open-set word recognition test, group mean scores (Figures 4 & 5) for words and phonemes are 92% (SD = 6) and 96% (SD = 2) correct, respectively. There was no significant correlation between CNC scores and age of listener (Figure 6).

Emotion Identification: Individual scores ranged from 53-97% correct (mean = 80%; SD = 13.4). All participants performed significantly above chance (Figure 7): for this task and number of trials, scores > 38.8% correct are significantly above the 95% confidence interval for chance performance. A notable trend was seen toward better performance with increasing age (Figure 12), though the correlation with age was not statistically significant ($r = 0.66$, $p = 0.073$).

Emotion Discrimination: Individual scores ranged from 63-100% correct (mean = 92%; SD = 14). For this test, 7 of 8 children scored significantly above chance (scores > 70.8% correct) (Figure 8). The correlation between emotion discrimination performance and listener age was also not statistically significant. However, the scatterplot in Figure 13 suggests a trend of increasing performance with increasing age ($r = 0.62$, $p = 0.10$).

Across-Gender Talker Discrimination: Individual scores ranged from 72-97% (mean = 93%; SD = 8.6). All participants performed significantly above chance (scores > 65.5% correct) (Figure 9). The correlation between percent-correct score and listener's age, though not statistically significant ($r = .47$, $p = .24$), suggests a trend of increasing performance with increasing age (Figure 14).

Within-Female Talker Discrimination: Individual scores ranged from 59-84% (mean = 73%; SD = 10). For this test, 6 of 8 participants scored significantly above chance (scores > 65.5% correct) (Figure 10). Again, the correlation between percent-correct score and listener's age, though not statistically significant ($r = .65$, $p = .08$), suggests a trend of increasing performance with increasing age (Figure 15).

Within-Male Talker Discrimination: Individual scores ranged from 53-88% (mean = 74%; SD = 10). All participants scored significantly above chance (scores > 65.5% correct) (Figure 11). The correlation between percent-correct score and listener's age, though not statically significant (r = 0.54, p = .17), suggests a trend of increasing performance with increasing age (Figure 16).

Correlations reported in Appendix B show no significant correlations between any demographic/audibility measures and any listening scores, although some trends were noted above with respect to listener's age. Perhaps surprisingly, there were no significant correlations between behavioral scores and listener's degree of HL. However, with such a small number of participants, statistically significant correlations require relatively large correlation values.

DISCUSSION:

These pediatric HA listeners with mild to moderately- severe hearing loss demonstrated high levels of word and phoneme recognition in quiet as evidenced by scores of ≥ 84 % on CNC words and ≥ 94 % on CNC phonemes. The majority of these listeners were able to correctly recognize emotional content in a spoken message. All children scored significantly above chance on the identification task, and all but one child scored significantly above chance on the discrimination task. For the talker discrimination tasks, the highest scores were achieved on the Across-Gender task with the group average score at 95% and all children scoring significantly above chance. The Within-Female and Within-Male talker discrimination tasks were more challenging with group average scores of 73% and 74% correct, respectively. All but one child scored significantly above chance on the Within-Male talker task, and six of the eight scored significantly above chance for the Within-Female talker task.

There appears to be a developmental effect for perception of emotion and discrimination of talkers for these HA listeners as evidenced by the trend for the youngest children to score more poorly than older children. In general, degree of hearing loss, as measured by the unaided PTA was not associated with speech perception performance. Measures of aided audibility, including the aided SII at 60 and the aided PTA, were also not associated with performance on any of the emotion or talker discrimination tasks. .

We hypothesized that pediatric HA listeners would perform more poorly than similarly aged children with normal hearing sensitivity, and better than children with CIs on these tests of emotion perception and talker discrimination. HA listeners presumably have better frequency resolution than CI listeners, and would thus have better performance on these tests. Results from these HA listeners were compared to data from NH (N = 11) and CI (N = 14) participants collected by Uchanski and colleagues (personal communication).

Participants with NH ranged from 5.9-10.8 years of age (mean = 7.7, SD = 10.8) and participants with CIs ranged from 5.0-10.4 years of age (mean = 6.8, SD = 1.8). All NH and CI listeners followed the same administration protocol for emotion perception and talker discrimination tasks as described previously. Mean scores are shown for the three listener groups (NH, CI & HA) in Figure 17. The pattern of results across all tests is the same: the NH group has the highest mean score followed by the HA group and then the CI group. The scores for emotion identification are 86% (SD = 12), 80% (SD = 13) and 51% (SD = 21) for the NH, HA and CI listener groups, respectively. The scores for emotion discrimination are 97% (SD = 5), 92% (SD = 14) and 75% (SD = 21) for the NH, HA and CI listener groups respectively. The mean score for the NH group remains at or above 90% correct for the three talker discrimination tasks (across-gender, within-female and within-male). The HA group scored 93% correct (SD = 9) on the across-gender talker discrimination test, but decreased to 73% (SD = 10) and 74% (SD = 10) for the within-female and within-male talker discrimination tasks respectively. The CI listeners mean score was 71% (SD = 18) for the across-gender task. However, the mean scores for both within-female and within-male talker tasks were not significantly above chance, 59% (SD = 9) and 58% (SD = 12) respectively.

As predicted, the NH listeners scored the highest on all tests of emotion perception and talker discrimination with mean group scores ranging from 86-97% correct. Overall the HA listeners scored better than the CI listeners suggesting that these HA listeners are better able to perceive emotion and discriminate between talkers than the CI listeners. The poor performance of the CI group may be due, in part, to the poor spectral resolution abilities of current CI systems (Carroll and Zeng, 2007). The within-female and within-male talker discrimination tasks were challenging for both the HA and CI listeners, though the CI listeners had considerably more difficulty as evidenced by average scores that were not significantly above chance performance. While these results indicate that children with acoustic hearing are better able to perceive emotion and discriminate between different talkers than children with CIs, it remains unclear as to how the degree of hearing, unaided or aided, relates to this ability. The degree of hearing was not significantly related to performance for these HA listeners, possibly because all children had hearing thresholds of 70 dB HL or better. All children had excellent aided audibility as evidenced by aided soundfield thresholds of 30 dB HL or better for the majority of frequencies tested (250-6000 Hz). It's also the case that the small sample size (N=8) of this HA group made it difficult to establish significance for many of the correlations.

These HA listeners were able, overall, to perceive emotional content in a spoken message quite well, although the youngest listeners (6.2 and 6.3 years old) tended to score lower than the others, especially on the identification task. Interestingly, a similar trend was noted for the NH group on emotion identification with scores for 3 of the 4 youngest listeners (5.9-6.5 years) ranging from 64-72% correct. Thus it may be reasonable to expect that scores for these youngest listeners would improve with typical emotional development. As a group, these HA listeners were able to discriminate males vs. females very well, but had more difficulty when they had to discriminate amongst males or amongst females. Again there was a trend for the youngest listeners to score more poorly, specifically on the within-female task. However, one must exercise extreme caution when interpreting these results. Due to the small sample sizes, significant amount of variability in the data, and possible developmental (age) effects for these tests, these results may not necessarily generalize to other larger groups of pediatric CI and HA listeners. These results do highlight several issues for clinicians. Firstly, high levels of performance on traditional open-set speech recognition tests are not necessarily associated with high levels of performance on “less traditional” tests of speech perception (e.g., emotion and talker perception). The lower performance of the CI group, possibly due to poor spectral resolution with electric hearing, should support consideration of using a hearing aid at the non-implanted ear when clinically feasible.

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TABLES

Table 1: Subject demographics.

Subject	Cause of HL	Age at ID	Age at HA fit (yrs)	Current Age (yrs)	Current HA's (R/L)
Subj 1	Genetic	failed NBHS	0.92	8.67	Widex Inteo
Subj 2	Unknown	failed NBHS	2.67	10.33	Phonak Naida III SP
Subj 3	Unknown	failed NBHS	1.75	6.25	Phonak Savia
Subj 4	Unknown	failed NBHS	0.58	8.25	Phonak Naida V SP
Subj 5	Birth-High Risk	failed NBHS	6	11.08	Phonak Naida III SP
Subj 6	Unknown	failed NBHS	0.42	6.17	Phonak Micro III
Subj 7	Genetic	failed NBHS	4.17	8.33	Phonak Naida III SP dAZ
Subj 8	Unknown	failed NBHS	0.42	6.29	Phonak Naida III UP dAZ

Table 2: SII at soft (50), average (60), and loud but comfortable (70) outputs.

	SII 50		SII 60		SII 70	
Subject	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Subj 1	NA	31	NA	40	NA	62
Subj 2	47	36	62	49	70	59
Subj 3	80	86	92	94	91	91
Subj 4	35	53	48	67	65	76
Subj 5	40	60	55	69	65	72
Subj 6	75	31	83	53	85	68
Subj 7	60	43	65	56	73	67
Subj 8	56	42	70	60	71	71

FIGURES

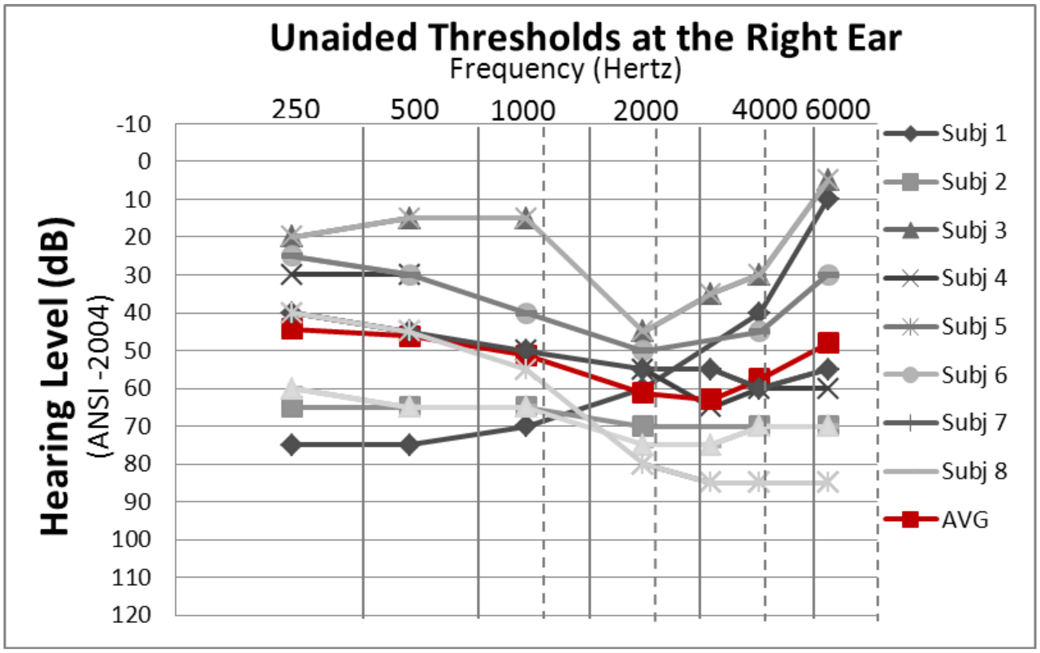


Figure 1: Unaided threshold for the right ear using insert earphones.

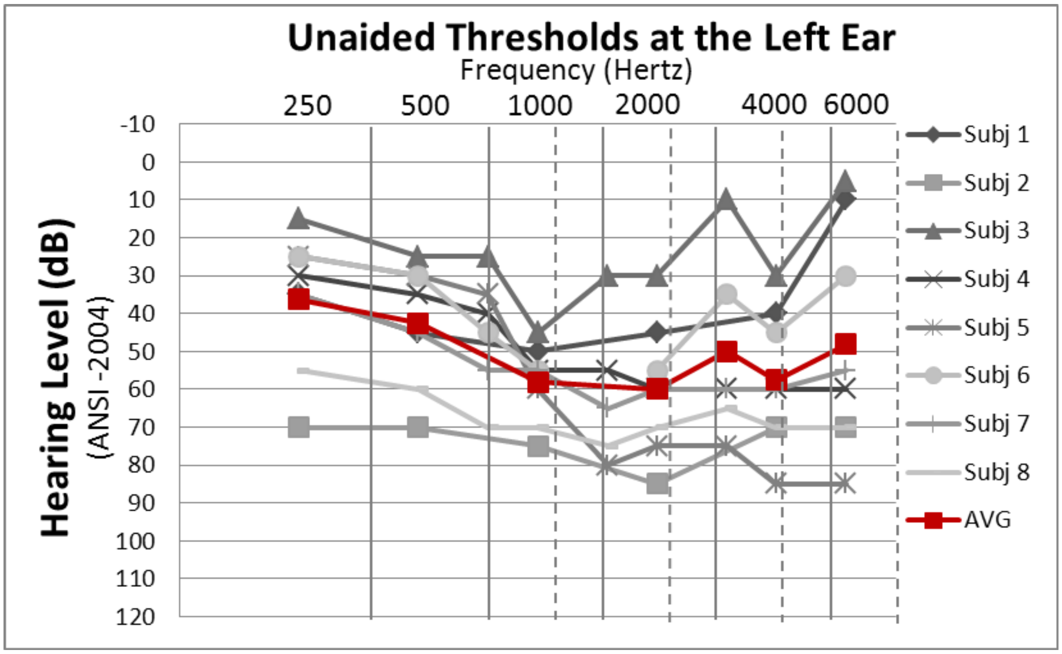


Figure 2: Unaided thresholds for the left ear using insert earphones.

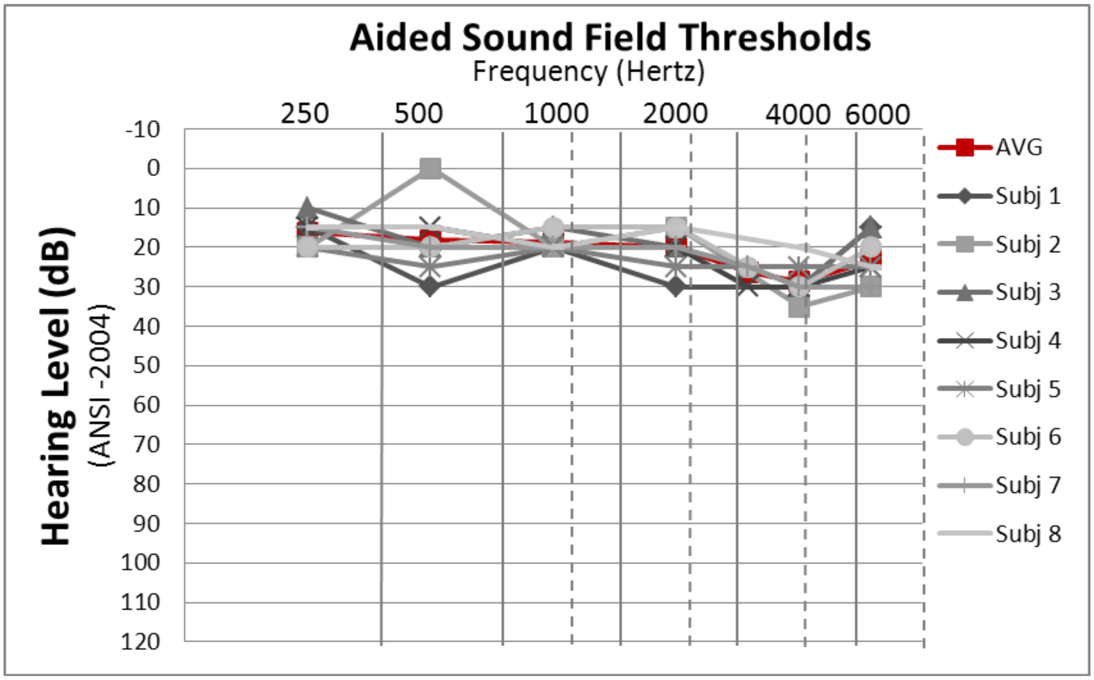


Figure 3: Aided sound field thresholds using subject's personal HAs.

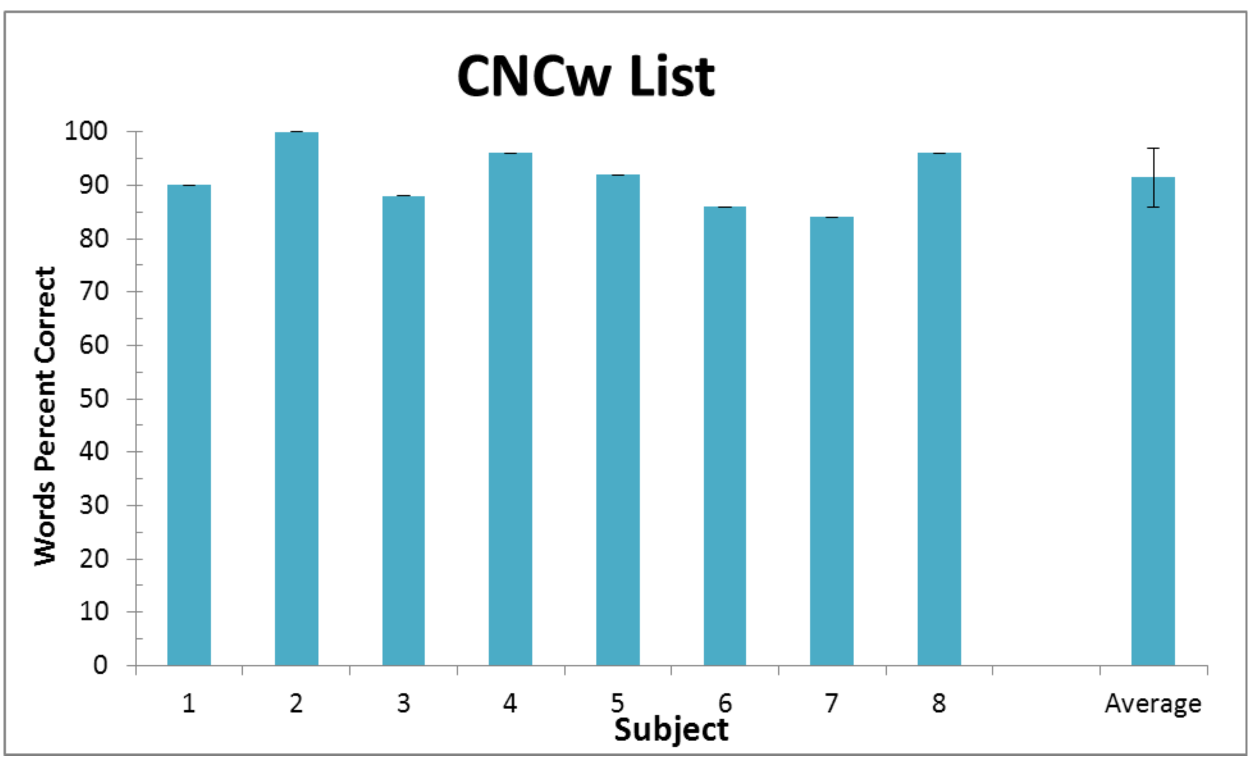


Figure 4: Individual and mean CNC word performance (% correct).

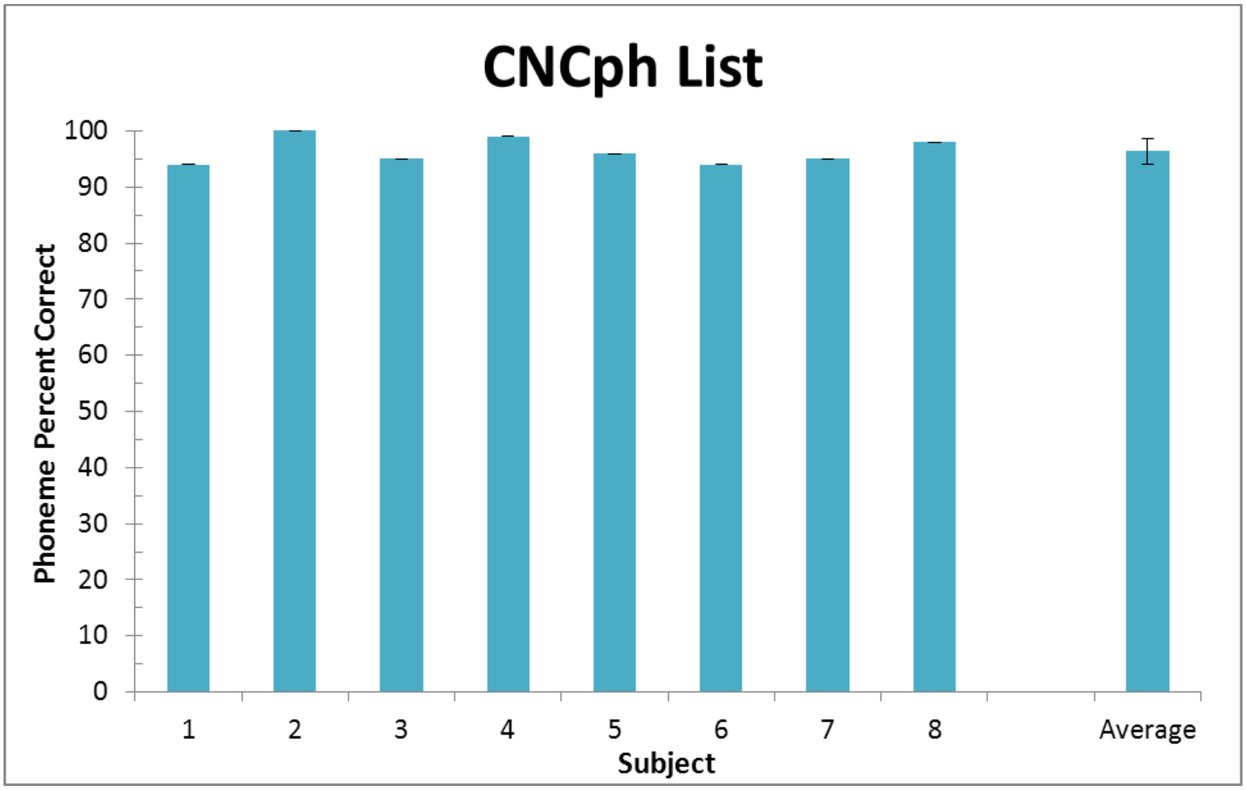
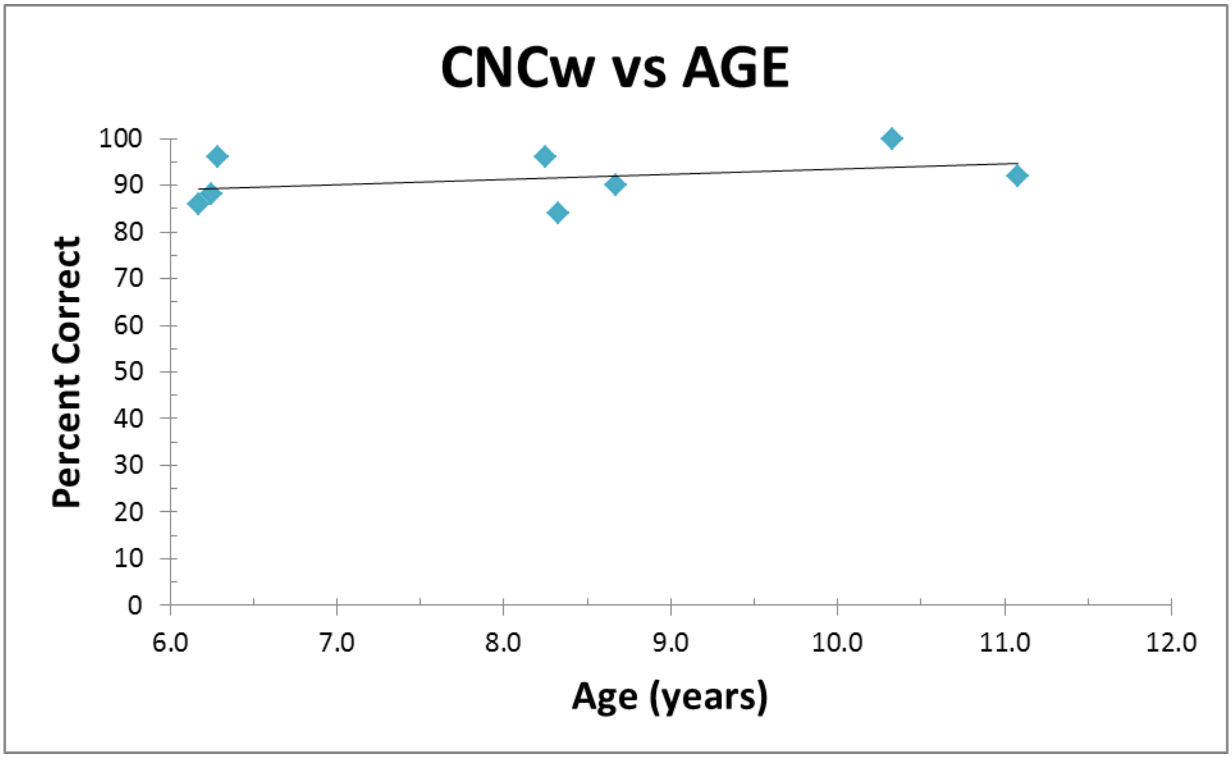


Figure 5: Individual and mean CNC phoneme performance (% correct).


CNCw vs AGE
Percent Correct
100
90
80
70
60
50
40
30
20
10
0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
Age (years)

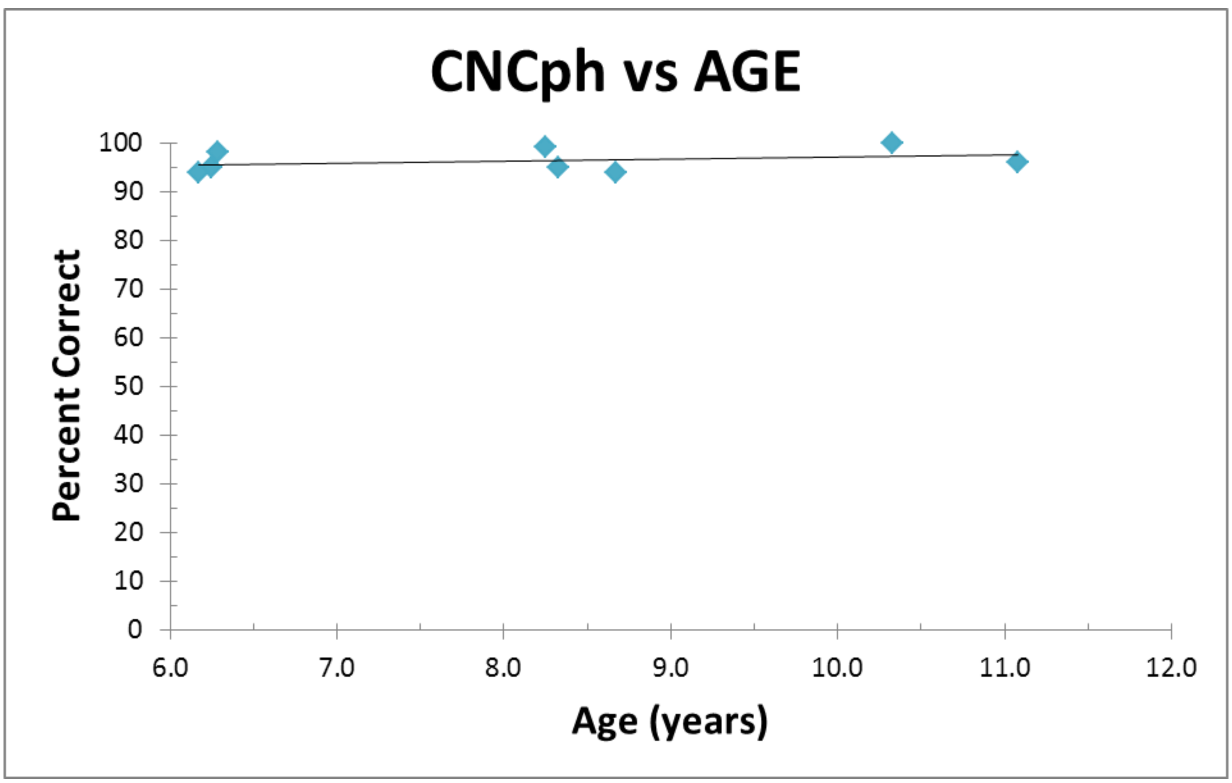

CNCph vs AGE
Percent Correct
100
90
80
70
60
50
40
30
20
10
0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
Age (years)

Figure 6: CNC word (CNCw, top panel) and phoneme scores (CNCph, bottom panel) vs. listener's age.

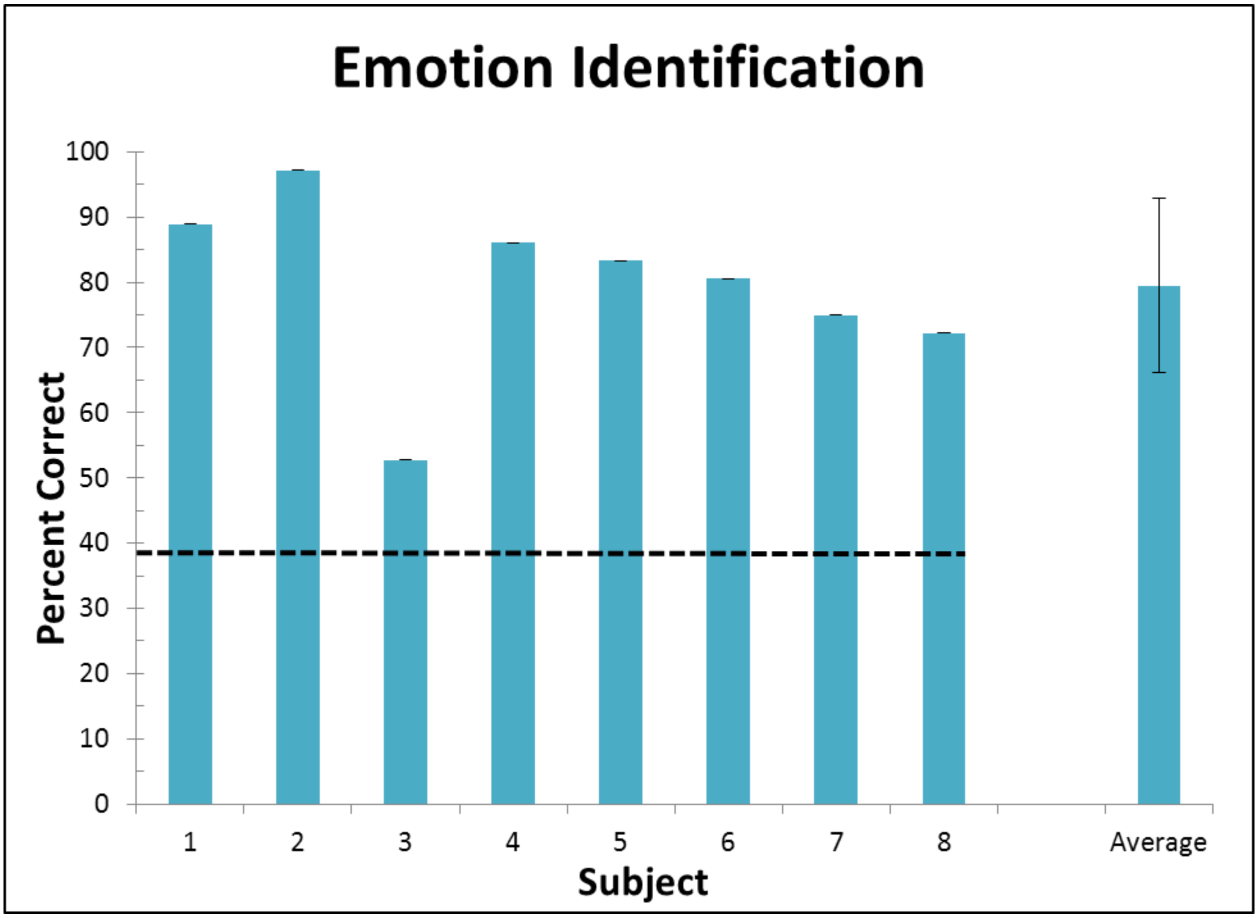


Figure 7: Individual and mean percent-correct scores for Emotion Identification. The dashed line represents performance reliably above chance (95% confidence interval).

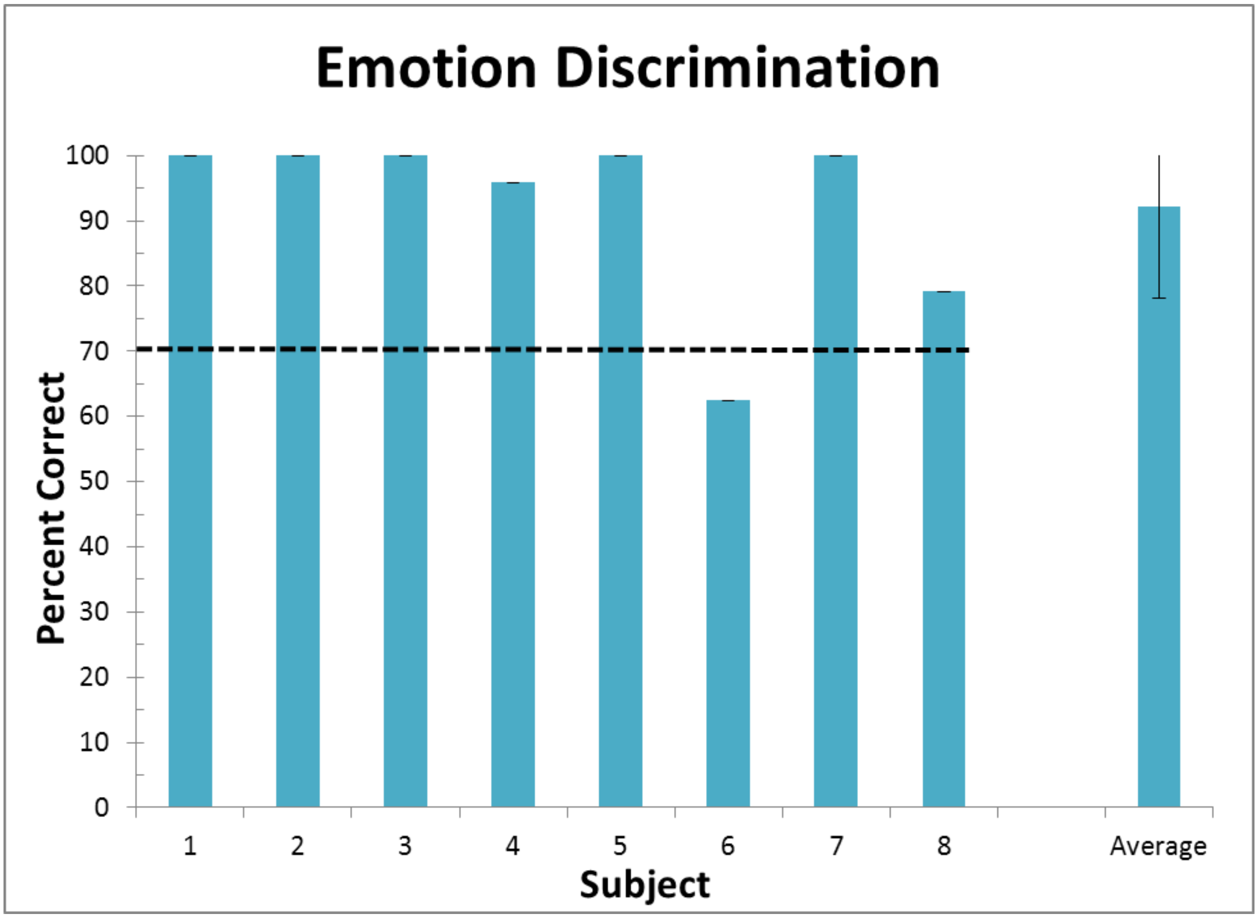


Figure 8: Individual and mean percent-correct scores for Emotion Discrimination. The dashed line represents performance reliably above chance (95% confidence interval).

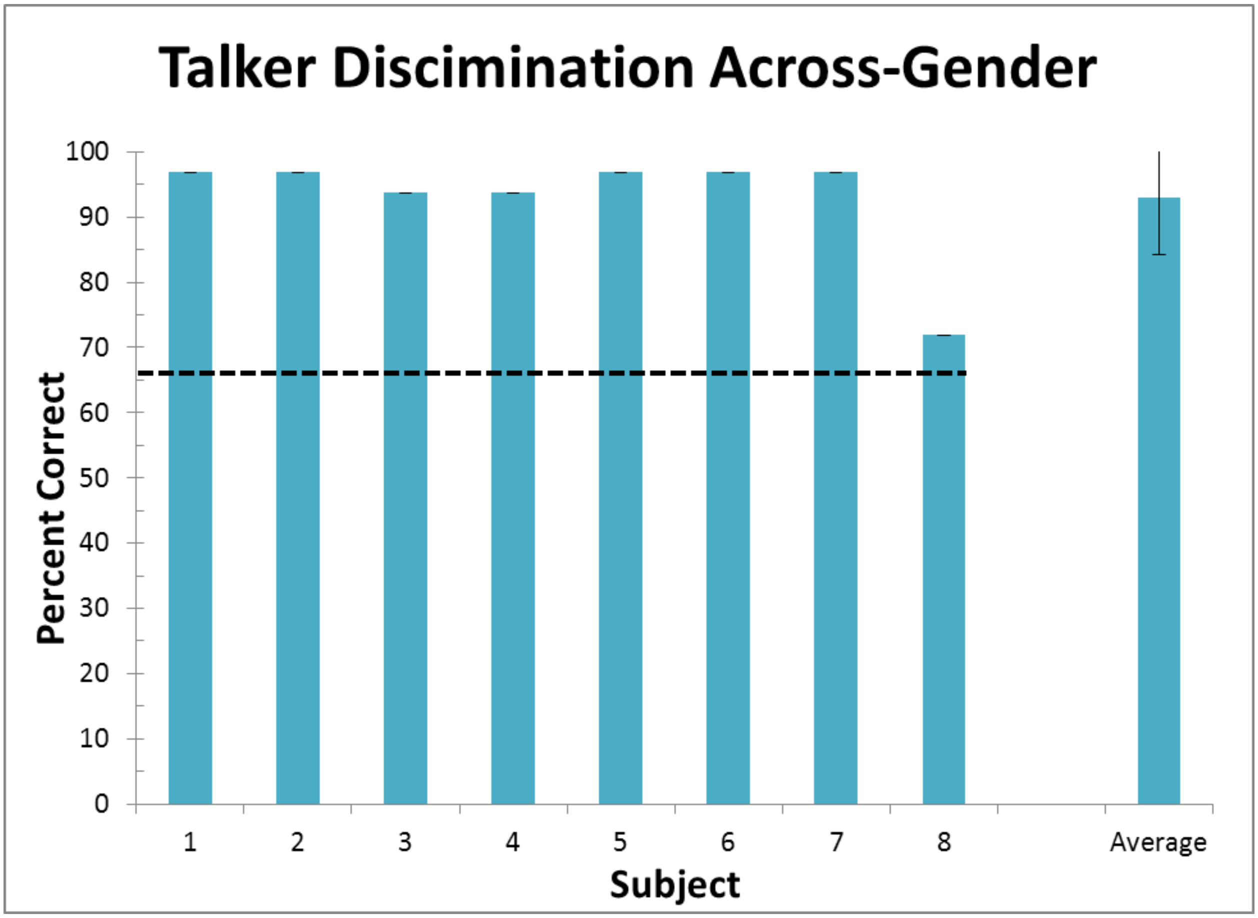


Figure 9: Individual and mean percent-correct scores for Across-Gender Talker Discrimination. The dashed line represents performance reliably above chance (95% confidence interval).

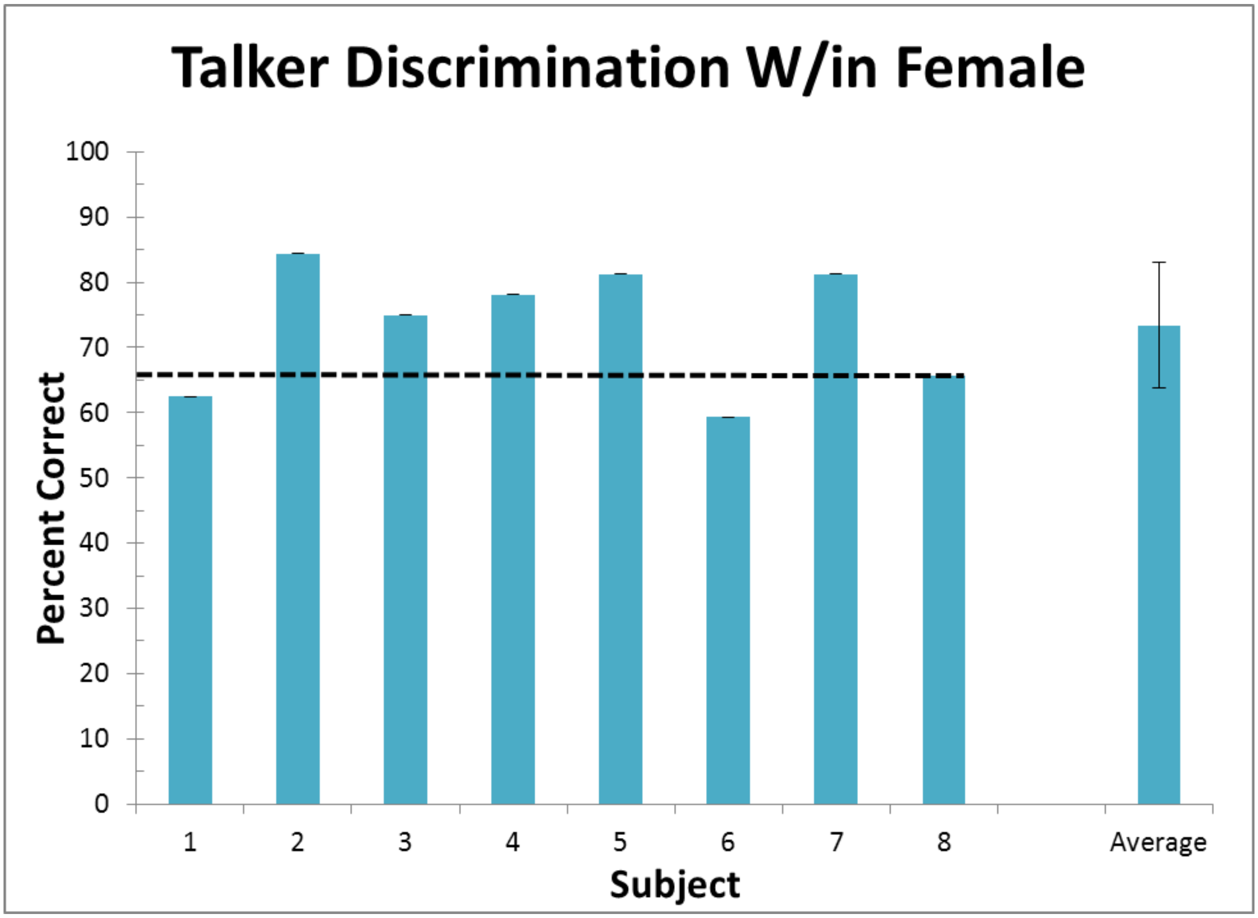


Figure 10: Individual and mean percent-correct scores for Within-Female Talker Discrimination. The dashed line represents performance reliably above chance (95% confidence interval).

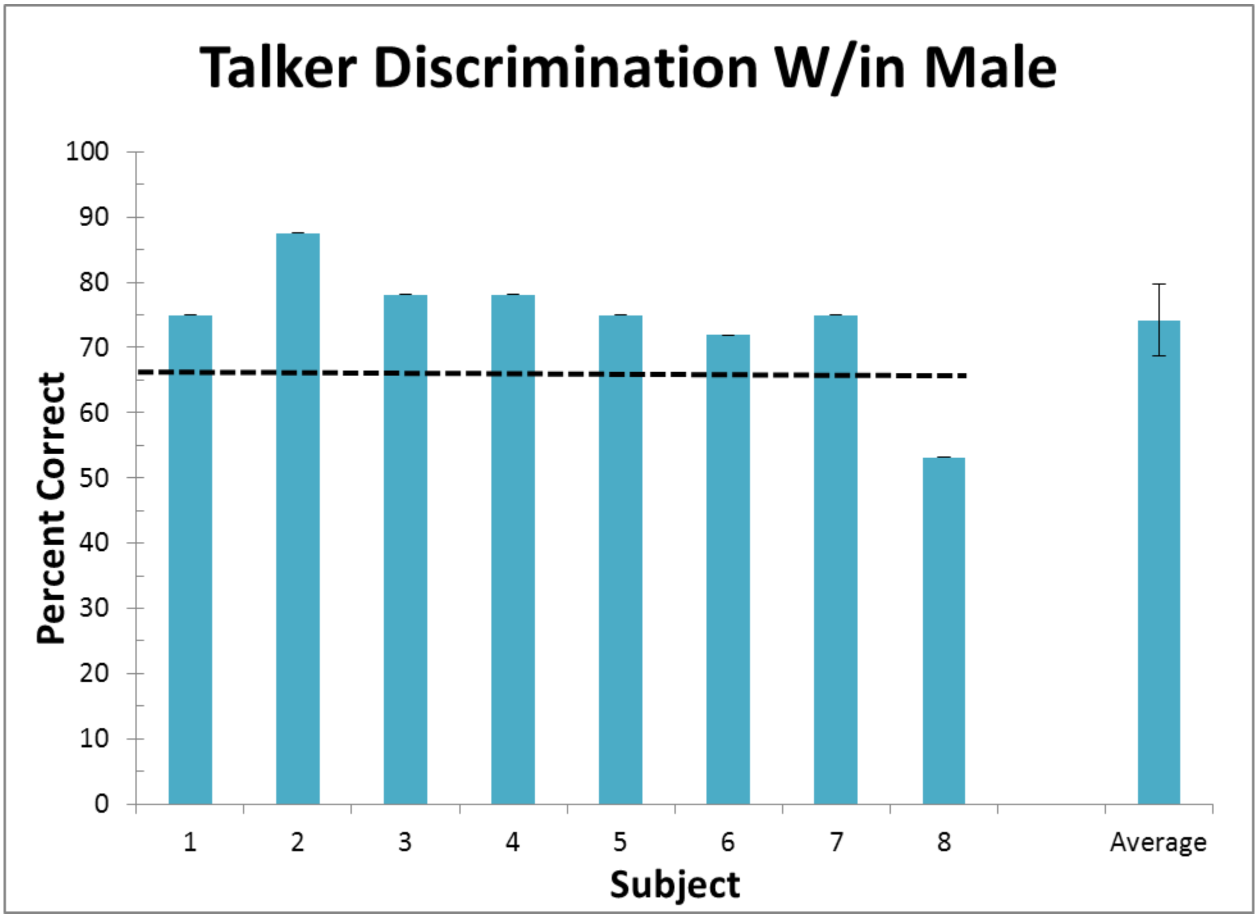


Figure 11: Individual and mean percent-correct scores for Within-Male Talker Discrimination. The dashed line represents performance reliably above chance (95% confidence interval).

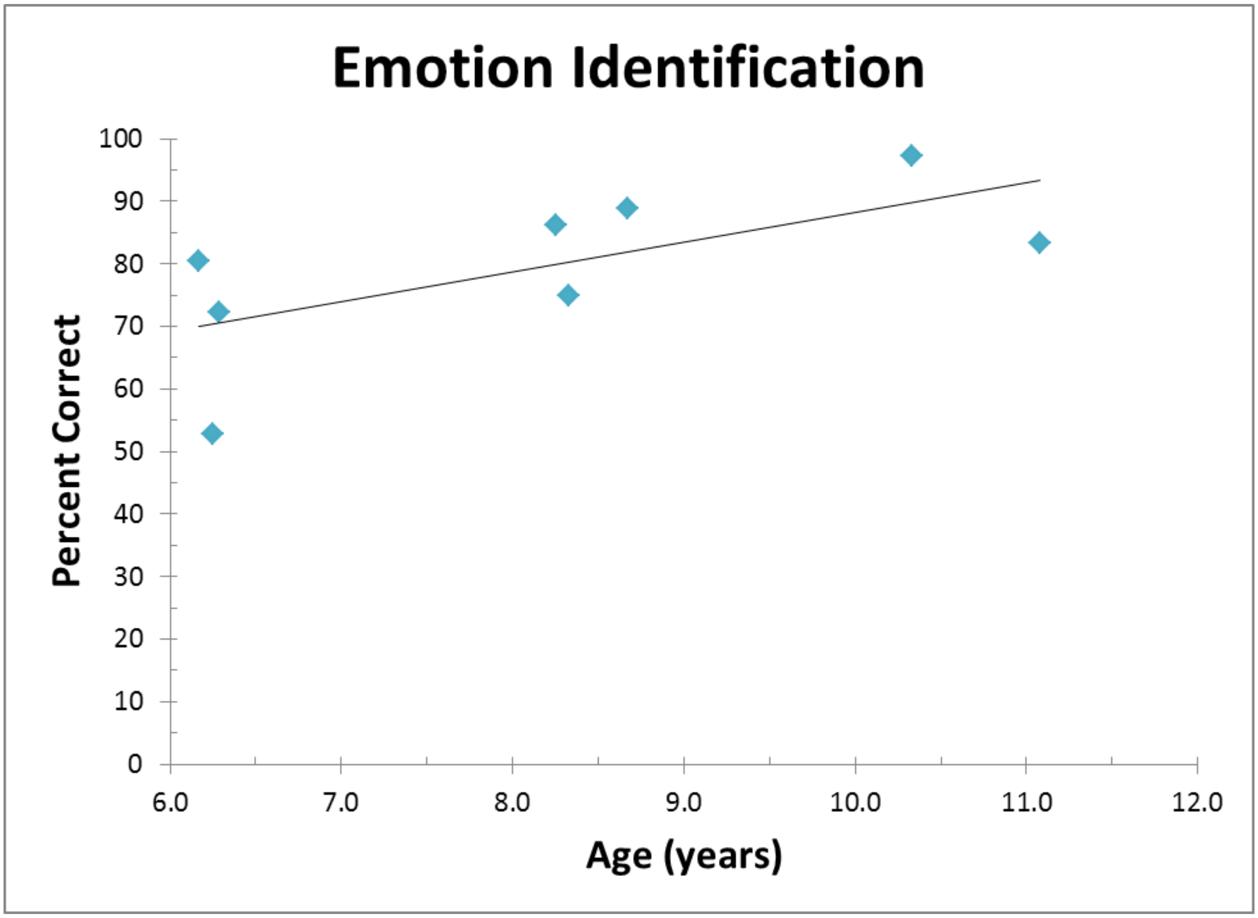


Figure 12: Individual percent-correct scores for Emotion Identification vs. listener's age.

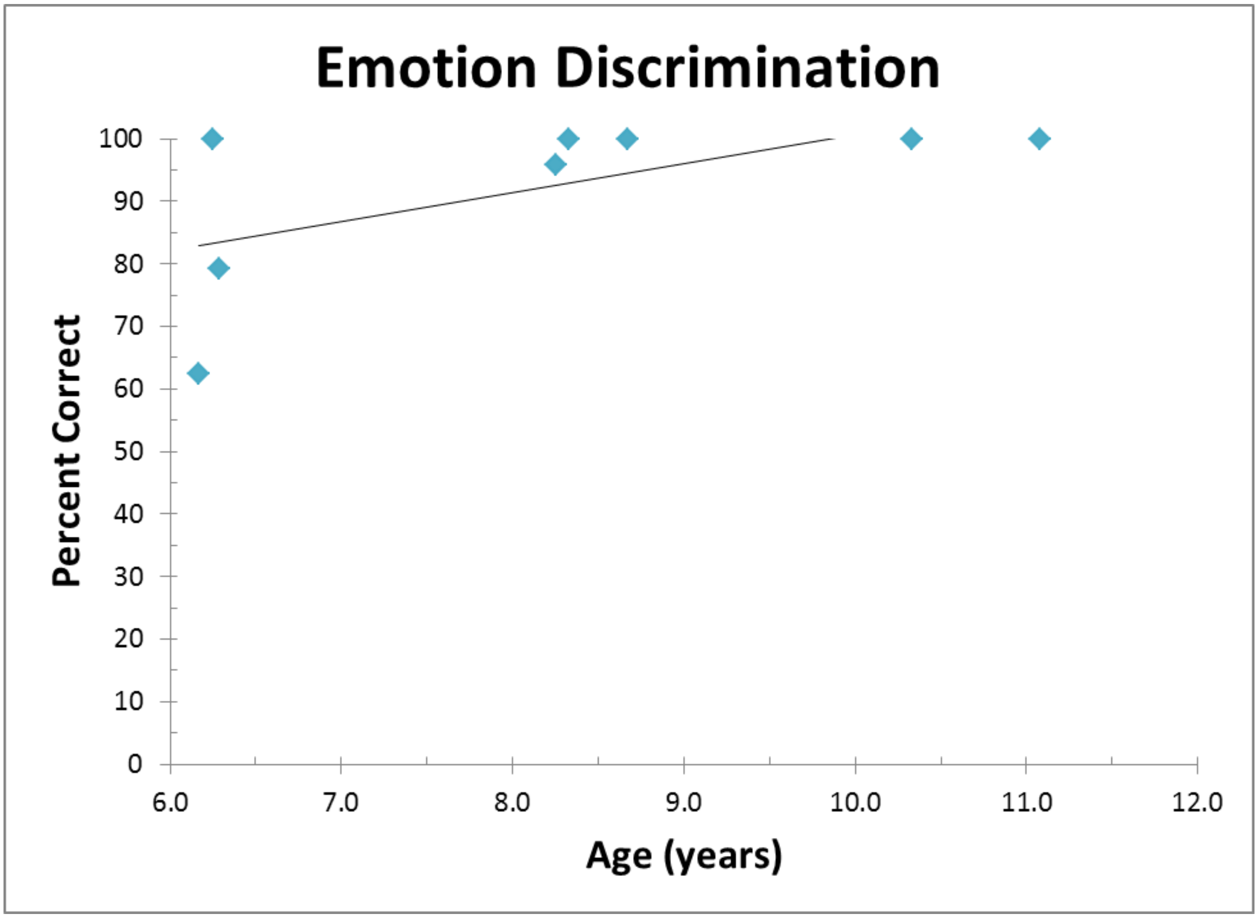


Figure 13: Individual percent-correct scores for Emotion Discrimination vs. listener's age.

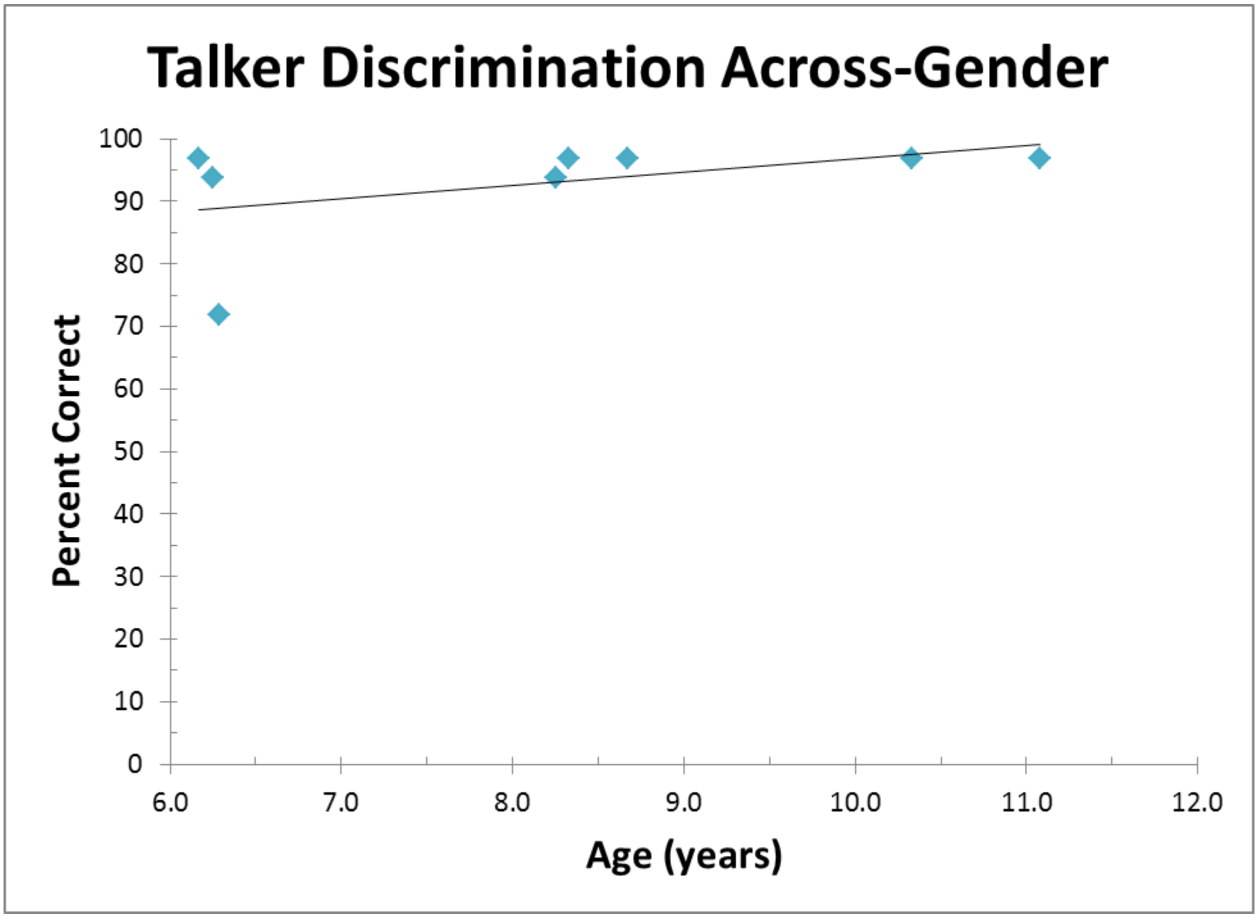


Figure 14: Individual percent-correct scores for Across-Gender Talker Discrimination vs. listener's age.

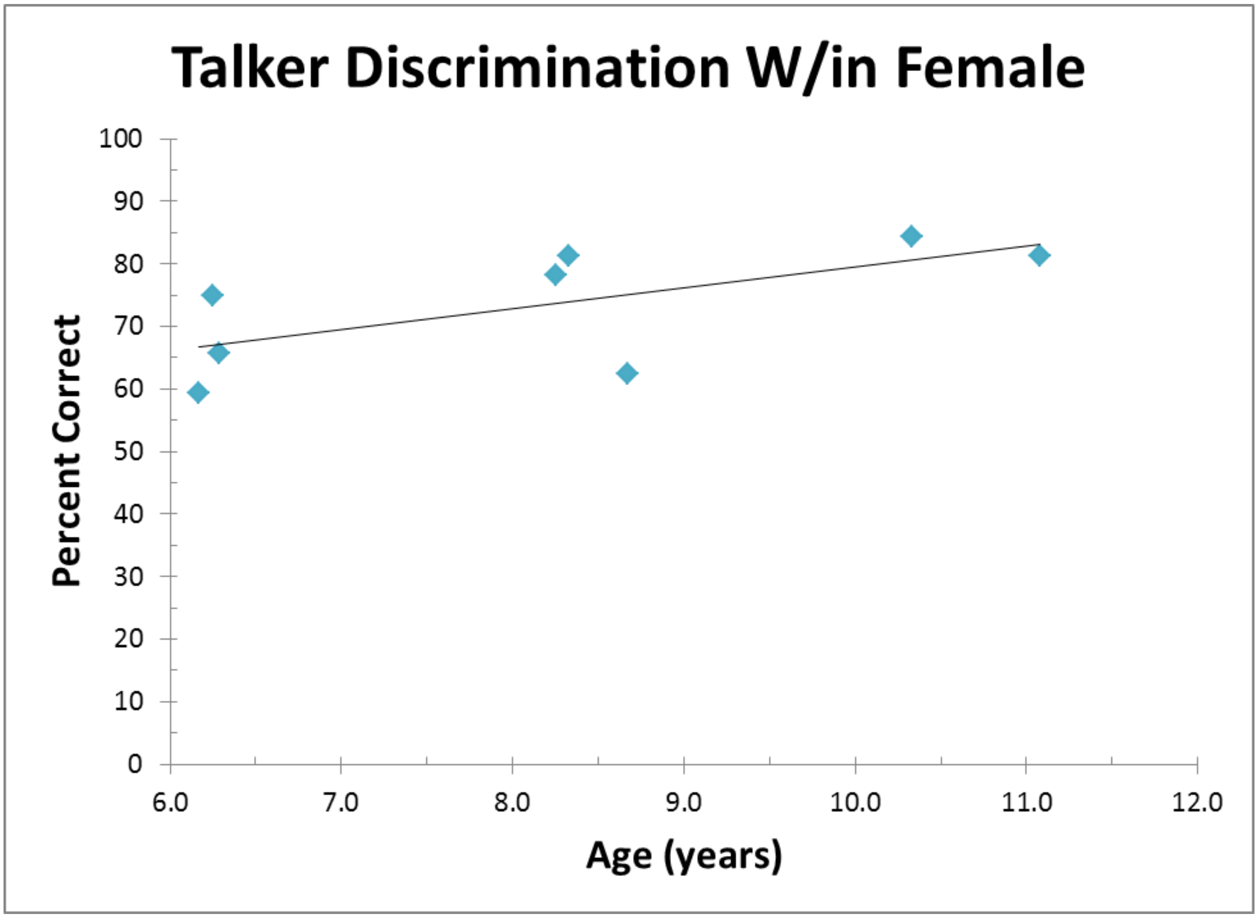


Figure 15: Individual percent-correct scores for Within-Female Talker Discrimination vs. listener's age.

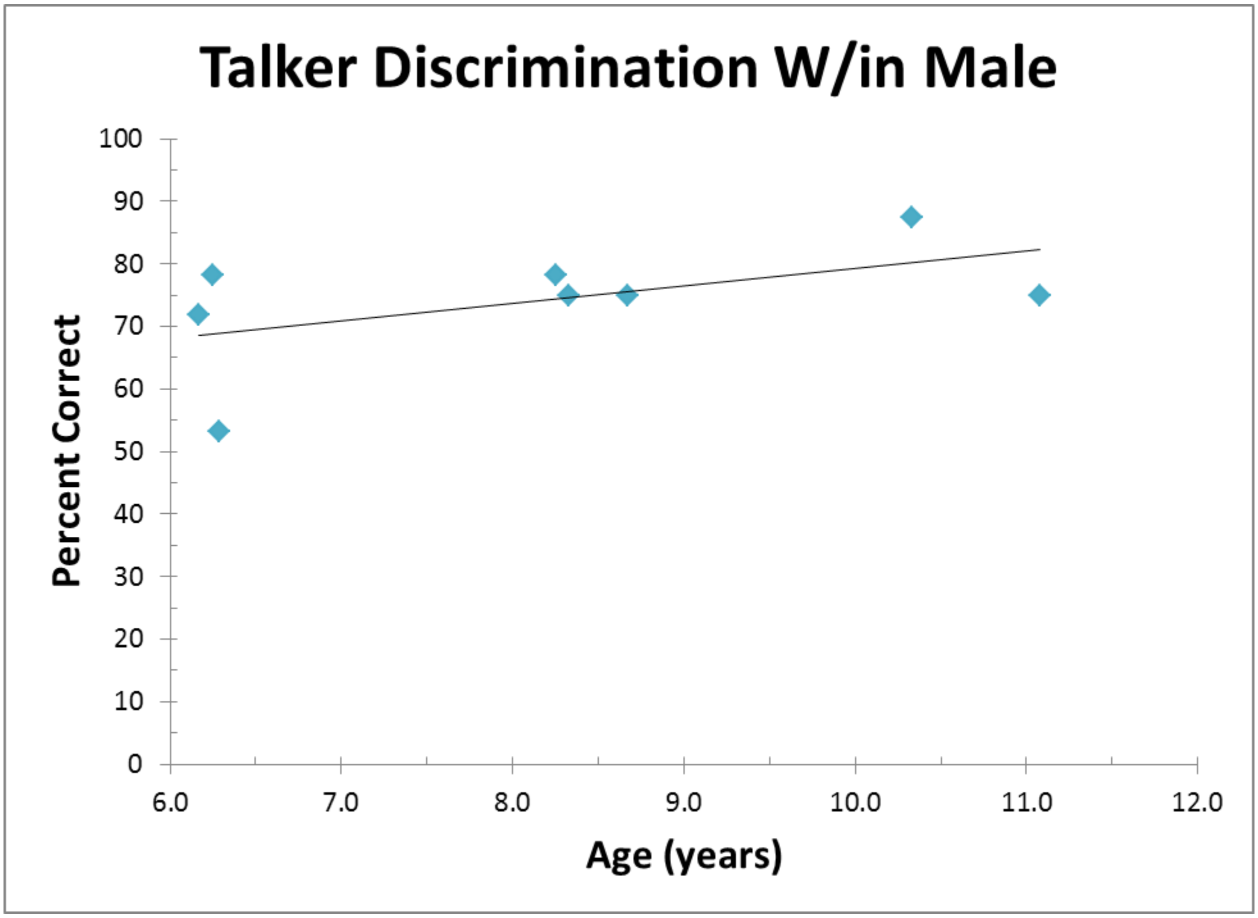


Figure 16: Individual percent-correct scores for Within-Male Talker Discrimination vs. listener's age.

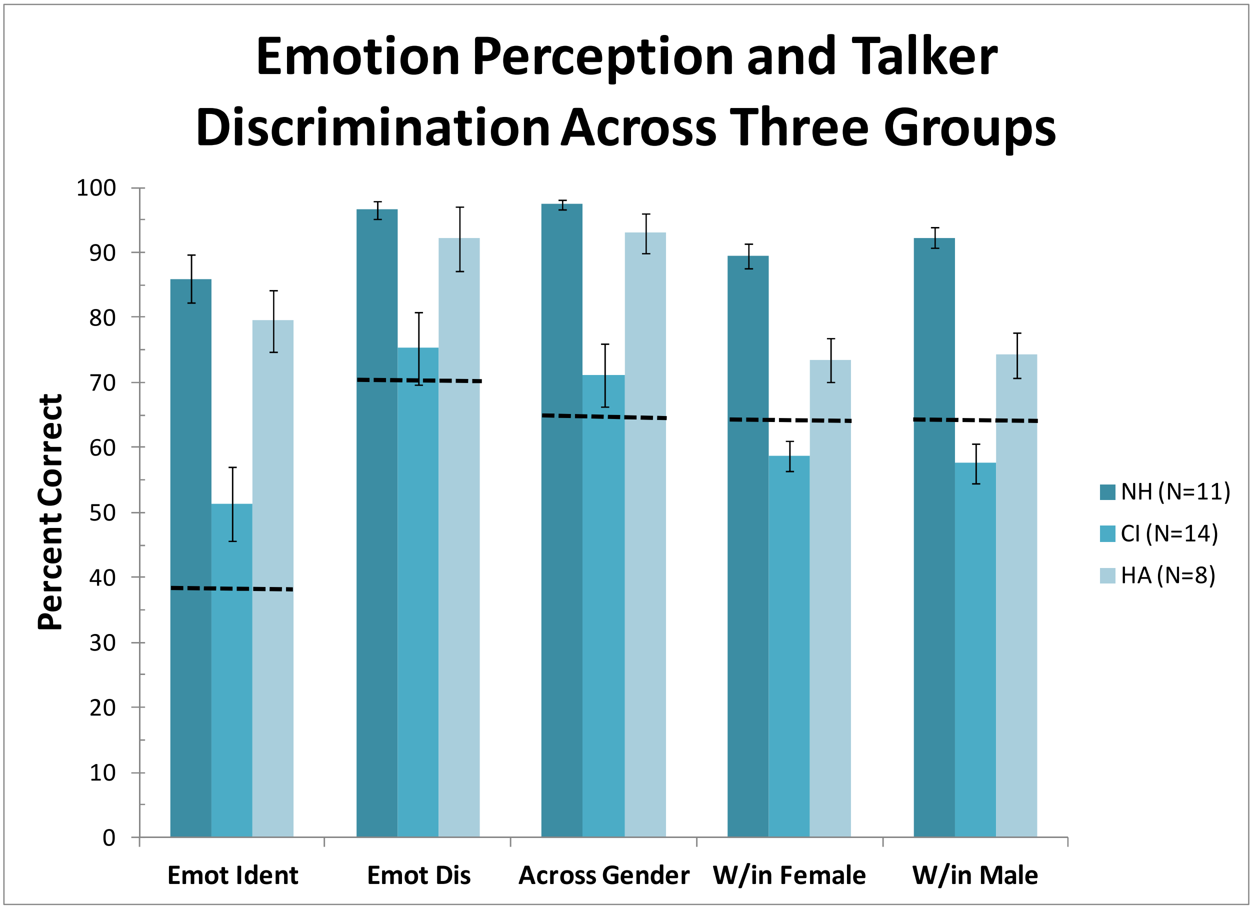


Figure 17: Group mean percent-correct scores for five behavioral tests for three groups of listeners, NH and CI (data from Uchanski, personal communication), and HA groups (this study).

APPENDIX A: BEHAVIORAL DATA

Subject	CNC	
	percent-correct words	percent-correct phonemes
1	90	94
2	100	100
3	88	95
4	96	99
5	92	96
6	86	94
7	84	95
8	96	98
Average	92	96
SD	5.5	2.3
min	84.0	94.0
max	100.0	100.0

Subject	Emotion (No. correct)		Emotion (% correct)	
	36	**24**	**36**	**24**
	Ident	Discrim	Ident (%)	(Discrim (%)
1	32	24	88.9	100
2	35	24	97.2	100
3	19	24	52.8	100
4	31	23	86.1	95.83
5	30	24	83.3	100
6	29	15	80.6	62.5
7	27	24	75.0	100
8	26	19	72.2	79.16
Average	28.6	22.1	79.5	92.2
SD			13.4	14.0
min			52.8	62.5
max			97.2	100.0

Subject	Talker Discrim (No. correct)			Talker Discrim (% correct)		
	32	**32**	**32**	**32**	**32**	**32**
	Across Gender	w/in Female	w/in Male	Across Gender	w/in Female	w/in Male
1	31	20	24	96.87	62.5	75
2	31	27	28	96.87	84.37	87.5
3	30	24	25	93.75	75	78.12
4	30	25	25	93.75	78.12	78.12
5	31	26	24	96.87	81.25	75
6	31	19	23	96.87	59.37	71.87
7	31	26	24	96.87	81.25	75
8	23	21	17	71.87	65.62	53.12
Average	29.8	23.5	23.8	93.0	73.4	74.2
SD				8.6	9.6	9.7
min				71.9	59.4	53.1
max				96.9	84.4	87.5

APPENDIX B: CORRELATIONS

SII 60 & Behavioral Scores

Column #	Column ID	r-value	p-value(correlation)	Lower CI	Upper CI	N
7	Ident	-0.72	0.05	-0.94	-0.02	8
9	Ident (%)	-0.72	0.05	-0.94	-0.02	8
1	Current Age	-0.52	0.18	-0.90	0.29	8
4	Best Un PTA	-0.52	0.19	-0.90	0.29	8
3	SF PTA	-0.49	0.22	-0.89	0.33	8
8	Discrim	-0.36	0.38	-0.85	0.46	8
10	(Discrim (%)	-0.36	0.38	-0.85	0.46	8
5	percent-correct words	-0.25	0.54	-0.81	0.55	8
11	Across Gender	-0.11	0.80	-0.76	0.64	8
14	Across Gender	-0.11	0.80	-0.76	0.64	8
6	percent-correct phonemes	-0.09	0.84	-0.75	0.66	8
16	w/in Male	-0.08	0.85	-0.74	0.66	8
13	w/in Male	-0.08	0.86	-0.74	0.66	8
12	w/in Female	0.03	0.94	-0.69	0.72	8
15	w/in Female	0.03	0.94	-0.69	0.72	8

Sound Field PTA & Behavioral Scores

Column #	Column ID	r-value	p-value(correlation)	Lower CI	Upper CI	N
5	percent-correct phonemes	-0.65	0.08	-0.93	0.11	8
4	percent-correct words	-0.44	0.28	-0.87	0.38	8
3	Best Un PTA	-0.34	0.41	-0.84	0.48	8
11	w/in Female	-0.29	0.48	-0.83	0.52	8
14	w/in Female	-0.29	0.48	-0.83	0.52	8
9	(Discrim (%)	0.28	0.51	-0.53	0.82	8
7	Discrim	0.28	0.51	-0.53	0.82	8
10	Across Gender	0.21	0.62	-0.58	0.80	8
13	Across Gender	0.21	0.62	-0.58	0.80	8
1	Current Age	0.18	0.67	-0.60	0.79	8
12	w/in Male	-0.14	0.73	-0.77	0.62	8
15	w/in Male	-0.14	0.73	-0.77	0.62	8
6	Ident	-0.01	0.98	-0.71	0.70	8
8	Ident (%)	-0.01	0.98	-0.71	0.70	8

Age & Behavioral Scores

Column #	Column ID	r-value	p-value(correlation)	Lower CI	Upper CI	N
4	Ident	0.66	0.07	-0.08	0.93	8
6	Ident (%)	0.66	0.07	-0.08	0.93	8
12	w/in Female	0.65	0.08	-0.10	0.93	8
9	w/in Female	0.65	0.08	-0.10	0.93	8
7	(Discrim (%)	0.62	0.10	-0.15	0.92	8
5	Discrim	0.62	0.10	-0.15	0.92	8
13	w/in Male	0.54	0.17	-0.27	0.90	8
10	w/in Male	0.54	0.17	-0.27	0.90	8
8	Across Gender	0.47	0.24	-0.35	0.88	8
11	Across Gender	0.47	0.24	-0.35	0.88	8
2	percent-correct words	0.38	0.35	-0.44	0.86	8
3	percent-correct phonemes	0.32	0.44	-0.50	0.84	8